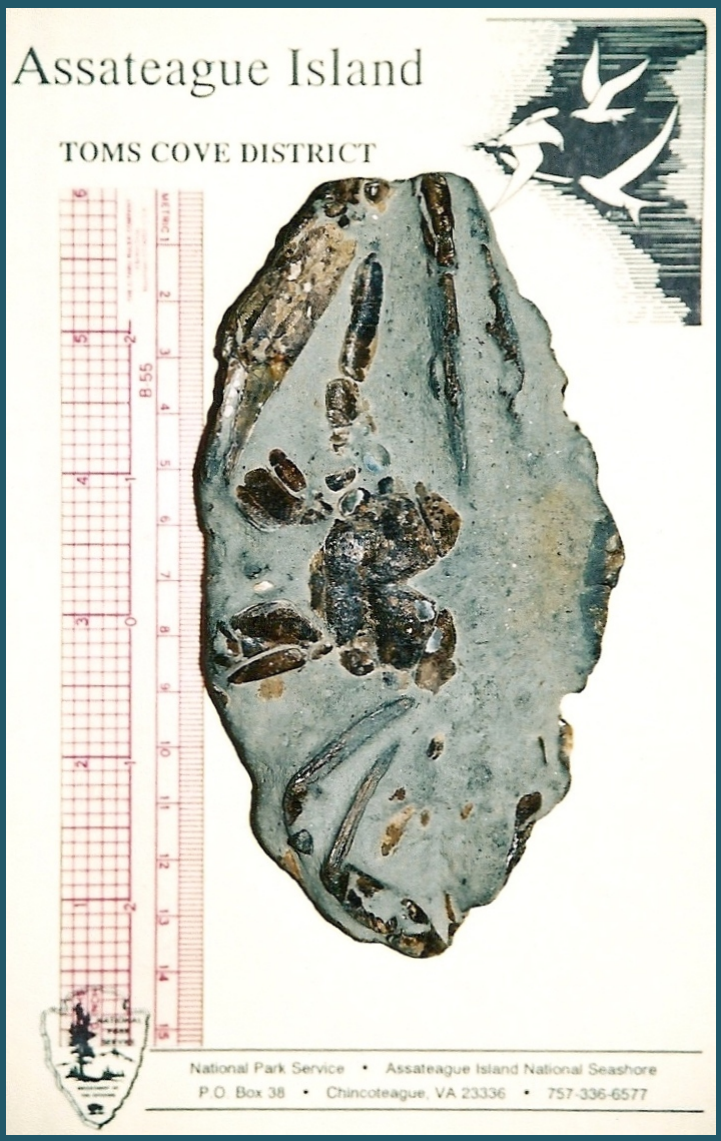
National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Paleontological Resource Inventory and Monitoring

Northeast Coastal and Barrier Network

Natural Resource Technical Report NPS/NCBN/NRTR—2014/897



ON THE COVER
A photo of a crab in a concretion that washed up on Assateague Island National Seashore (ASIS). A handful of similar fossils have washed up on the shore at ASIS over the years, mostly of mollusks.
Photograph: NPS photo

Paleontological Resource Inventory and Monitoring

Northeast Coastal and Barrier Network

Natural Resource Technical Report NPS/NCBN/NRTR—2014/897

Justin S. Tweet

Tweet Paleo-Consulting
9149 79th St. S.
Cottage Grove, MN 55016-2214

Vincent L. Santucci

National Park Service
Geological Resources Division
1201 Eye Street, NW (Room 1146)
Washington, D.C. 20005

Tim Connors

National Park Service
Geologic Resources Division
PO Box 25287
Denver, CO 8022

NOTE:

This report provides baseline paleontological resource data to National Park Service administration and resource management staff. The report contains information regarding the location of non-renewable paleontological resources within NPS units.

It is *not* intended for distribution to the public.

August 2014

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

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Technical Report Series is used to disseminate results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service mission. The series provides contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the Northeast Coastal and Barrier Network intranet (http://www1.nrintra.nps.gov/im/units/ncbn/index.cfm, NPS access only) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Tweet, J. S., V. L. Santucci, and T. Connors. 2014. Paleontological resource inventory and monitoring: Northeast Coastal and Barrier Network. Natural Resource Technical Report NPS/NCBN/NRTR—2014/897. National Park Service, Fort Collins, Colorado.

NPS 962/125676, August 2014

Contents

Page

Figures....ix
Tables....xii
Appendix....xii
Executive Summary....xiii
Acknowledgments....xv
Dedication....xvii
Introduction....1
NCBN Geological Background....2
Report Organization and Methodology....7
Organization of the Park Narratives....8
Report Methodology....9
References Cited....11
Inventory and Monitoring Strategies and Resource Management Guidance....13
Paleontological Resource Inventory Strategies....13
Comprehensive Park-Specific Surveys....13
Service-wide Thematic Inventories....13
Inventory and Monitoring Network-Based Summaries....14
Paleontological Resource Monitoring Strategies....14
Coastal Paleontological Resources....14
Paleontological Resource Management Legislation and Guidance....15
2009 Paleontological Resource Preservation Act....15
NPS Management Policies....16
Other Resources....16
Education and Outreach Opportunities....17
References Cited....17
Citations for I&M Network-Based Summaries....20
Assateague Island National Seashore....28
Geologic Background....28

Contents (continued)

Page

Sources of Paleontological Resources 33
Offshore and Subsurface Deposits (Upper Miocene?–Upper Pleistocene) 33
Unnamed Holocene Deposits 37
Park Collections 38
Cultural Resource Contexts 38
Paleontological Resource Management, Preliminary Recommendations 38
References Cited 39
Additional References 44
Data Sets 46
Cape Cod National Seashore 47
Geologic Background 48
Sources of Paleontological Resources 53
Subsurface (Various Ages of Fossils in Pleistocene Deposits) 53
Quaternary Deposits (Uppermost Pleistocene–Holocene; Transported Fossils as Old as Cambrian) 56
Park Collections 61
Cultural Resource Contexts 62
Paleontological Resource Management, Preliminary Recommendations 63
References Cited 64
Additional References 73
Data Sets 76
Colonial National Historical Park 77
Geologic Background 78
Sources of Paleontological Resources 84
Subsurface (Various Ages) 85
Chesapeake Group: Eastover Formation (Upper Miocene) 86
Chesapeake Group: Yorktown Formation (Lower–Upper Pliocene) 88
Other Quaternary Deposits (Upper Pleistocene–Holocene) 95
Potential Sources of Paleontological Resources 97

Contents (continued)

Page

Bacons Castle Formation (Lower Pleistocene) 97
Windsor Formation (Lower or Middle Pleistocene) 98
Chuckatuck Formation (Lower or Middle Pleistocene) 98
Shirley Formation (Middle Pleistocene) 99
Tabb Formation (Upper Pleistocene) 100
Park Collections 101
Cultural Resource Contexts 108
Paleontological Resource Management, Preliminary Recommendations 108
References Cited 109
Additional References 124
Data Sets 126
Fire Island National Seashore 129
Geologic Background 129
Sources of Paleontological Resources 135
Subsurface (Upper Cretaceous and Quaternary) 135
Surficial Quaternary sediments (Pleistocene–Holocene) 138
Park Collections 140
Cultural Resource Contexts 141
Paleontological Resource Management, Preliminary Recommendations 141
References Cited 142
Additional References 149
Data Sets 150
Gateway National Recreation Area 152
Geologic Background 153
Sources of Paleontological Resources 157
Subsurface (Upper Cretaceous and Quaternary) 157
Surficial Quaternary Sediments (Pleistocene–Holocene) 161
Park Collections 167

Contents (continued)

Page

Cultural Resource Contexts 168
Paleontological Resource Management, Preliminary Recommendations 168
References Cited 169
Additional References 177
Data Sets 180
George Washington Birthplace National Monument 181
Geologic Background 181
Sources of Paleontological Resources 184
Subsurface (Various Ages) 184
Chesapeake Group: Calvert Formation (Lower–Middle Miocene) 185
Unnamed Quaternary Deposits (Holocene) 190
Potential Sources of Paleontological Resources 190
Tabb Formation (Upper Pleistocene) 190
Park Collections 192
Cultural Resource Contexts 192
Paleontological Resource Management, Preliminary Recommendations 193
References Cited 193
Additional References 203
Data Sets 207
Sagamore Hill National Historic Site 208
Geologic Background 208
Potential Sources of Paleontological Resources 213
Subsurface (Upper Cretaceous and Quaternary) 213
Surficial Quaternary Sediments (Upper Pleistocene–Holocene) 215
Park Collections 216
Cultural Resource Contexts 217
Paleontological Resource Management, Preliminary Recommendations 217
References Cited 218

Contents (continued)

Page

Additional References 224
Data Sets 226
Thomas Stone National Historic Site 227
Geologic Background 227
Potential Sources of Paleontological Resources 231
Pamunkey Group: Nanjemoy Formation (Lower Eocene) 231
Chesapeake Group: Calvert Formation (Lower–Middle Miocene) 234
Upland Gravels (Upper Miocene?–Lower Pleistocene?) 237
Unnamed Quaternary Sediments (Holocene) 238
Park Collections 238
Cultural Resource Contexts 238
Paleontological Resource Management, Preliminary Recommendations 239
References Cited 239
Additional References 250
Data Sets 252
Non-I&M network units within the NCBN 253
Fort McHenry National Monument and Historic Shrine (FOMC) 254
Fort Monroe National Monument (FOMR) 254
Independence National Historical Park (INDE) 257
Thomas Edison National Historical Park 258
References Cited 259
Additional References 262
Data Sets 262

Figures

Page

Figure 1. Map of Northeast Coastal and Barrier Network parks (NPS map).....2

ASIS Figure 1. A modern salt marsh at Toms Cove; peaty sediments deposited in similar settings are widely distributed in the shallow subsurface of ASIS (NPS).....28

ASIS Figure 2. Geography of ASIS (NPS).....31

ASIS Figure 3. Schematic geomorphological map of ASIS.....32

ASIS Figure 4. Examples of fossil crabs in concretions that washed up on ASIS (VLS).....35

CACO Figure 1. CACO is composed in large part of unconsolidated glacial sediments, which erode rapidly (NPS).....47

CACO Figure 2. Geography of CACO (NPS).....49

CACO Figure 3. Schematic geological map of CACO.....54

CACO Figure 4. Great Pond in Wellfleet is one of CACO's many kettle ponds.....59

COLO Figure 1. A cliff in the Yorktown Formation near Yorktown on the York River (Clark et al. 1912).....77

COLO Figure 2. Geography of COLO (NPS). The detached Cape Henry Memorial (CAME) is not included.....81

COLO Figure 3. Schematic geological map of COLO (NPS).....82

COLO Figure 4. Martin Lister's 1687 illustration of a fossil shell later known as Chesapecten jeffersonius, as reproduced in Ward and Blackwelder (1975).....84

COLO Figure 5. Barnacle mass, VDMR F-00146 (photo courtesy Virginia Department of Geology and Mineral Resources).....102

COLO Figure 6. *Turritella alticostata*, VDMR F-00148 (photo courtesy Virginia Department of Geology and Mineral Resources).....102

FIIS Figure 1. Sunken Forest, on the north side of Fire Island in FIIS. Organic material here has been dated to the past few hundred years (Sirkin 1972) (NPS).....130

FIIS Figure 2. Geography of FIIS (NPS).....132

FIIS Figure 3. Schematic geological map of FIIS.....133

FIIS Figure 4. Fire Island has grown westward by several miles over the past 200 years (Stoffer 2003, USGS).....134

GATE Figure 1. Fossils often wash up on the beaches of GATE, such as this beach on Sandy Point (NPS).....152

GATE Figure 2. Geography of GATE (NPS; modified to make park water stand out).....156

Figures (continued)

Page

GATE Figure 3 (left). Fossiliferous concretions: “A. concretion displaying massive bioturbation structures (hammer handle is 1 foot for scale); B. Concretion containing fossils of jingle shells, spruce pine cones, bone, and oyster shell.....163

GATE Figure 4 (right). “Calcareous sponges: A. sponge encrusting a quahog shell; B. sponge encrusting an oyster shell; C. Stony Coral encrusting a concretion 163

GATE Figure 5 (left). “Bivalves: A-C: Oysters preserved in growth position preserved in sideritic sandstone matrix; found on Breezy Point, NY. 164

GATE Figure 6 (right). “Bivalves: A-B. gastropods (mud dog whelk); Breezy Point, NY. C. surf clam; Breezy Point, NY. D. razor clam; Sandy Hook, NJ 164

GATE Figure 7 (left). “Arthropods: A-C. Blue claw crabs (Breezy Point, NY). D-E. green crabs (Breezy Point, NY). F. spider crab (Sandy Hook, NJ). G. barnacles attached to shell (Sandy Hook, NJ); H. American lobster claw (Sandy Hook, NJ)” (Stoffer 2003; USGS).....165

GATE Figure 8 (right). Vertebrate fossils from Rockaway Beach, NY. “A. American walrus skull (left ventral view - note tusk socket); B. whale vertebrae. C-F. fish or shark vertebrae. G-H. unidentified vertebrae” (Stoffer 2003; USGS).....165

GATE Figure 9. A *Crassostrea* (bivalve) fossil washed up on the beach at Great Kills in GATE by Hurricane Sandy (VLS).....166

GEWA Figure 1. The Calvert Formation along the Potomac River at GEWA; fossils such as shark teeth sometimes erode out of these exposures (VLS).....181

GEWA Figure 2. Schematic geological map of GEWA 183

GEWA Figure 3 (left). Teeth of the sharks *Hemipristis serra* (left) and *Isurus hastalis* (right) from the Calvert Formation of GEWA (photo by Rijk Moräwe, reproduced from Hunt et al. 2006). 187

GEWA Figure 4 (right). A loose vertebra found on a GEWA shore (VLS). 187

GEWA Figure 5. Shark teeth in GEWA collections (VLS).....192

GEWA Figure 6. Pits left by unauthorized collecting (VLS). 192

SAHI Figure 1. Looking out from the beach at SAHI to Cold Spring Harbor (NPS).....209

SAHI Figure 2. Geography of SAHI (NPS).....211

SAHI Figure 3. Schematic geological map of SAHI.....212

THST Figure 1. Haberdeventure, the Thomas Stone estate (NPS). 227

THST Figure 2. Geography of central THST (NPS).....229

Figures (continued)

Page

THST Figure 3. Schematic geological map of THST 230

THST Figure 4. Two views of the bivalve *Meretrix ovata* var. *ovata*, based on a specimen recovered from the Nanjemoy Formation west of Port Tobacco (Maryland Geological Survey 1901:Plate XXXIV). 232

THST Figure 5. The holotype of the common Nanjemoy Formation bivalve *Venericardia potapacoensis*, from the Potapaco Member west of Port Tobacco (Maryland Geological Survey 1901:Plate XXXL). 233

EDIS Figure 1. The fossiliferous stone from EDIS (VLS). 258

INDE Figure 1. The mastodon tooth fragment from INDE (inset), with a life restoration of a mastodon (photo by Peter Harholdt, illustration by Sarah Jeppsen). 258

Tables

Page

ASIS Table 1. Summary of ASIS stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest 33

CACO Table 1. Summary of CACO stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest 55

COLO Table 1. Summary of COLO stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest 83

COLO Table 2. Fossil taxa named from specimens found within COLO. 104

COLO Table 3. Fossil taxa named from specimens possibly found within COLO 105

FIIS Table 1. Summary of FIIS stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest 135

GATE Table 1. Summary of GATE stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest 157

GEWA Table 1. Summary of GEWA stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest 184

SAHI Table 1. Summary of SAHI stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest 213

THST Table 1. Summary of THST stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest 231

FOMR Table 1. Fossils reported from FOMR wells..... 257

Appendix

Page

Appendix: Geologic Time Scale 263

Executive Summary

Paleontological resources (fossils) are any remains of past life preserved in a geologic context. Paleontological resources are non-renewable resources found in at least 246 National Park System units. Despite the abundance and diversity of these resources throughout the National Park Service (NPS), until recently, few parks have had adequate baseline paleontological resource data.

The NPS National Inventory and Monitoring (I&M) Program and the NPS Geologic Resources Division have developed various strategies to provide parks with the baseline paleontological resource data necessary for greater understanding and appropriate management of these resources. This report presents an updated paleontological resource summary for the parks of the Northeast Coastal and Barrier Network (NCBN). The summary was compiled through extensive literature reviews, review of park records and archives, inventories of museum collections and records, and interviews with park staff and professional geologists and paleontologists. Preliminary paleontological resource management recommendations are also included for each park.

The parks of the NCBN have an unusual collective fossil record: unlike many areas, where fossils are found at or near bedrock outcrops, a significant proportion of the fossil reports in NCBN units are of material found in well borings, or of specimens that have been transported and washed up on shore by storms. Wells and other borings that yielded fossils have been reported from Assateague Island National Seashore (ASIS; Maryland and Virginia), Cape Cod National Seashore (CACO; Massachusetts), Colonial National Historical Park (COLO; Virginia), Fire Island National Seashore (FIIS; New York), Gateway National Recreation Area (GATE; New Jersey and New York), and George Washington Birthplace National Memorial (GEWA; Virginia), as well as Fort Monroe National Monument (FOMR; Virginia), geographically within the NCBN but not part of the Inventory and Monitoring program. Transported or washed-ashore fossils are reported from ASIS, CACO, COLO, GATE, and GEWA. Another typical fossil occurrence consists of Quaternary plant matter and microfossils found in the shallow subsurface, frequently used for studies of paleoclimate and paleoecology. ASIS, CACO, COLO, FIIS, and GATE have yielded fossils of this type. The only units that are known to exhibit the typical mode of fossils eroding from surface exposures within park boundaries are CACO, COLO, and GEWA. Two units, Sagamore Hill National Historic Site (SAHI; New York) and Thomas Stone National Historic Site (THST; Maryland), have not yet yielded fossils, but both are within fossiliferous areas and something may eventually be found in one or both.

Aside from glacially transported stones with Cambrian and Devonian fossils found in CACO, the fossil record of NCBN parks only extends back to the Late Cretaceous (see the Appendix for a geologic time scale). The best fossil records belong to CACO and COLO. CACO has perhaps the most diverse record, because glaciers transported fossiliferous materials from a variety of formations to Cape Cod, and because of the many kettle ponds that have served as basins for sediment deposition. The kettle ponds have attracted a great deal of study because of their utility for paleoclimatological and paleoenvironmental studies. COLO has a historically distinguished fossil record centered around the Pliocene-age Yorktown Formation. Classic fossil localities of the

Yorktown Formation were once exposed throughout much of its bluffs, but are now largely inaccessible due to shore control measures instituted during the first half of the 20th century. It is thought that a bivalve specimen from the area of Yorktown (in COLO) recovered in the late 17th century was the first fossil to be illustrated from North America, by Martin Lister in 1687, although it would not be recognized as a fossil for another century and its provenance was misinterpreted as the Virgin Islands. It was eventually named Pecten jeffersonius and today, as Chesapecten jeffersonius, the species is the state fossil of Virginia. Fossils from Yorktown have been described in the literature since the 1820s, although new descriptions have slowed since the shore control efforts. At this time, COLO is the only unit of the NCBN that is a source of type specimens (name-bearing specimens) of fossil organisms, and is also the only unit to have widely distributed museum specimens. At least 25 fossil species and as many as 121 appear to have been named from fossils recovered within COLO, and fossils from the Yorktown area are reposited in museums throughout the eastern United States and Europe.

GATE and GEWA are in the next tier of fossil resources. They are noted for transported fossils washing onto their shores following storms. At GATE, various formations in the New York Bight contribute fossiliferous concretions, mostly containing mollusk and crustacean remains, but plant debris and vertebrate fossils also appear. GEWA's shore accumulates fossils from the Miocene-age Calvert Formation, mostly shark teeth. Fossil shark teeth have also been found in shell middens at GEWA, and may have been used as scrapers. Both areas present management challenges. Fossils are uncommon to date at ASIS and FIIS, both barrier islands that reached their present locations in the past few thousand years. At ASIS, a handful of fossils have washed up on shore, and some peat and shells have been recovered during studies of the subsurface and growth of Assateague Island. Fossils are not known to have washed up on FIIS yet, but deep cores have recovered Cretaceous microfossils, and Quaternary fossils have been found closer to the surface. The non-network unit FOMR has an extensive subsurface record, thanks to three wells that have yielded a variety of fossils. There are many other non-network units within the NCBN, but few have much potential for paleontological resources. There is one notable exception: a fragment of a mastodon tooth was found at an archeological site in Independence National Historical Park (INDE), and may have been in the possession of Benjamin Franklin.

Together, the fossils of the NCBN are particularly useful for illustrating the geologic history of the area over the past few million years. They have great potential for providing insight on future conditions as climate and sea level changes bring the NCBN closer to how it was in the recent past.

Acknowledgments

The authors graciously thank all those individuals, both within and outside of the National Park Service (NPS) who have contributed valuable information, comments, and suggestions for this report. Reports such as this are impossible without extensive input from those people who know the resources the best.

Special thanks to NPS park staff who provided extensive information, comments, suggestions, and/or reviewed their park's section, including: Sara Stevens (NCBN coordinator); Jim Comiskey (Northeast Regional I&M Coordinator); Bill Hulslander and Courtney Schupp (ASIS); Mark Adams, William Burke, Susan Moynihan, Jason Taylor, and Megan Tyrrell (CACO); Jonathan Connolly, Dorothy Guyer, and David Riggs (COLO); Michael Bilecki and Chris Olijnyk (FIIS); Eola Dance and Kirsten Talken-Spaulding (FOMR); Doug Adamo (GATE); Amy Muraca (GEWA and THST); David Lassman (GWMP); Rijk Moräwe (ORPI); and Kelly Fuhrmann, Scott Gurney, and Amy Verone (SAHI).

A number of individuals from institutions outside the National Park Service were also instrumental in the development of this report. We extend our appreciation to: Carl Mehling (American Museum of Natural History); Stephen Godfrey (Calvert Marine Museum); Kate Roderick (Cape Cod Museum of Natural History); Violetta Wolf (Museum of Science [Boston]); Henryk Behnke and Ed Johnson (Staten Island Museum); Phil Stoffer (U.S. Geological Survey, emeritus); Patricia Sanford (University of Wisconsin–Madison); Michael Enomoto and Matthew Heller (Virginia Division of Geology and Mineral Resources); and Lauck Ward (Virginia Museum of Natural History). Rebecca Beavers, Steve Simon, and Heather Walborn of the NPS Geologic Resources Division (GRD) provided comments and photographs. The continued valuable support and information provided by additional GRD staff, including Dave Steensen, Hal Pranger, Lisa Norby, Jason Kenworthy, Jim F. Wood, and Julia Brunner, is greatly appreciated.

Finally, this report would not have been possible without the funding from the NPS National Inventory and Monitoring Program and the support of the NCBN and GRD. The enthusiasm and support of Bert Frost (outgoing Associate Director, NPS Natural Resource Stewardship and Science) and Steve Fancy (retired Chief, Office of Inventory, Monitoring and Evaluation) is acknowledged. We extend a sincere thanks to Bert and Steve for providing the means upon which this work, and similar work, can be accomplished.

Dedication

We dedicate the Northeast Coastal and Barrier (NCBN) Inventory and Monitoring Network Paleontological Resource Inventory and Monitoring report to Rebecca Beavers, Ph.D., National Park Service Coastal Geology & Coastal Adaptation to Climate Change Coordinator. Because the NCBN is a network consisting principally of coastal park areas, we take this opportunity to recognize Rebecca for her many contributions to the management of coastal park resources throughout the National Park System. Rebecca has served as our agency's subject matter expert for coastal geology and processes involving 85 coastal parks with shorelines and submerged lands which collectively total more than 17,700 km (11,000 miles). Rebecca's work combines state of the art science and resource management to assist park managers with a full spectrum of coastal resource issues from storm impacts, such as those experienced with Superstorm Sandy, to long-term coastal adaptation issues intimately linked to climate change and sea level rise. Our thanks to Rebecca for her years of dedicated service to our coastal parks and their associated cultural and natural resources.



Introduction

Paleontological resources, or fossils, are any remains of past life preserved in geologic context. There are two main types of fossils: body fossils and trace fossils. Body fossils are the physical remains of an actual organism (shells, bones, teeth, plant leaves, etc.), while trace fossils (burrows, coprolites, footprints, trackways, etc.) preserve evidence of an organism's activity or behavior. Fossils are non-renewable natural resources that possess scientific, educational, and interpretive value. In the National Park Service (NPS) there are three fossil context categories: in situ (fossils found in sediment or rock layers), in museum collections, or in cultural resource contexts (building stones, archeological resources, historic documents, and ethnographic legends or stories). This report addresses fossil discoveries in all of these contexts.

The establishment of baseline paleontological resource data is essential for the appropriate management of fossils found within National Park System units. Although at least 246 units have been identified with paleontological resources, few parks have adequate baseline paleontological resource data.

In conjunction with the NPS Geologic Resources Division (GRD) and the NPS Inventory and Monitoring (I&M) Program, paleontological resource inventories have been initiated in dozens of parks and are further described in the Methodology and Inventory Strategies section of this report. This report presents paleontological resource inventory and monitoring data compiled for the parks of the Northeast Coastal and Barrier I&M Network (NCBN).

The Northeast Coastal and Barrier Network includes eight NPS areas along the East Coast from Virginia to Massachusetts as shown in Figure 1: Assateague Island National Seashore (ASIS), Cape Cod National Seashore (CACO), Colonial National Historical Park (COLO), Fire Island National Seashore (FIIS), Gateway National Recreation Area (GATE), George Washington Birthplace National Memorial (GEWA), Sagamore Hill National Historic Site (SAHI), and Thomas Stone National Historic Site (THST). The NCBN units are relatively large, at least for NPS units east of the Mississippi, although a significant portion of the administered areas are under water. The smallest is SAHI at 33.60 ha (83.02 acres), and the largest is CACO at 17,647.73 ha (43,608 acres). The eight units fall into two main groups: those established primarily for their natural coastal resources (ASIS, CACO, FIIS, and GATE), and those established in recognition of Revolutionary War-era figures and events (COLO, GEWA, and THST). Numerous non-I&M units are also geographically within the NCBN. Most are small (<24 ha/60 acres) and were established in recognition of a person or a culturally significant landmark, and generally have small likelihoods of including fossils. At least two do, though: Fort Monroe National Monument (FOMR), where many fossils have been found in a series of wells; and Independence National Historical Park (INDE), where a fragment of a mastodon tooth possibly owned by Benjamin Franklin has been found.

The fossil record of the NCBN is particularly strong for the Quaternary. They are useful for describing the recent past and for analyzing the responses of these ecologically fragile areas to change. The fossils of the NCBN also have a historical connection: the first North American fossil to be illustrated probably came from somewhere now in COLO or the immediate vicinity.

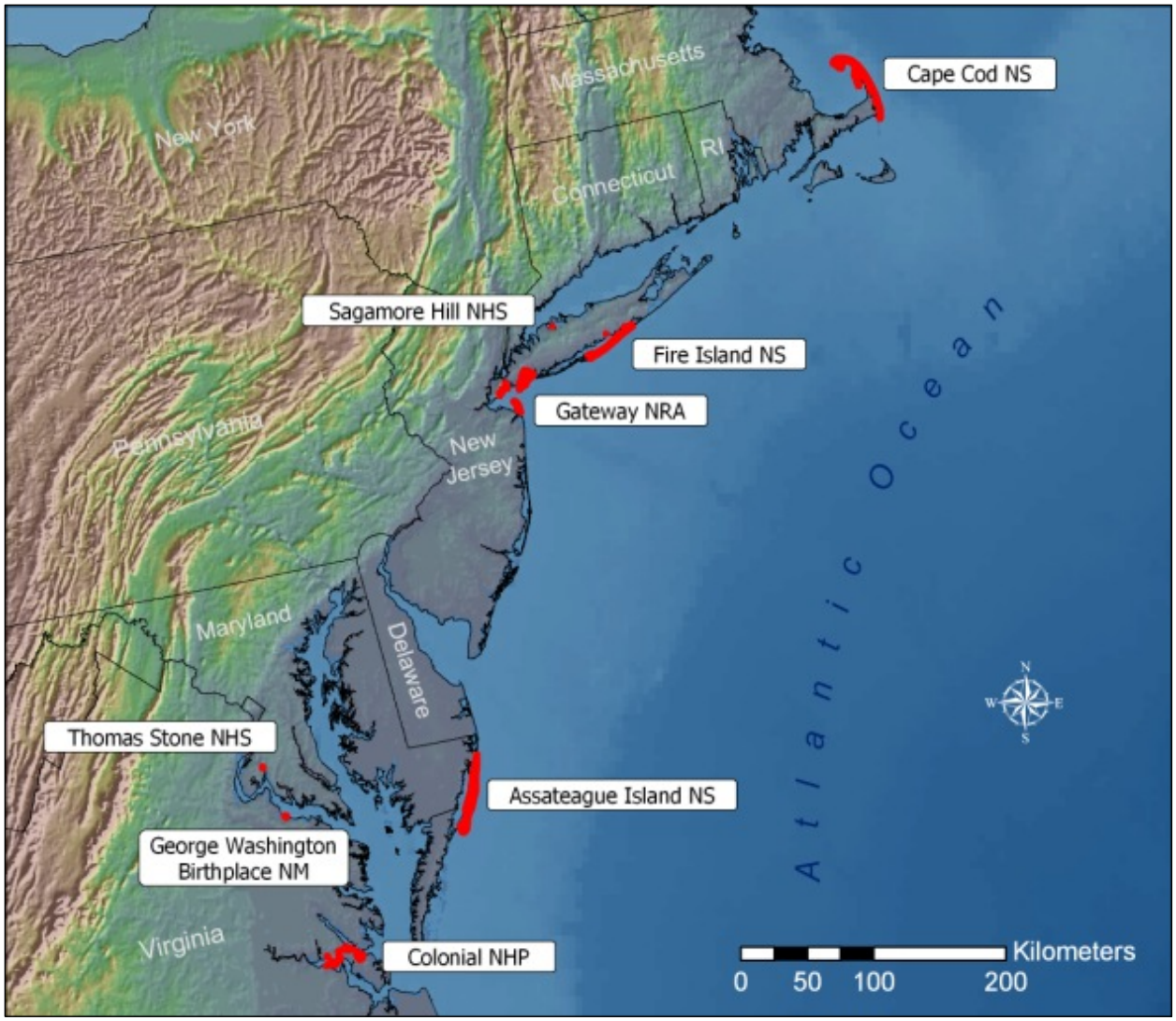


Figure 1. Map of Northeast Coastal and Barrier Network parks (NPS map).

NCBN Geological Background

The geologic history of the NCBN (discussed in greater detail in the individual park summaries that follow) is biased to the Quaternary. There are no exposures of formations older than the Eocene in any NCBN park, and there are few surface exposures of Eocene (THST), Miocene (COLO, GEWA, and THST), and Pliocene (COLO) sediments (see the Appendix for a geologic time scale). Otherwise, all of the surficial exposures in NCBN parks date to the Pleistocene and Holocene. Various Cretaceous and Cenozoic formations are exposed near NCBN units, and wells have accessed other formations beneath the surfaces of most of the parks, which expand the geologic record. In terms of depositional settings, the NCBN is best for shallow marine and coastal sediments, not unlike their modern environments. This makes the fossil record here particularly useful for comparative purposes, examining the effects of climatic and ecological changes in the recent past.

The eight units of the NCBN share a basic history. A core taken from any of them, drilled through the various sediments to crystalline bedrock, will generally pass through unconsolidated shallow coastal marine and/or coastal plain sediments before bedrock is reached. At the northern end of the NCBN, these sediments are Quaternary over Cretaceous, except at CACO, where practically the entire column to bedrock is composed of Pleistocene glacial and marine sediments. The Virginia and Maryland units have more diverse stratigraphy, with much of the Cenozoic represented in some places, and the deposits are mostly shallow coastal marine in origin. The formations are almost all unlithified (not solid rock), with the exception of isolated beds, and trace multiple marine advances (transgressions) and retreats (regressions) as sea level rose and fell. The oldest sediments, from the Cretaceous, generally originated on coastal plains, while the younger sediments are generally shallow marine to estuarine in origin. With the drawdown of sea level due to the formation of continental ice sheets, coastal terrestrial sedimentation returned by the Pleistocene to the NCBN, and the section of the network from about Long Island north has undergone glaciation. Because of these various factors, the fossil record of NCBN parks is biased to coastal, shallow marine organisms from the Cenozoic; aside from fossiliferous glacially transported boulders within CACO, nothing older than about 100 Ma (million years ago), the Early–Late Cretaceous boundary, has been found.

The geologic history of the NCBN area has been quiet since the Early Jurassic, about 180 Ma. Before this time, the eastern margin of North America had been quite active. Over a period of about 300 million years, a series of volcanic island arcs, microcontinents, and other small continental blocks collided with North America and became incorporated into the continent, a process known as accretion. Eventually, Africa, Europe, North America, and South America met as part of the supercontinent Pangaea, during the Pennsylvanian and into the Permian. This process created the Appalachian Mountains. The only records of Paleozoic or older events that can be seen at the surface in NCBN parks are rock fragments transported by glaciers, best known from CACO where Cambrian and Devonian fossils have been found.

During the Triassic, the supercontinent began to break apart. Numerous narrow rift basins formed along the new divisions, and great quantities of lava erupted in these valleys around 201 Ma. The Palisades of the Hudson River Valley formed at this time, and rift basins are thought to be present deep beneath younger sediments under Long Island and Cape Cod. The rocks of the rift basins often host abundant fossils of terrestrial, fluvial, and lacustrine organisms, but none are known from NCBN units.

Thick wedges of coastal plain and shallow marine formations began to form in the NCBN before 100 Ma, as sea level rose. As noted above, these formations form much of the accessible subsurface of NCBN units. The Cretaceous formations are best known from beneath the NPS units of the New York City/Long Island area: FIIS, GATE, and SAHI. Within these units, the Cretaceous sediments can only be accessed by wells, but surface exposures are present in the immediate vicinity and eroded fossils have probably washed up on GATE's shorelines. The formations include from oldest to youngest the Raritan Formation, the Magothy Formation, several divisions of the Matawan Group, and several divisions of the Monmouth Group. The oldest sediments are continental in origin, while the younger sediments include marine and continental deposits. The Raritan and Magothy formations

are noted for their plant fossils and amber. The overlying Matawan and Magothy groups preserve diverse marine invertebrates and vertebrates that lived along the Cretaceous Atlantic coast.

Erosion has removed the post-Cretaceous, pre-Quaternary deposits in many areas from New York City north, but sediments from this time are common south of it. Shallow marine deposits assigned to the Pamunkey Group (Paleocene–Eocene) and Chesapeake Group (Oligocene–Pliocene) are either exposed at the surface or known from the subsurface of COLO, GEWA, and THST. As the Atlantic Ocean periodically advanced and retreated over the millions of years, it left behind a wedge of shallow marine deposits separated by erosional hiatuses. Abundant marine invertebrates and vertebrates flourished during the sea highstands.

At about 35 Ma, the quiet unremarkable cycles of rising and falling sea levels were interrupted by the impact of an asteroid or comet just north of the modern mouth of Chesapeake Bay. The object left a crater perhaps 90 km (58 miles) and 1.3 km (0.8 miles) deep. The sediments beneath it down to bedrock were scoured and redeposited, with tsunamis spreading the debris. Understandably, this event has made interpreting the pre-35 Ma sediments a confusing matter, especially before it was known that an impact had occurred. It also disrupted the aquifers, so that to this day the groundwater of the crater area is of poor quality. One odd consequence is that three deep wells were drilled at Fort Monroe (now Fort Monroe National Monument [FOMR], within the NCBN but not in the I&M program) before it was concluded that there was no potable water; construction of each well brought up many fossils.

The Pamunkey Group is exposed only at THST, as the Lower Eocene Nanjemoy Formation. The rate of deposition was low, on what would have been a continental shelf, and the climate was warm temperate. Mollusks, especially bivalves, are the most common fossils. Some other formations from the Pamunkey Group are represented in wells (the Paleocene Aquia Formation at GEWA and the Chickahominy Formation at COLO and FOMR); they would have had similar depositional settings and conditions.

The Oligocene is not definitely represented at any NCBN unit, although it might be present in the subsurface of FOMR. A much better record is known for the Miocene. Miocene sediments of the Chesapeake Group are exposed at COLO, GEWA, and THST, and have been reached beneath FOMR and possibly ASIS. GEWA and THST have exposures of the Lower to Middle Miocene Calvert Formation, a marine unit that has become famous for its vertebrate remains. It is best studied farther north in the Chesapeake Bay, along the Calvert Cliffs, but it has yielded numerous fossils from GEWA and the vicinity. Shark teeth constantly appear on the shore at GEWA, eroded from upstream, washed in by storms, or eroded out of the park's deposits. The glaciation of the Earth's polar caps was in progress during the Miocene, and cyclic deposition in the Calvert Formation suggests that various parameters of the Earth's rotation and orbit were affecting glaciation, as they do today (Milankovitch cycles). The climate was still warmer than the present, with a subtropical to tropical marine climate prevailing during deposition.

Upper Miocene and Pliocene deposits can be seen at COLO and are present in the subsurface beneath ASIS and FOMR. At COLO, the Upper Miocene Eastover Formation precedes the Pliocene

Yorktown Formation. Again, these are shallow marine formations deposited near the coast of eastern North America, with abundant fossils of marine invertebrates and vertebrates. The Yorktown Formation includes the most extensive marine highstand since the Eocene. There had been cooling during the Late Miocene, but warming during the Pliocene allowed a subtropical fauna to become established along the Virginia coast.

Changes in global geography that blocked or diverted circulation, like the formation of the Isthmus of Panama, the closure of the Mediterranean Sea, and the growth of the Himalayas, reinforced a general cooling trend. As more water was removed from circulation into Antarctic and Arctic ice, global sea level lowered, and ice became the major control on sea level instead of tectonics, which operate much more slowly. Lower sea levels meant that large areas that had been submerged much of the time since the Late Cretaceous were no subjected to sea level rises of much smaller extent and duration. Instead of widespread shallow seas, rivers would become more estuarine during sea level rises, and estuaries would become more marine. This pattern dominates the Pleistocene of the southern half of the NCBN, and can be seen in deposits at COLO and GEWA.

The northern half of the NCBN was shaped by direct and indirect effects of glaciation during the Pleistocene and into the Holocene. Glaciers reached about as far south as New York City and Long Island, scraping off the upper layers of sediments during advances and dumping vast amounts of transported debris in retreats. Multiple glacial advances have occurred over about the past 2.6 million years, but each successive glaciation destroys much of the evidence of preceding glaciations, so only the events of the most recent glaciation are well known. In the past 200,000 years, there have been two major glacial stages separated by a warmer interglacial. The older glacial stage is known as the Illinoian and lasted from about 191,000 to 125,000 years ago. It was followed by the Sangamonian (or Sangamon) interglacial, which lasted from about 125,000 to 85,000 or 75,000 years ago. During the Sangamonian, sea level rose to elevations slightly above present, as reflected in coastal marine deposits from this time. The Sangamonian was followed by the Wisconsinan (or Wisconsin) glaciation, the most recent glacial stage. It is not uncommon for radiocarbon dates along the coast to suggest a sea level highstand near present elevations during the Wisconsinan, about 30,000 years ago, but this is controversial; reconstructions of ice volume and sea level do not support it, and other dating methods suggest Sangamonian ages, with the radiocarbon sources being contaminated.

The North American continental glacier of the Wisconsinan stage is known as the Laurentide ice sheet. It reached its maximum extent between 25,000 and 20,000 years ago, then went into retreat. At the height of the glaciation, sea level was as much as 130 m (430 ft) lower than present, with wide areas of the modern continental shelf exposed to the air and converted to broad coastal plains. Fossils of plants and animals that inhabited these plains are sometimes recovered by accident by dredgers, or are washed up on shores. The large durable teeth of mammoths and mastodons are common dredge recoveries.

Many of the coastal landforms of the northern NBCN were produced by the Wisconsinan glaciation. Long Island is largely composed of two Wisconsinan moraines. The more southerly, the Ronkonkoma moraine, is older and formed at the maximum extent of the ice sheet. The more northerly, the Harbor Hill moraine, formed around 18,000 years ago during the retreat of the ice

sheet, and is present in the SAHI area. Both moraines have equivalents along the southern margin of New England. Inner Cape Cod has the Buzzards Bay and Sandwich moraines, which are equivalent to the Harbor Hill moraine. Outer Cape Cod (including CACO) is younger, having formed from outwash deposited along the boundary between two glacial lobes around 17,000 to 14,000 years ago.

The Wisconsinan stage ended around 11,000 years ago, after thousands of years with ice in retreat. As glaciers left an area, meltwater lakes formed in newly exposed depressions, behind dams of glacial drift, and in front of or beneath the retreating ice. These lakes frequently drained catastrophically as moraines collapsed, new outlets were exposed by retreating glaciers, and via other processes. Additionally, in the immediate aftermath of a glacial retreat, elevations of land surfaces changed dramatically, rebounding and subsiding as the crust adjusted following the removal of the burden of a kilometer or more of ice. In coastal areas, this can produce complex combinations of marine and freshwater lacustrine deposits, as seen in and around CACO. At a smaller scale, blocks of ice left behind by glaciers often formed distinctive basins known as kettle ponds. These ponds trapped thousands of years of pollen, spores, and microfossils, and have been used to reconstruct the climate of CACO.

Rising sea levels submerged the lower coastal plain after the collapse of the continental ice sheets. In some areas, barrier islands have formed offshore as a result of the coastal processes. They include Assateague Island (ASIS) and Fire Island (FIIS). Both islands are geologically young, on the order of a few thousand years old in their current locations, and are dynamic and subject to rapid changes. CACO (Provincetown Hook) and GATE (Sandy Hook) also include significant areas created by Holocene coastal processes.

Humans arrived in the NCBN region at least 11,000 years ago. It is likely that much of the early history of human presence has been lost in the NCBN because of post-glacial sea level rise. Humans have often exploited coastal regions because of the diversity and abundance of natural resources, and abundant shell middens from the past few thousand years show that the early inhabitants of the NCBN were no exception, but the coastal regions of 11,000 years ago are now far offshore. The archeological record from the past few thousand years is strong.

It is not known when people first noticed fossils in the NCBN region. The English colonists in coastal Virginia began to utilize Cenozoic shell deposits for fertilizer soon after they arrived in the early 17th century. Naturalists active in the 1680s noted the shells as well. At some point, a few specimens were collected and sent to Martin Lister in London, who illustrated them in his “Historiae Conchyliorum”, published primarily between 1685 and 1692. The first that he illustrated was the first fossil illustrated from North America, a shell now recognizable as an example of *Chesapecten jeffersonius*, the state fossil of Virginia. This fossil probably came from in or near COLO, at Yorktown, although Lister misinterpreted a label “A virg” as a reference to the Virgin Islands. He also did not think it was a fossil, and in fact had described other fossils as natural inorganic imitations of living forms. The Yorktown shell beds were first brought to wider scientific notice just after the American Revolutionary War. Extensive collections of the fossils were made in the early 19th century by John Finch and distributed to various scientists, but were inexplicably thought to have come from Miocene beds in Maryland.

The framework for understanding the Cretaceous and Cenozoic coastal plain sediments and Quaternary glacial deposits in the NCBN was mostly completed in the last few decades of the 19th century and the first few decades of the 20th century, with a steady stream of improved geologic descriptions and maps since then. Aside from COLO, none of the NCBN units has been historically noted for its fossils, and paleontological information is often contained in other publications, particularly in descriptions of subsurface geology. Exposures of pre-upper Pleistocene formations are limited in the NCBN units, being hidden by modern cover and poorly fossiliferous glacial deposits, so in situ fossils are relatively uncommon, and many fossils are washed in (as seen at ASIS, CACO, COLO, GATE, and GEWA) or have been transported by glaciers (CACO). This situation is unlikely to change in the near future, especially with the covering of most COLO exposures to prevent further coastal erosion. Because most sediments at or near the surface are late Quaternary in age, fossils in the NCBN units as a whole are best represented from this time. The strong Quaternary fossil record is of use for park management. The presence or absence of certain fossils can help describe the history of movement of coastal features, such as the locations of shells and peat beds at ASIS, CACO, and FIIS. Microfossils are commonly used to describe past climate regimes and how ecosystems respond to change. CACO's kettle pond fossils are the best example, but marsh sediments have also been studied at COLO and GATE. There are few known museum collections of NCBN fossils, outside of the Yorktown Formation shells of COLO, which can be found in many eastern North American institutions and in European museums. Small collections are present or were present at ASIS, COLO, GEWA, and GATE.

Collectively, the paleontological resources of the NCBN park units contribute to a greater understanding of the history of life on earth. Continued paleontological resource inventories will serve to expand this ever-widening base of paleontological knowledge represented throughout the NPS. Although at least 246 parks have already been identified as containing paleontological resources, much of what is to be known about the history of life on earth remains to be discovered.

Report Organization and Methodology

This report summarizes the paleontological resources of park units in the Northeast Coastal and Barrier Inventory & Monitoring Network (NCBN). The report consolidates baseline paleontological resource data for each network park to support management operations, planning, and science-based decision making as required by NPS management policies and the Paleontological Resources Preservation Act (2009). This section of the report details the organization of the report and summarizes how the report was written.

Each network report includes an executive summary, introduction with geologic background, methodology chapter (this chapter), description of resource management strategies, and individual park narratives, which are described below. Some network reports include information for non-network parks, those that are not officially part of the Inventory and Monitoring Network, but are within the geographic boundaries of the network. Such parks were included in instances where paleontological resources were documented. For more information regarding different paleontological resource inventory strategies, refer to the chapter on Paleontological Resource Management.

This 2014 Northeast Coastal and Barrier Network Paleontological Resource Inventory and Monitoring report represents a substantial update of the previous NCBN paleontology summary completed by Kenworthy and Santucci (2003). The methodology section below describes the changes between the original report and this document.

Organization of the Park Narratives

Each park narrative contains the following sections.

Geologic Background

The Geologic Background section contains basic geographic information for the park and lists pertinent geology and paleontology references. A brief geologic history is included to provide context for the fossils discovered within or near the park.

Sources of Paleontological Resources

The Sources of Paleontological Resources section reviews each fossil-bearing rock unit within the park. The history of paleontological resource field work in the park is summarized. A brief geologic description is included as well as the scope and significance of paleontological resources known to occur within the park. The section is organized stratigraphically from oldest rock unit to youngest.

Potential Sources of Paleontological Resources

The rock units listed in the Potential Sources section are units mapped within the park that potentially contain fossils. Although fossils have not been previously documented from those units within the park, fossils have been discovered within those units at localities outside of the park. In some cases, the lack of documented fossils within a particular park or a specific geologic unit in a park, may simply be due to the fact that field inventories for fossils have never been undertaken in the park. As with the Sources section, the geologic units are listed stratigraphically from oldest to youngest.

Park Collections

The Park Collections section summarizes museum collections of fossils associated with the park. Such collections may be housed within the park or in external museum or university repositories. Fossil collections maintained by the park may include specimens discovered both from within and outside the park. It is important to recognize that the park's museum Scope of Collections may include fossils from localities outside of the park boundaries. Regional museums and other outside repositories may curate fossils collected within the park prior to or subsequent to the park's establishment. Both contexts are included in the report. The Smithsonian Institution National Museum of Natural History maintains significant collections of National Park Service fossils, and the U.S. Geological Survey has much relevant documentary material.

Cultural Resource Contexts

Resource stewardship strategies and management plans typically address paleontological resources that are known to occur within the rocks of the park. Fossils may also occur in a variety of cultural resource contexts, including: in association with archeological resources, ethnographic stories and legends, prehistoric and historic structures, or other documented historical occurrences. Fossils may be found as tools, jewelry, spiritual or ceremonial objects, or other cultural objects in archeological

sites. A few ethnographic stories and legends told by American Indians and "mountain men" of the American West incorporate fossils. Building stones often contain fossils. In addition, archives, journals, memoirs, and photographs include other historical accounts of fossils in NPS areas. Kenworthy and Santucci (2006) summarizes such occurrences and provides examples.

Paleontological Resource Management, Preliminary Recommendations

In addition to geology and paleontology content, the authors suggest "next steps" for paleontological resource management and stewardship at each park. The recommendations are based on discussion with park staff and other geologists or paleontologists, or as part of broader NPS paleontological resource management strategies. These strategies are summarized in the next chapter. Parks may choose to address the recommendations based upon available staff time, training, and budget. Contact the NPS Geologic Resources Division for technical assistance or further guidance.

References Cited and Additional References

Each park narrative has a bibliography that is divided into two sections. References mentioned in the park narrative are included in the References Cited section. References discovered during the data-mining process that maybe of secondary value or interest are listed in the Additional References section. These publications were not included in the narrative, but are relevant to the park, commonly containing additional detail beyond the scope of the narrative.

Data Sets

The Data Sets section includes a list of research projects, museum collections, NPS Geologic Resources Inventory-produced geologic map data, archives, or other files and information relevant to the fossils of a particular park.

Figures, Photographs, and Graphics

The first network-based paleontological resource summaries (completed between 2002 and 2011) did not include figures, photographs, or other graphics aside from the report cover and a network map. This second generation of Inventory & Monitoring Network-based paleontological resource inventory reports include basic geologic maps, stratigraphic columns, paleontological resource summary tables, and photographs for each park when available. Many of the geologic maps are adapted from the NPS Geologic Resources Inventory (GRI) map data for each park. These data are available in GIS format and support accompanying GRI reports, all of which are available from the GRI publications page: http://www.nature.nps.gov/geology/inventory/gre_publications.cfm. The stratigraphic columns illustrates a compiled section of all the rock units mapped in the park along with rock unit name, age, map symbol, thickness, and lithology. Also new to the second generation network-based reports is a summary table listing all the fossiliferous geologic units within the park, fossils collected within the park and the inferred depositional environment. Photographs of park fossils are inserted where appropriate.

Report Methodology

Inventory & Monitoring Network-based paleontological resource inventories compile baseline paleontological resource data for each of the parks within a particular network, and as such, require considerable research and data mining. To minimize costs, field work is not normally conducted as

part of the report preparation process. This section details the research methodology and report preparation, review, publication, and distribution for network-based paleontological inventories.

Between 2002 and 2011, network-based inventories were completed for all of the 32 I&M networks. In 2001, the Northern Colorado Plateau Network technical committee supported a modest funding proposal to develop a prototype paleontological resource inventory for the network. Koch and Santucci (2002) represented the first attempt at compiling baseline paleontological resource data at a network level. That report laid the foundation upon which similar work would be completed for each of the I&M Networks in the National Park System. Between 2002 and 2006, 13 network reports were completed using small amounts of funds provided from each network. Funding from the NPS I&M Program was designated to systematically complete the remaining 19 reports between 2006 and 2011.

This second-generation report represents a substantial revision of the original Northeast Coastal and Barrier Network summary, completed in 2003 (Kenworthy and Santucci 2003). This updated network-based paleontological resource inventory report represents a new template and format for future revisions to other network summaries.

Although field work is still not typically performed in association with network-based reports, in a few instances, field work complimented the original park inventories. In some cases, field work has been conducted in response to recommendations provided in the initial network-based paleontological resource inventory reports. Any new field data are incorporated into the updated reports.

Research

One of the most important components of any paleontological resource inventory is an intensive literature search and data mining. The American Geological Institute's GeoRef is the leading database for geology references, indexing more than 3.3 million references to North American geology dating back to the 1660s. To compile the appropriate literature base for this report, the authors conducted intensive GeoRef searches for general and park-specific publications.

Additional databases or information catalogs include the NPS Integrated Resource Management Applications (IRMA) portal (https://irma.nps.gov/app/portal/home), the U.S. Geological Survey (USGS) library system (http://library.usgs.gov/) and publications warehouse (http://pubs.er.usgs.gov/), as well as museum, university, and other institutional libraries and archives.

The literature search also includes un-published material, or "gray literature," from park files, museum archives, local newspapers, field notes, and other sources. In addition to literature searches, interviews with park staff, university faculty, geologists from the USGS and state geological surveys, and even local amateur geologists or paleontologists can often yield unpublished information regarding park paleontological resources. These interviews frequently result in capturing data that might otherwise be undocumented and potentially lost or unrecognized.

Report authors develop a comprehensive list of geologic units within each park by consulting published geologic maps and other sources. Geologic maps show the types of rocks and the associated geological formations within a park area. These maps alone can often suggest the potential for paleontological resources to occur within a park. The NPS GRI Program is producing standardized digital geologic map data (GIS) for all I&M Program parks. When available, the updated network-based paleontological resource inventory reports adapt GRI map data for each of the parks.

The nomenclature for geologic formations evolves over time and can differ based upon different geological interpretations. To maximize consistency with other NPS geology products, this report generally followed the geologic nomenclature used in GRI maps and report when they were available. The USGS maintains the National Geologic Map Database (NGMDB), which includes a searchable lexicon of valid geologic formation names (http://ngmdb.usgs.gov/Geolex/geolex_home.html). This lexicon provides a basic summary for each formation, summarizes current and past usage of the various formation names found in the literature, and provides an annotated bibliography for each formation.

Narrative

Information from these various sources is compiled into a narrative report for each park. The narrative is organized according to the scheme detailed earlier in this section.

Review

The park narratives and compiled report are extensively peer reviewed by professional geologists or paleontologists, as well as NPS staff from each park and the NPS Geologic Resources Division. Upon completion of a compiled, draft report, network staff have the opportunity to provide review. Network staff also determine if the previous technical review was adequate for publication.

Publication and Distribution

The peer-reviewed, network-approved reports are published in the NPS Natural Resource Report series. To minimize production costs, hard copies are not generally produced. The reports are distributed in PDF format to park and network staff and available to other NPS staff via the Integrated Resource Management Applications portal. Report reviewers and paleontologists working in the parks may also receive copies. The reports are not intended for, or distributed to, the general public due to the sensitive nature of paleontological resource locality information.

References Cited

Kenworthy, J. P. and V. L. Santucci. 2006. A preliminary inventory of NPS paleontological resources found in cultural resource contexts, part 1: General overview. Pages 70–76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at: http://www.nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf (accessed April 2014).

Kenworthy, J. P. and V. L. Santucci. 2003. Paleontological resource inventory and monitoring: Northeast Coastal and Barrier Network. TIC# D-340. National Park Service, Denver, Colorado.

Inventory and Monitoring Strategies and Resource Management Guidance

Paleontological Resource Inventory Strategies

In order to better document fossil occurrences and to provide baseline paleontological resource data to NPS areas, the NPS GRD and the NPS I&M Program have established three paleontological resource inventory strategies. These strategies include: comprehensive park-specific inventories, Service-wide thematic inventories, and I&M Network-based summaries.

Comprehensive Park-Specific Surveys

Comprehensive park-specific surveys identify all known paleontological resources within a single NPS unit. A team of specialists from within the NPS and from educational institutions and cooperators work with the targeted park to identify and address all aspects of its paleontological resources. The surveys commonly include sections addressing: park geology, paleontological resources inventory (species list and other compilations), localities, museum collections and curation, interpretation, management and protection, and recommendations. Paleontological resource training for park staff is an important component of many comprehensive park paleontological resource inventories.

Park-specific comprehensive paleontological resource inventories have been completed for Amistad National Recreation Area (Visaggi et al. 2009), Arches National Park (Swanson et al. 2005; Madsen et al. 2012), Bighorn Canyon National Recreation Area (Santucci et al. 1999), Chesapeake and Ohio Canal National Historical Park (Clites and Santucci 2010), Death Valley National Park (Nyborg and Santucci 1999), Santa Monica Mountains National Recreation Area (Koch et al. 2004), Walnut Canyon National Monument (Santucci and Santucci 2001), Yellowstone National Park (Santucci 1998, the first park to have such a survey completed), and Zion National Park (DeBlieux et al. 2005). Similar paleontological resource inventories are currently underway at Big Bend National Park, Glacier Bay National Park and Preserve, and Golden Gate National Recreation Area.

Service-wide Thematic Inventories

Service-wide thematic paleontological resource inventories compile data regarding specific types of paleontological resources that occur in parks throughout the NPS. These reports offer brief summaries of each occurrence of a particular type or category of fossils documented within a particular park. These reports are based primarily on literature review and communication with park staff and professional geologists and paleontologists.

The first thematic paleontological resource inventory identified 19 NPS units that preserve fossil vertebrate tracks (Santucci et al. 1998). Subsequent discoveries have increased the number of parks identified with fossil vertebrate tracks to 25 and warranted an updated publication (Santucci et al. 2006). Another thematic inventory identified paleontological resources associated with NPS caves in 35 parks (Santucci et al. 2001). Service-wide thematic inventories have also been initiated for fossil fish (Hunt et al. 2006), Cenozoic fossil vertebrate tracks and burrows (Santucci et al. 2014a), fossil coprolites (Hunt et al. 2012), fossil packrat middens (Tweet et al. 2012), and fossils found in cultural resource contexts (Kenworthy and Santucci 2006). An inventory of paleontological resources

associated with NPS coastal and shoreline parks is planned as a future thematic paleontological resource project, and an inventory of USGS paleontological localities within NPS units is in progress (Santucci et al. 2014b). Smaller-scale inventories have documented the paleontological resources of NPS units in Utah (Santucci 2000) and fossil plants from the National Capital Region (Santucci et al. 2014c).

Inventory and Monitoring Network-Based Summaries

Network-based paleontological resource inventories compile baseline paleontological resource data for each of the parks within a particular I&M Network. Between 2002 and 2011, network-based inventories were completed for all 32 I&M Networks. This report represents an overhaul and substantial revision of the NCBN report, the second I&M Network report completed. For more information on the content of network-based summaries and how they are completed, refer to the Report Organization and Methodology chapter. Citations for the completed reports are listed in the References Cited section. A comprehensive summary report is currently being developed to present an overview and highlights of the 10-year effort to document fossils throughout the NPS using the network-based strategy. Four summary reports are planned, including reports that present data based on geologic time, taxonomy, museum collections and fossil type specimens. These reports are anticipated to be finalized in 2014. See Santucci et al. (2012) for a brief overview.

Paleontological Resource Monitoring Strategies

Following the compilation of baseline paleontological resource inventories, monitoring of fossil localities represents the next phase in paleontological resource management. Santucci and Koch (2003) presented a preliminary strategy for monitoring paleontological resources and identified natural and human-related impacts to fossils. Santucci et al. (2009) presented a more comprehensive strategy for paleontological resource monitoring that identified natural and human-related stressors upon paleontological resources, described five vital signs, and provided examples of study design and case studies. The five vital signs include: (1) erosion, geologic factors; (2) erosion, climatic factors; (3) catastrophic geohazards; (4) hydrology/bathymetry; and (5) human access/public use. The vital signs discussions provide detailed recommendations for resource managers, incorporating expertise, personnel, and equipment needed, approximate cost, and labor intensity. Santucci et al. (2009) is one chapter in the Geological Monitoring manual that provides guidance for monitoring various geologic resources and processes. The manual (Young and Norby 2009) was published by the NPS Geologic Resources Division and Geological Society of America.

Coastal Paleontological Resources

Paleontological resources occur in two general contexts in coastal areas: 1) fossils preserved in situ within rock or sedimentary strata exposed along the coastal marine margins; and 2) fossils which are transported and accumulated in coastal areas. Both types of coastal occurrences of paleontological resources can yield fossils in supratidal, intratidal, and subtidal zones.

Coastal paleontological resources are subject to a variety of natural processes which influence the stability and distribution of fossils in coastal environments. Tides, storms, and sea level rise all contribute to both the exposure and destruction of coastal paleontological resources. Hurricanes and other large storm events can rapidly erode fossiliferous cliffs along coastlines, shorelines, and

beaches. The energy of storm events can sometimes result in fossils being scoured from strata exposed in subtidal areas, and fossils being transported to intratidal zones and beaches or other supratidal areas along coasts.

The impacts of storms are well documented along the shoreline at George Washington Birthplace National Monument (GEWA), where fossiliferous exposures are rapidly receding (see the GEWA chapter of this document for more information). New fossils were washed up at both GEWA and Assateague Island National Seashore (ASIS; see the ASIS chapter of this document for more information) following Hurricane Irene in August 2011. At Gateway National Recreation Area (GATE; see the GATE chapter of this document for more information) in New York, fossils often wash up following storms. For example, after Superstorm Sandy hit the Atlantic Coast of the United States in October 2012, there were reports of accumulations of fossils transported onto the beaches from offshore, especially on the beaches in Long Island. Fossils of the oyster genus *Crassostrea* were discovered along the beaches at Fort Tilden and Great Kills during November 2012.

The coastal occurrences of paleontological resources attract hobbyist fossil collectors to the beaches to gather shark teeth and other fossils from tidal zones and beaches. Paleontologist Carl Mehling (American Museum of Natural History, New York City) and geologist Phil Stoffer (U.S. Geological Survey emeritus) acknowledged the post-storm accumulations of fossils along the beaches in New York. There is currently very little information available regarding coastal paleontological resources and focused work related to the scientific and resource management considerations of coastal fossils is needed.

Paleontological Resource Management Legislation and Guidance

I&M Network reports such as this are meant to provide network parks with sound baseline paleontological resource data that can stimulate future research, interpretation, education, or resource management projects. Science-based management of resources identified through these inventories is mandated by many NPS policies including the newly enacted Paleontological Resource Preservation Act (PRPA).

2009 Paleontological Resource Preservation Act

The Paleontological Resource Preservation Act (P.L. 111-11; "PRPA") was signed into law on March 30, 2009 as part of the Omnibus Public Lands Act of 2009. PRPA will serve as explicit authority for the management, protection and interpretation of paleontological resources in parks. PRPA regulations are currently (March 2012) being finalized by the National Park Service, Bureau of Land Management, and the U.S. Forest Service. PRPA specifically provides the NPS with the following mandates to enhance paleontological resources stewardship:

- §6302 calls for the management and protection of paleontological resources using scientific principles and expertise. The NPS should develop plans for inventory, monitoring, and the scientific and educational use of paleontological resources. Planning should emphasize interagency coordination and collaboration and where possible include non-federal partners, the scientific community, and the public.

- §6303 calls for the establishment of education programs to increase public awareness about the significance of paleontological resources.
- §6304 calls for the development of a specific permit for the collection of NPS paleontological resources. The new legislation and other existing authorities clarify and reaffirm issues of property ownership, accountability, access and confidentiality of locality information associated with the management of NPS paleontological resources.
- §6305 calls for the curation of NPS paleontological resources, along with any associated data or records, in approved repositories.
- §6306 provides clarity regarding prohibited acts involving paleontological resources and specifies criminal penalties associated with these prohibited acts.
- §6307, along with other existing authorities, enables the NPS to seek civil penalties and restitution for the violation of any prohibited activities involving paleontological resources.
- §6308 provides the NPS a confidentiality provision with an exemption from the disclosure of any information associated with the nature and specific location of NPS paleontological resources.
- §6310 directs the Secretaries of the Interior and Agriculture to issue regulations appropriate to carry out the Act.

NPS Management Policies

In addition to the PRPA, several other authorities influence the management of NPS paleontological resources. The 2006 National Park Service Management Policies (§1.4.6) stipulates that paleontological resources are considered park resources and values that are subject to the "no impairment" standard set forth by the NPS Organic Act in 1916. Basic guidelines for management of paleontological resources are found in sections 4.8.2 and 4.8.2.1 of the 2006 NPS Management Policies (http://www.nps.gov/policy/MP2006.pdf).

Other Resources

Paleontological resource management issues were the subject of a Report of the Secretary of the Interior in May 2000, viewable online at http://www.blm.gov/heritage/docum/fossilrpt.pdf. That report was prepared in response to a Congressional request for an assessment of the need for a unified federal policy on the collection, storage and preservation of fossils and for standards that would maximize the availability of fossils for scientific study.

The Paleontological Resources Management section of Natural Resource Management Reference Manual 77 provides guidance and additional information regarding the implementation and continuation of paleontological resource management programs (http://www.nature.nps.gov/rm77/paleo.cfm).

As described above, Santucci et al. (2009) provided guidance for paleontological resource monitoring.

The NPS manages more than 445,000 catalogued fossil specimens in collections across the country. Many thousands more specimens await cataloging. For information regarding fossils in museum collections, refer to the NPS Museum management handbook, particularly Part I, Appendix U (http://www.nps.gov/museum/publications/handbook.html).

Education and Outreach Opportunities

Fossils occupy an enduring place in the hearts and mind of the public, presenting excellent opportunities for education and outreach. These opportunities support provisions in the Paleontological Resources Preservation Act (above) as well as the NPS natural resource stewardship mission. The NPS Geologic Resources Division coordinates two fossil-related education and outreach opportunities with a national scope: National Fossil Day and the Junior Paleontologist program. National Fossil Day is a celebration organized to promote public awareness and stewardship of fossils, as well as to foster a greater appreciation of their scientific and educational value. Learn more at the NFD website: http://nature.nps.gov/geology/nationalfossilday/index.cfm. The Junior Paleontologist program (part of the Junior Ranger program) provides opportunities for children to explore the ways that paleontologists work, learn about earth's history, and protect fossils and the rocks in which they are found. For more information, visit the Junior Paleontologist program webpage: http://nature.nps.gov/geology/nationalfossilday/jrpaleo.cfm. Contact the Geologic Resources Division for information on how to participate in either program.

In conclusion, our knowledge of the fossil record is only as good as our previous field season. The potential for new paleontological discoveries is proportionally related to our understanding as managers and stewards of this non-renewable evidence of life from the past. We believe that the baseline information provided in these reports and the resulting increased understanding of paleontological resources will inevitably result in paving the way for future fossil discoveries in NPS areas.

References Cited

Clites, E. C. and V. L. Santucci. 2010. Preliminary paleontological resource field survey: Chesapeake and Ohio Canal National Historical Park. Natural Resource Report NPS/NRPC/NRR—2010/197. National Park Service, Fort Collins, Colorado.

DeBlieux, D. D., J. A. Smith, J. L. McGuire, J. I. Kirkland, and V. L. Santucci. 2005. Zion National Park paleontological survey. Utah Geological Survey, Salt Lake City, Utah.

Hunt, R. K., V. L. Santucci, and J. P. Kenworthy. 2006. A preliminary inventory of fossil fish from NPS units. Pages 63–69 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/8%20Hunt%202.pdf (accessed April 2014).

Kenworthy, J. P. and V. L. Santucci. 2006. A preliminary inventory of NPS paleontological resources found in cultural resource contexts, part 1: General overview. Pages 70–76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf (accessed April 2014).

Koch, A. L., V. L. Santucci, and T. R. Weasma. 2004. Santa Monica Mountains National Recreation Area paleontological survey. NPS Geologic Resources Division, Denver, Colorado. Technical Report NPS/NRGRD/GRDTR—04/01. Available at http://nature.nps.gov/geology/paleontology/surveys.cfm (accessed April 2014).

Madsen, S. K., J. I. Kirkland, D. D. DeBlieux, V. L. Santucci, P. Inkenbrandt, and J. Tweet. 2012. Paleontological resources inventory and monitoring at Arches National Park, Utah. Utah Geological Survey Contract Deliverable.

Nyborg, T. G. and V. L. Santucci. 1999. The Death Valley National Park paleontological survey. National Park Service, Geologic Resources Division, Denver, Colorado. Technical Report NPS/NRGRD/GRDTR—99/01. Available at http://nature.nps.gov/geology/paleontology/surveys.cfm (accessed April 2014).

Santucci. V. L. 1998. The Yellowstone paleontological survey. Yellowstone Center for Resources, National Park Service, Yellowstone National Park, Wyoming. Report YCR-NR-98-1. Available at http://nature.nps.gov/geology/paleontology/surveys.cfm (accessed April 2014).

Santucci, V. L. 2000. A survey of paleontological resources from the national parks and monuments in Utah. Pages 535–556 *in* D. A. Sprinkel, P. B. Anderson, and T. C. Chidsey, Jr., editors. Geology of Utah's parks and monuments. Utah Geological Association, Salt Lake City, Utah. Publication 28.

Santucci, V. L. and A. L. Koch. 2003. Paleontological resource monitoring strategies for the National Park Service. Park Science 22(1):22–25. Available at http://www.nature.nps.gov/parkscience/index.cfm?ArticleID=16 (accessed April 2014).

Santucci, V. L. and V. L. Santucci, Jr. 1999. An inventory of paleontological resources from Walnut Canyon National Monument, Arizona. *in* V. L. Santucci and L. McClelland, editors. Paleontological research volume 4. Technical Report NPS/NRGRD/GRDTR-99/03. National Park Service, Geologic Resources Division, Lakewood, Colorado. Available at http://nature.nps.gov/geology/paleontology/pub/grd4/nsp_paleo_vol4.pdf (accessed April 2014).

Santucci, V. L., A. P. Hunt, and M. G. Lockley. 1998. Fossil vertebrate tracks in National Park Service areas. *Dakoterra* 5:107–114.

Santucci, V. L., D. Hays, J. Staebler, and M. Milstein. 1999. A preliminary assessment of paleontological resources at Bighorn Canyon National Recreation Area, Montana and Wyoming. Pages 18–22 *in* V. L. Santucci and L. McClelland, editors. Paleontological Research Volume 4. Technical Report NPS/NRGRD/GRDTR-99/03. National Park Service, Geologic Resources Division, Lakewood, Colorado. Available at http://nature.nps.gov/geology/paleontology/pub/grd4/nsp_paleo_vol4.pdf (accessed April 2014).

Santucci, V. L., J. Kenworthy, and R. Kerbo. 2001. An inventory of paleontological resources associated with National Park Service caves. NPS Geologic Resources Division, Denver. Technical Report NPS/NRGRD/GRDTR-01/02. TIC# D-2231. Available at http://nature.nps.gov/geology/paleontology/pub/cavepaleo.pdf (accessed April 2014).

Santucci, V. L., A. P. Hunt, T. Nyborg, and J. P. Kenworthy. 2006. Additional fossil vertebrate tracks in National Park Service areas. Pages 152–158 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/21%20Santucci%20et%20al..pdf (accessed April 2014).

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado. Available at http://nature.nps.gov/geology/monitoring/paleo.cfm (accessed April 2014).

Santucci, V. L., J. S. Tweet and J. P. Kenworthy. 2012. Paleoblitz: uncovering the fossil record of the national parks. *Park Science* 29(1):29–32.

Santucci, V. L., J. S. Tweet, D. Bustos, T. Nyborg, and A. P. Hunt. 2014a. An inventory of Cenozoic fossil vertebrate tracks and burrows in National Park Service areas. Pages 469–488 in M. G. Lockley S. G. Lucas, editors. Fossil footprints of western North America. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 62.

Santucci, V. L., J. M. Ghist, and R. B. Blodgett. 2014b. Inventory of U.S. Geological Survey paleontology collections to identify fossil localities in National Park Service Areas. *Dakoterra* 6:215–218.

Santucci, V. L., C. Knight, and M. Antonioni. 2014c. Fossil plants from the National Park Service areas of the National Capital Region. *Dakoterra* 6:181–190.

Swanson, B. A., V. L. Santucci, S. K. Madsen, A. S. Elder, and J. P. Kenworthy. 2005. Arches National Park paleontological survey. NPS Geologic Resources Division, Denver, Colorado. Technical Report NPS/NRGRD/GRDTR—05/01.

Tweet, J. S., V. L. Santucci, and A. P. Hunt. 2012. An inventory of packrat (*Neotoma* spp.) middens in National Park Service areas. Pages 355–368 *in* A. P. Hunt, J. Milàn, S. G. Lucas, and J. A. Spielmann, editors. Vertebrate coprolites. New Mexico Museum of Natural History and Science, Albuquerque, NM. Bulletin 57. Available at http://www.nature.nps.gov/Geology/paleontology/Publications/surveys/thematic/TWEET_SANTUCCI_HUNT_2012_NPS_PACKRAT_MIDDENS.pdf (accessed April 2014).

Visaggi, C. C., J. G. Johnson, A. S. Johnson, J. P. Kenworthy, and V. L. Santucci. 2009. Paleontological resource survey: Amistad National Recreation Area. Natural Resource Report NPS/NRPC/GRD/NRR—2009/133. National Park Service, Fort Collins, Colorado.

Young, R. and L. Norby, editors. 2009. Geological monitoring. Geological Society of America, Boulder, Colorado. Available at http://nature.nps.gov/geology/monitoring/index.cfm (accessed April 2014).

Citations for I&M Network-Based Summaries

Citations are listed alphabetically by network

Appalachian Highlands Network (APHN)

Santucci, V. L., R. T. P. McKenna, J. P. Kenworthy, and T. Connors. 2008. Paleontological resource inventory and monitoring: Appalachian Highlands Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/080. National Park Service, Fort Collins, Colorado.

Arctic Network (ARCN)

Elder, W., V. L. Santucci, J. P. Kenworthy, R. B. Blodgett, and R. T. P. McKenna. 2009. Paleontological resource inventory and monitoring: Arctic Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/276. National Park Service, Fort Collins, Colorado.

Central Alaska Network (CAKN)

Santucci, V. L., R. B. Blodgett, W. P. Elder, J. S. Tweet, and J. P. Kenworthy. 2011. Paleontological resource inventory and monitoring: Central Alaska Network. Natural Resource Technical Report NPS/NRSS/NRTR—2011/510. National Park Service, Fort Collins, Colorado.

Chihuahuan Desert Network (CHDN)

Santucci, V. L., J. P. Kenworthy, and C. C. Visaggi. 2007. Paleontological resource inventory and monitoring: Chihuahuan Desert Network. National Park Service TIC# D-500.

Cumberland Piedmont Network (CUPN)

Hunt-Foster, R., J. P. Kenworthy, V. L. Santucci, T. Connors, and T. L. Thornberry-Ehrlich. 2009. Paleontological resource inventory and monitoring: Cumberland Piedmont Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/235. National Park Service, Fort Collins, Colorado.

Eastern Rivers and Mountains Network (ERMN)

Koch, A. L. and V. L. Santucci. 2004. Paleontological resource inventory and monitoring: Eastern Rivers and Mountains Network. TIC# D-265. National Park Service, Denver, Colorado.

Great Lakes Network (GLKN)

Hunt, R. K., J. P. Kenworthy, and V. L. Santucci. 2008. Paleontological resource inventory and monitoring: Great Lakes Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/120. TIC# D-65. National Park Service, Fort Collins, Colorado.

Greater Yellowstone Network (GRYN)

[Original Report] Koch, A. L. and V. L. Santucci. 2003. Paleontological resource inventory and monitoring: Greater Yellowstone Network. TIC# D-1025. National Park Service, Denver, Colorado.

[Updated Report] Tweet, J. S., V. L. Santucci, and T. Connors. 2013. Paleontological resource inventory and monitoring—Greater Yellowstone Network. Natural Resource Technical Report NPS/NRR—2013/794. National Park Service, Fort Collins, Colorado.

Gulf Coast Network (GULN)

Kenworthy, J. P., V. L. Santucci, and C. C. Visaggi. 2007. Paleontological resource inventory and monitoring: Gulf Coast Network. TIC# D-750. National Park Service, Denver, Colorado.

Heartland Network (HTLN)

Hunt, R. K., J. P. Kenworthy, and V. L. Santucci. 2008. Paleontological resource inventory and monitoring: Heartland Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/132. TIC# D-66. National Park Service, Fort Collins, Colorado.

Klamath Network (KLMN)

Santucci, V. L. and J. P. Kenworthy. 2009. Paleontological resource inventory and monitoring: Klamath Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/208. TIC# D-22. National Park Service, Fort Collins, Colorado.

Mediterranean Coast Network (MEDN)

[Original Report] Koch, A. L. and V. L. Santucci. 2003. Paleontological resource inventory and monitoring: Mediterranean Coast Network. TIC# D-177. National Park Service, Denver, Colorado.

[Updated Report] Tweet, J. S., V. L. Santucci, and T. Connors. 2012. Paleontological resource inventory and monitoring: Mediterranean Coast Network. Natural Resource Technical Report NPS/MEDN/NRTR—2012/640. National Park Service, Fort Collins, Colorado

Mid-Atlantic Network (MIDN)

Kenworthy, J. P., C. C. Visaggi, and V. L. Santucci. 2006. Paleontological resource inventory and monitoring: Mid-Atlantic Network. TIC# D-800. National Park Service, Denver, Colorado.

Mojave Desert Network (MODN)

Santucci, V. L., A. L. Koch, and J. P. Kenworthy. 2004. Paleontological resource inventory and monitoring: Mojave Desert Network. TIC# D-305. National Park Service, Denver, Colorado.

Northeast Coastal and Barrier Network (NCBN)

[Original Report] Kenworthy, J. P. and V. L. Santucci. 2003. Paleontological resource inventory and monitoring: Northeast Coastal and Barrier Network. TIC# D-340. National Park Service, Denver, Colorado.

North Coast and Cascades Network (NCCN)

Fay, L. C., J. P. Kenworthy, and V. L. Santucci. 2009. Paleontological resource inventory and monitoring: North Coast and Cascades Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/250. National Park Service, Fort Collins, Colorado.

Northern Colorado Plateau Network (NCPN)

[Original Report] Koch, A. L. and V. L. Santucci. 2002. Paleontological resource inventory and monitoring: Northern Colorado Plateau Network. TIC# D-206. National Park Service, Denver, Colorado.

[Updated Report] Tweet, J. S., V. L. Santucci, T. Connors, and J. P. Kenworthy. 2012. Paleontological resource inventory and monitoring: Northern Colorado Plateau Network. Natural Resource Technical Report NPS/NCPN/NRTR—2012/585. National Park Service, Fort Collins, Colorado.

National Capital Region Network (NCRN)

Kenworthy, J. P. and V. L. Santucci. 2004. Paleontological resource inventory and monitoring: National Capital Region. TIC# D-289. National Park Service, Denver, Colorado.

Northeast Temperate Network (NETN)

Tweet, J., V. L. Santucci, and J. P. Kenworthy. 2010. Paleontological resource inventory and monitoring: Northeast Temperate Network. Natural Resource Technical Report NPS/NRPC/NRTR—2010/326. TIC# 962/102111. National Park Service, Fort Collins, Colorado.

Northern Great Plains Network (NGPN)

Tweet, J. S., V. L. Santucci, and J. P. Kenworthy. 2011. Paleontological resource inventory and monitoring: Northern Great Plains Network. Natural Resource Technical Report NPS/NRPC/NRTR—2011/437. National Park Service, Fort Collins, Colorado.

Pacific Islands Network (PACN)

Hunt, R. K., V. L. Santucci and J. P. Kenworthy. 2007. Paleontological resource inventory and monitoring: Pacific Islands Network. TIC# D-24. National Park Service, Denver, Colorado.

Rocky Mountain Network (ROMN)

Koch, A. L., J. P. Kenworthy, and V. L. Santucci. 2004. Paleontological resource inventory and monitoring: Rocky Mountain Network. TIC# D-436. National Park Service, Denver, Colorado.

Southern Colorado Plateau Network (SCPN)

Tweet, J., V. L. Santucci, J. P. Kenworthy, and A. L. Mims. 2009. Paleontological resource inventory and monitoring: Southern Colorado Plateau Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/245. TIC# D-59. National Park Service, Fort Collins, Colorado.

Southeast Alaska Network (SEAN)

Santucci, V. L. and J. P. Kenworthy. 2008. Paleontological resource inventory and monitoring: Southeast Alaska Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/108. TIC# D-155. National Park Service, Fort Collins, Colorado.

Southeast Coast Network (SECN)

Tweet, J., V. L. Santucci, and J. P. Kenworthy. 2009. Paleontological resource inventory and monitoring: Southeast Coast Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/197. TIC# D-89. National Park Service, Fort Collins, Colorado.

San Francisco Bay Area Network (SFAN)

Elder, W. P., T. Nyborg, J. P. Kenworthy, and V. L. Santucci. 2008. Paleontological resource inventory and monitoring: San Francisco Bay Area Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/078. TIC# D-20. National Park Service, Fort Collins, Colorado.

South Florida-Caribbean Network (SFCN)

Toscano, M. A. , J. P. Kenworthy, and V. L. Santucci. 2010. Paleontological resource inventory and monitoring: South Florida / Caribbean Network. Natural Resource Technical Report NPS/NRPC/NRTR—2010/335. National Park Service, Fort Collins, Colorado.

Sierra Nevada Network (SIEN)

Santucci, V. L. and J. P. Kenworthy. 2007. Paleontological resource inventory and monitoring: Sierra Nevada Network. Natural Resource Technical Report NPS/NRPC/NRTR—2007/053. TIC # D-21. National Park Service, Fort Collins, Colorado.

Sonoran Desert Network (SODN)

Tweet, J., V. L. Santucci, and J. P. Kenworthy. 2008. Paleontological resource inventory and monitoring: Sonoran Desert Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/130. TIC# D-58. National Park Service, Fort Collins, Colorado.

Southern Plains Network (SOPN)

Koch, A. L. and V. L. Santucci. 2003. Paleontological resource inventory and monitoring: Southern Plains Network. TIC# D-107. National Park Service, Denver, Colorado.

Southwest Alaska Network (SWAN)

Kenworthy, J. P. and V. L. Santucci. 2003. Paleontological resource inventory and monitoring: Southwest Alaska Network. TIC# D-93. National Park Service, Denver, Colorado.

Upper Columbia Basin Network (UCBN)

Kenworthy, J. P., V. L. Santucci, M. McNerney, and K. Snell. 2005. Paleontological resource inventory and monitoring: Upper Columbia Basin Network. TIC# D-259. National Park Service, Denver, Colorado.

General NCBN Information

Northeast Coastal and Barrier I&M Network:
http://science.nature.nps.gov/im/units/NCBN/index.cfm

Geological Survey Websites

American Geological Institute: http://www.agiweb.org/

Geological Society of America: http://www.geosociety.org/

Connecticut Geological Survey:
http://www.ct.gov/deep/cwp/view.asp?a=2701&q=487928&deepNav_GID=1641

Delaware Geological Survey: http://www.dgs.udel.edu/

Maryland Geological Survey: http://www.mgs.md.gov/index.html

Massachusetts Geological Survey: http://www.geo.umass.edu/stategeologist/

New Jersey Geological and Water Survey: http://www.state.nj.us/dep/njgs/

New York State Geological Survey: http://www.nysm.nysed.gov/nysgs/index.html

Rhode Island Geological Survey: http://web.uri.edu/geo/rhode-island-geological-survey/

Virginia Department of Mines, Minerals, and Energy:
http://www.dmme.virginia.gov/dgmr/divisongeologymineralresources.shtml

U.S. Geological Survey: http://www.usgs.gov/

Library Catalogs

Smithsonian Institution Research Information System: http://www.siris.si.edu/

U.S. Geological Survey Library Catalog: http://library.usgs.gov/

WorldCat.org: http://www.worldcat.org/

Museums

National Park Service Museum Collections Catalog: http://www.museum.nps.gov/splashsearch.htm

Academy of Natural Sciences: http://www.ansp.org/

American Museum of Natural History: http://www.amnh.org/

Calvert Marine Museum: https://calvertmarinemuseum.com/

Cape Cod Museum of Natural History: http://www.ccmnh.org/

Museum of Comparative Zoology (Harvard University): http://www.mcz.harvard.edu/

Museum of Science (Boston): http://www.mos.org/

Museum of the Earth (Paleontological Research Institution): http://www.museumoftheearth.org/

New Jersey State Museum: http://www.state.nj.us/state/museum/index.htm

New York State Museum: http://www.nysm.nysed.gov/

Peabody Museum of Natural History (Yale University): http://www.peabody.yale.edu/

Smithsonian National Museum of Natural History Dept. of Paleobiology: http://paleobiology.si.edu/

Staten Island Museum: http://www.statenislandmuseum.org/

Virginia Museum of Natural History: http://www.vmnh.net/

Other Websites of Interest for NCBN Geology

Delaware Valley Paleontological Society: http://dvps.essentrix.net/

Geological Association of New Jersey: http://www.ganj.org/

Geological Society of Connecticut: http://www.geologicalsocietyofconnecticut.org/

Geological Society of Washington: http://www.gswweb.org/

Geology and Geography of New York Bight Beaches:
http://www.geo.hunter.cuny.edu/bight/index.html

Maryland Geological Society: http://www.ecphora.net/mgs/

New York State Council of Professional Geologists: http://www.nyscpg.org/

New York State Geological Association: http://nysga.net/

New England Intercollegiate Geological Conference: http://w3.salemstate.edu/~lhanson/NEIGC/

New Jersey Paleontological Society: http://www.njpaleo.org/

New York Paleontological Society: http://www.nyps.org/

Resource Management/Legislation Documents

NPS 2006 Management Policies (§1.4; Park Management):
http://www.nps.gov/policy/mp/chapter1.htm

NPS 2006 Management Policies (§4.8.2.1; Paleontological Resources):
http://www.nps.gov/policy/mp/chapter4.htm

NPS 1998 Omnibus Management Act (paleontological resource summary):
http://www.nature.nps.gov/geology/paleontology/paleo_5_1/index.htm

NPS Natural Resource Management Reference Manual #77 (paleontology section):
http://www.nature.nps.gov/rm77/paleo.cfm

Assessment of Fossil Management on Federal & Indian Lands:
http://www.fs.fed.us/geology/fossil.pdf

National Park Service Paleontology Program Sites

NPS Geologic Resources Division: http://www.nature.nps.gov/geology/

NPS GRD Geologic Resource Inventory Products (scoping summaries, GRI reports, digital geologic maps): http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

NPS Paleontology Program: http://www.nature.nps.gov/geology/paleontology/

NPS Park Paleontology Newsletter (published 1999-2004):
http://www.nature.nps.gov/geology/paleontology/newsletter.cfm

I&M Network paleontological resource summary project website and PDFs of all reports (InsideNPS): http://inside.nps.gov/waso/custommenu.cfm?lv=4&prg=753&id=4518

NPS Technical Information Center (Denver, repository for technical (TIC) documents):
http://etic.nps.gov/

Other Geology/Paleontology Tools

Bates, R. L. and J. A. Jackson, editors. American Geological Institute dictionary of geological terms (3rd edition). Bantam Doubleday Dell Publishing Group, New York.

NeoMap (Neogene Mammal Mapping Portal): http://www.ucmp.berkeley.edu/neomap/

Neotoma (Quaternary fossil database): http://www.neotomadb.org/

NOAA Paleoclimatology: http://www.ncdc.noaa.gov/paleo/paleo.html

Paleobiology Database (search for fossil taxonomy, localities, or geologic formations):
http://paleodb.org/cgi-bin/bridge.pl

Paleontology Portal (general fossil info based on geographic location or geologic time): http://www.paleoportal.org/

University of California-Berkeley Museum of Paleontology online paleontology exhibits: http://www.ucmp.berkeley.edu/

U.S. Geological Survey digital state geology maps: http://tin.er.usgs.gov/geology/state/

U.S. Geological Survey Geologic Terms Glossary: http://www.nature.nps.gov/geology/usgsnps/misc/glossaryAtoC.html#A

U.S. Geological Survey Paleontological Terms Glossary: http://geology.er.usgs.gov/paleo/glossary.shtml

U.S. Geological Survey National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/

U.S. Geological Survey Geologic Names Lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/geolex_home.html

U.S. Geological Survey Geographic Names Information System (GNIS; search for place names and geographic features, and plot them on topographic maps or aerial photos): http://gnis.usgs.gov/

U.S. Geological Survey GeoPDFs (download searchable PDFs of any topographic map in the United States): http://store.usgs.gov (click on “Map Locator”).

U.S. Geological Survey Publications Warehouse (many USGS publications are available online): http://pubs.er.usgs.gov/

U.S. Geological Survey, description of physiographic provinces: http://tapestry.usgs.gov/Default.html

Assateague Island National Seashore

Assateague Island National Seashore (ASIS) encompasses Assateague Island, a 60 km (37 mile)-long barrier island off the Atlantic coast of Maryland and Virginia. It includes many natural resources, and is noted for its white sandy beaches and wild horses. Many coastal environments are found around it, such as salt marshes (ASIS Figure 1). ASIS was authorized September 21, 1965, and had a boundary change July 10, 1992. It encompasses 16,384 ha (40,486 acres), of which 3,350 ha (8,257 acres) are on land, and 13,034 ha (32,194 acres) are under water (area after Carruthers et al. 2011). The ownership of Assateague Island involves several entities. ASIS includes most of the land on the Maryland side and the sea immediately surrounding the island. Most of the land on the Virginia side is included in Chincoteague National Wildlife Refuge, a 3,630 ha (8,970 acre) parcel administered by the U.S. Fish and Wildlife Service. A small portion of the Maryland side is part of Assateague State Park, near the northern end of the island.



ASIS Figure 1. A modern salt marsh at Toms Cove; peaty sediments deposited in similar settings are widely distributed in the shallow subsurface of ASIS (NPS).

Geologic Background

Assateague Island is located in Worcester County, Maryland, and Accomack County, Virginia, off the coast of the southern Delmarva Peninsula. The island is bounded by Ocean City Inlet on the

north, the Atlantic Ocean on the east, Chincoteague Inlet on the southwest, and Chincoteague Bay (south) and Sinepuxent Bay (north) on the west (ASIS Figure 2). Chincoteague Island is separated from the southwest corner of Assateague Island by a narrow channel. Wallops Island, which is NASA property, is separated from Toms Cove Hook at the south end of Assateague Island by Chincoteague Inlet. Ocean City, Maryland, on the north side of Ocean City Inlet, becomes the nearest large city during the summer vacation season. Otherwise, Salisbury, Maryland, is the nearest major city at about 40 km (25 miles) northwest of Assateague State Park.

Publications that describe the geology and paleontology of ASIS and Assateague Island in general focus primarily on modern island processes. Documents that are most relevant for purposes of managing fossil resources include Richards (1936, 1962), Weigle (1974), Field and Duane (1976), Halsey (1976, 1978), Halsey et al. (1977), Owens and Denny (1978, 1979), Goettle (1981), Mixon et al. (1982), Mixon (1985), Eshelman and Grady (1986), Slingerland (1989), Toscano et al. (1989), Dillow et al. (2002), Kenworthy and Santucci (2003), Thornberry-Ehrlich (2005), Morton et al. (2008), NPS (2009, 2011), Krantz (2010), and Schupp (2013). The NPS Geologic Resources Division coordinated a Geologic Resource Inventory workshop for ASIS in July 2005 (Thornberry-Ehrlich 2005) and produced a digital geologic map for the historic site in 2009 (NPS 2009) and a geologic resource evaluation report in 2013 (Schupp 2013). The initial paleontological resource inventory and summary was prepared by Kenworthy and Santucci (2003).

The southern Delmarva Peninsula has been tectonically quiet since North America rifted from Africa and Europe in the early Mesozoic (see the Appendix for a geologic time scale). There has been one major disruption of the rocks and sediments in the vicinity since then: around 35 Ma (million years ago), a meteor impacted the future Chesapeake Bay (Poag 1997; Johnson et al. 1998; Powars and Bruce 1999). The resulting crater was up to 90 km (56 miles) across and 1.3 km (0.8 miles) deep, with an area of 6,400 km^2 (2,500 $miles^2$) (Poag 1997) (but see Collins and Wünnermann [2005], which interprets the original structure as less than half that size). The center of the crater is near the tip of the Delmarva Peninsula, and the outer rim of the structure is far south of ASIS, so the greatest effects of the impact were somewhat remote from the area of the seashore.

More recent events have been less dramatic. The sediments immediately underlying Assateague Island, to a depth of about 50 m (160 ft), record several episodes of deposition from the Pliocene to the Pleistocene. The Pliocene marine Yorktown Formation underlies most coastal areas in Virginia and Maryland, including Assateague Island (Mixon 1985; Toscano et al. 1989). It is overlain by the Beaverdam Formation, a Pliocene unit. This formation probably began as a river system channeling into the underlying sediments, then transitioned to a marine system during a marine advance. Overlying the Beaverdam Formation is the Sinepuxent Formation, an upper Pleistocene formation deposited in marginal marine settings during a marine transgression (Owens and Denny 1978). In some areas of the Delmarva Peninsula, additional units are present between these major formations, illustrating the local history of marginal marine and coastal terrestrial deposition (Owens and Denny 1978, 1979; Mixon et al. 1982; Mixon 1985; Toscano et al. 1989; Hobbs 2004). Sea levels during Pleistocene ice ages were much lower than present, by tens of meters, and this extended the coast far to the east. As a result, rivers flowed across areas now on the continental shelf to reach the Atlantic

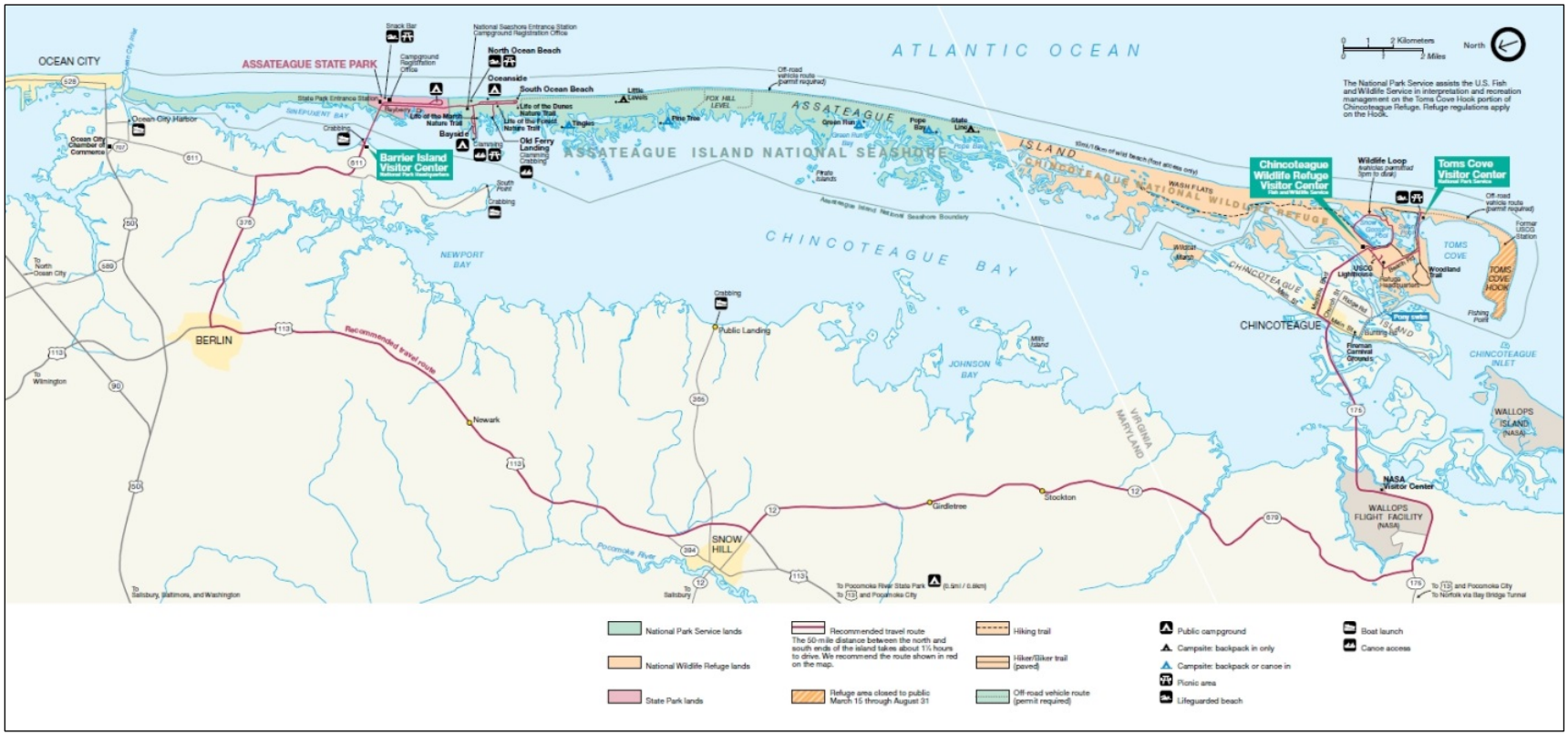
(Toscano et al. 1989; Hobbs 2004). Some of these Pleistocene paleochannels can be found offshore of Assateague Island. A major ancestral St. Martin River channel cut southeast through the area that Ocean City now occupies (Toscano et al. 1989). Pollen evidence indicates that the climate switched occasionally from mild temperate to cold temperate during the Pleistocene, as sea level switched between regressing and transgressing and glaciers alternated between growth and retreat (Toscano et al. 1989).

Assateague Island itself is a very recent feature, with no core of bedrock at or near the surface. The islands and ridges seaward of Chincoteague Island are only about 2,000 years old (Slingerland 1989). Field and Duane (1976) noted that by extrapolating the recorded history of the island's growth "the whole of Assateague Island conceivably could have developed by spit extension in the past 1,000 yr if it remained at its present location." Halsey (1976) reproduced a 1673 map (from a 1670 survey) that did not show a coalesced island but a number of unconnected shoals. Leatherman and Maurmeyer (1989) suggested that the north part of Assateague Island would migrate onto the mainland around 2020.

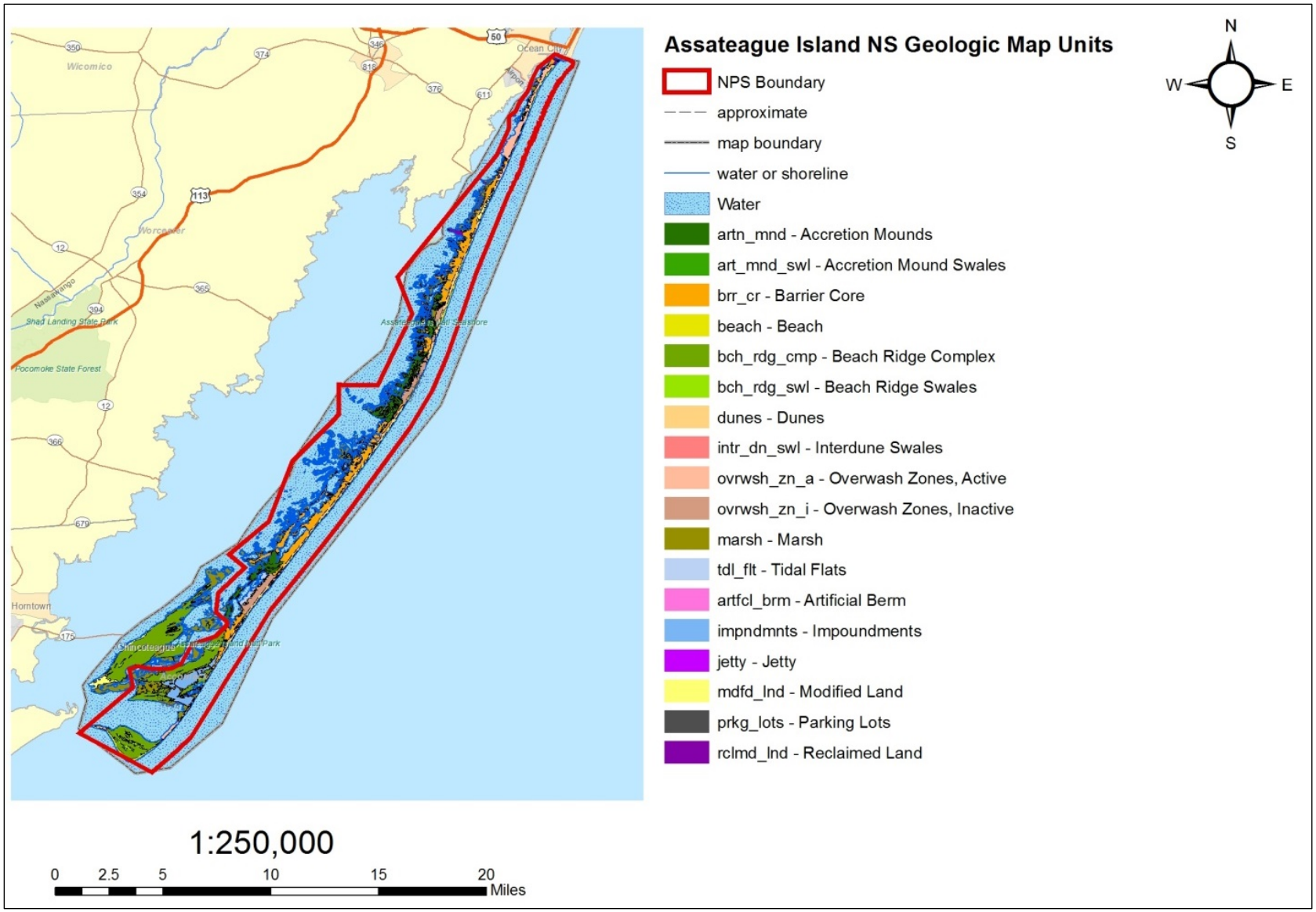
Sea level has risen significantly since the Last Glacial Maximum, approximately 25,000 to 20,000 years ago. The rate of rise has varied over time. During the early Holocene, about 10,000 to 5,000 years ago, relative sea level along the Delaware coast rose about 3 mm/year (0.1 in/year). At the end of this period, the local sea level was about 11 m (36 ft) below present (Horton et al. 2009). The rate then appears to have slowed to about 1.5 to 2.0 mm/year (0.06 to 0.08 in/year), based on the timing of salt marsh formation and the depth of their deposits (Kraft 1976). Assateague Island dates to this period of relatively slow sea level rise. The rate of relative sea level rise is once again increasing, and is increasing faster in the NCBN than elsewhere (Sallenger et al. 2012).

In addition to changes in sea level and the rate of rise, the dynamic natural barrier system has been influenced since the colonial period by human actions to preserve shipping lanes and harbors, protect valuable beachfront property, and so forth, which disrupt currents and sediment flow. The southern end of Assateague Island is noted for its rapidly changing geography, as illustrated by a map available through the NPS at http://www.nps.gov/asis/naturescience/loader.cfm?csModule=security/getfile&pageid=414824, showing about 7 km (a little over 4 miles) of southward extension since 1859. The northern end has also undergone rapid change due to the stabilization of the Ocean City inlet, which has disrupted longshore sediment supply (B. Hulslander, ASIS chief of resource management, pers. comm., May 2014).

Humans arrived in the Delmarva Peninsula sometime thousands of years ago; a projectile point of the Clovis culture (about 12,000 to 10,000 years old) has been found in Accomack County (McCary 1986). However, evidence of humans on Assateague Island only goes back to about the late 17th century (Underwood and Hiland 1995; Thornberry-Ehrlich 2005). The scarcity of fresh water has made it unappealing as a place of permanent residence, and the dynamic environment is not conducive to preservation of archeological sites. The island that was present several thousand years ago has probably been completely reworked and would be east of the current island.



ASIS Figure 2. Geography of ASIS (NPS).



ASIS Figure 3. Schematic geomorphological map of ASIS. Map graphic adapted from digital geomorphologic map data available at the following URL: https://irma.nps.gov/App/Reference/Profile?Code=1047585.

Geologic units exposed at the surface in ASIS are limited to Holocene deposits (Owens and Denny 1978; Mixon et al. 1982; Mixon 1985) (ASIS Figure 3). The immediate subsurface of the island includes in ascending order the Pliocene Yorktown Formation, the Pliocene? Beaverdam Formation, and the upper Pleistocene Sinepuxent Formation (Owens and Denny 1978, 1979; Mixon 1985). The known paleontological resources of ASIS derive from the Sinepuxent Formation, Holocene sediments, and undetermined offshore units that contribute the fossils occasionally washed onto the beaches by storms (ASIS Table 1). The Holocene sediments are fossil-poor, due to their age and setting. Instead, future discoveries of fossils will result from storms transporting fossils from eroded offshore sediments or from sediments underlying the island that are exposed by erosion or breaching, or exposed during drilling projects or other excavations on the island. Fossils from the subsurface offer few management challenges; until extracted, they are protected from erosion, theft, and vandalism beneath sediments, and they are almost all microfossils such as foraminifera ("amoebas with shells"), pollen, and ostracodes (seed shrimp), so they are not apparent to casual collectors and hobbyists, and lack value to commercial collectors. Transported fossils are of greater concern than buried fossils, because of their portability. The shore sand itself doubtless includes some fraction of sand-sized fossil shell fragments.

ASIS Table 1. Summary of ASIS stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text.

Formation	Age	Fossils Within ASIS	Depositional Environment
Holocene surficial sediments	Holocene	Peat and mollusks (past 4,500 years)	Beach, dune, intertidal, and marsh settings
Sinepuxent Formation (subsurface)	late Pleistocene	Peat and mollusks including bivalves	Bay, estuarine, and salt marsh
Beaverdam Formation and older subsurface formations	Upper Miocene? to Pliocene in the near subsurface	None to date; peat with associated plant fossils and invertebrate trace fossils are most likely	Fluvial to marginal marine
Offshore deposits (washed in)	Holocene to as old as Paleozoic if identifications are correct	Corals (including possible tabulate corals), bivalves, ammonites, crabs, a possible sea lion jaw, and an unidentified specimen	Various; most reported fossils appear to be marine

Sources of Paleontological Resources

The fossils of ASIS present opportunities for education, interpretation, and scientific research in the national seashore.

Offshore and Subsurface Deposits (Upper Miocene?–Upper Pleistocene)

The past few million years of changing sea levels in the Delmarva Peninsula area has produced a number of localized formations deposited in marginal marine and estuarine settings, three of which (the Sinepuxent, Beaverdam, and Yorktown formations) make up the shallow subsurface (to 30 m

[100 ft]) of Assateague Island (Owens and Denny 1978, 1979; Mixon 1985). The Sinepuxent Formation is a marginal marine unit, including lagoonal and estuarine deposits (McLaughlin et al. 2008). The depositional setting may have begun as a bay, more restricted in the northeast and more open in the southwest, followed a salt marsh (Owens and Denny 1978). The formation is composed of dark, poorly sorted, fine to medium sand that coarsens upward, with peat and peaty sand at the top. It is up to 20 m (60 ft) thick (Owens and Denny 1979). A typical section would encounter it about 6 m (20 ft) below sea level, continuing down to about 21 m (70 ft) (Owens and Denny 1978).

The Beaverdam Formation beneath it is composed of white, green, or pale blue gray sand with local gravel beds and clay. The lower part is thought to be fluvial, and the upper part is marginal marine, tracing a transition from a marine regression to a transgression (Owens and Denny 1979). It was probably deposited during the Late Pliocene or early Pleistocene. Owens and Denny (1979) regarded it as Pliocene, but part of the upper Pliocene is now considered lower Pleistocene. The Beaverdam Formation is up to 30 m (100 ft) thick, near Ocean City, but is generally a third or less of that thickness (Owens and Denny 1978, 1979). The base of the formation is about 30 m (100 ft) below sea level at Ocean City and rises going south. Based on Owens and Denny (1979)'s contour map, the formation would be expected to pinch out north of the Maryland–Virginia state line. Alternatively, Toscano et al. (1989) plotted the formation as present beginning about 16 to 21 m (52 to 69 ft) below the island for more or less its entire length.

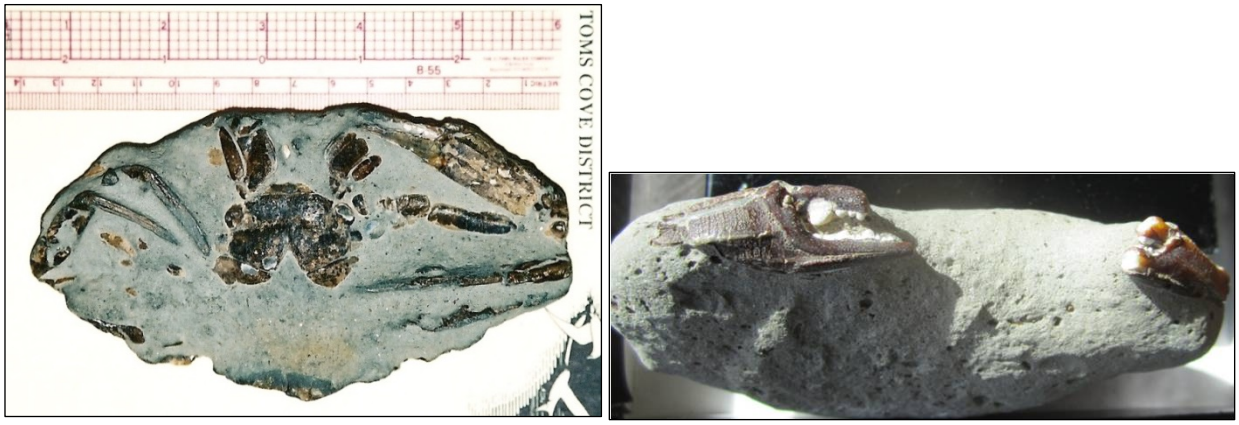
Beneath these two units is the Yorktown Formation (Mixon 1985), earlier identified as the "Yorktown-Cohansey(?) Formation" by Owens and Denny (1978, 1979). This formation is well-known from Colonial National Historical Park about 120 km (75 miles) to the southwest. The deposits include lower and upper shelly sand units sandwiching a clayey and silty unit, and have shallow marine and deltaic influences (Mixon 1985). The presence of the bivalve *Isognomon* (Owens and Denny 1978) indicates the presence of older Miocene beds as well (this genus is characteristic of the Eastover Formation, beneath the Yorktown Formation [Powars and Bruce 1999]).

The Sinepuxent Formation suggests sea levels 1.5 m (5 ft) higher than present (Owens and Denny 1979). Although sometimes dated to about 30,000 years old (Owens and Denny 1979), it is probably closer to 100,000 to 80,000 years old (McLaughlin et al. 2008; Ramsey 2010).

Various fossils of Pleistocene and older ages have been found at Assateague Island and the vicinity. ASIS maintains a small collection of fossils that have been found on the beaches of the island since the 1970s by seashore staff and visitors (ASIS Figure 4). These fossils either washed in from offshore or eroded from the island's core. They are generally fragmentary and include corals, bivalves, an ammonite, crabs, a "funnel-shaped casting", and a possible sea lion jaw (which would be unusual because sea lions are not known from the northern Atlantic) (Kenworthy and Santucci 2003). Collections information for these specimens can be found in the "Park Collections" section below. Kenworthy and Santucci (2003) regarded the fossils as probably Pleistocene in age, but ammonites went extinct at the end of the Cretaceous, and several of the corals were described as "tableate"; if this is a typo for "tabulate", then the corals represent a lineage that went extinct at the end of the Permian. Both the ammonite and any tabulate corals would have been eroded and reworked from

older formations. More recently, Whaley et al. (2012) reported that Hurricane Irene (late August 2011) caused concretions containing mollusks and crabs to wash up on ASIS beaches.

Bivalve shells described as “worn and apparently fossils” were reported by Richards (1936) from the sand at the southern end of Assateague Island (the Chincoteague National Wildlife Refuge portion of the island). They include *Chione cancellata*, *Crassinella lunatula parva*, *Donax variabilis*, and *Arca ponderosa*, warm-water species no longer living in the area.



ASIS Figure 4. Examples of fossil crabs in concretions that washed up on ASIS (VLS).

Richards reported that the fossils originally came from the Pamlico Formation (an obsolete term for relatively young Pleistocene marine deposits) of the Peorian Interglacial (now considered part of the Wisconsinan glacial stage, which occurred between about 85,000 and 11,000 years ago). The fossil site was also mentioned briefly by Richards (1962) and Spencer and Campbell (1987). Because the fossils were not found in situ, it is unclear if they derived from the Sinepuxent Formation or another unit. Richards (1936) also reported fossil shells of the gastropod *Nassa* from deposits in the adjoining Sinepuxent Bay.

Mammal fossils have been reported on the beaches of the Delmarva coastal islands since at least the 1820s. Fossils from Metompkin Island and other islands in Accomack County include specimens of the giant beaver *Castoroides*, walruses, and a gray whale. Fishing and dredging boats often pull up fossils of large extinct mammals from offshore, including specimens of mastodons, mammoths, musk oxen, and bison (Eshelman and Grady 1986), and some vertebrate fossils have been given to the seashore by clam dredging operators (Whaley et al. 2012). Mitchill et al. (1827) reported a partial walrus skull from somewhere in the county (then spelled “Accomac”). De Kay (1842) named it *Trichechus virginianus* without comment. The species is now considered to be a synonym of the modern walrus species *Odobenus rosmarus*. The specimen was apparently at the New York Lyceum of Natural History, but was destroyed in a fire (Hay 1923). The description of the locality was vague; it may have been recovered from within the National Wildlife Refuge in the Virginia portion of Assateague Island. Another walrus skull from Accomack County was found by R. P. Stevens in the

1870s (Newberry 1873). Fraley (1874) briefly discussed a walrus skull from "Accomac Harbor", which may or may not be the same as one of the other two specimens. Hay (1923) implied that it was the same as the Mitchill skull, but this seems unlikely: the fire at the Lyceum occurred in 1866 and was a total loss (Anonymous 1866), so unless the specimen had been removed prior to that date, it could not have been available to the American Philosophical Society in Philadelphia in the 1870s. More recently, a mammoth tusk reportedly washed up on the beach of nearby Wallops Island, just south of Assateague Island (Kenworthy and Santucci 2003).

Most of the seashore's other fossils appear to derive from the Sinepuxent Formation, with the best-preserved body fossils of this formation from clayey sands in the lower part of the formation. They include abundant mollusks, particularly the bivalves *Tagelus plebius* and *Mulinia lateralis*, attributed to a restricted bay or back barrier setting (Owens and Denny 1978). Unspecified material from the north end of the island, north of Assateague State Park, has been dated to 34,000 radiocarbon years before present (Owens and Denny 1978). (Note that radiocarbon dates are not the same as calendar dates, and must be calibrated to approximate calendar years. Dates here were calibrated using Calib 7.0 [http://calib.qub.ac.uk/calib/] where appropriate. "Present" in "before present" is 1950.) In addition, Pleistocene bivalves and shell hash have been found in the sediments below Fishing Spit (Halsey 1976). No formation was assigned, but the Sinepuxent Formation is most likely.

Peat from this formation widely underlies the island and vicinity, particularly at a level about 9 m (30 ft) below the island; this bed is known logically enough as the "30-ft peat horizon". Peat at about this level has been dated from several locations. From below the Assateague State Park parking lot, peat has been dated variously to 32,750 ± 1,650 radiocarbon years before present (40,300–33,250 calibrated years before present) (Halsey 1976) and 31,000 ± 1,000 radiocarbon years before present (36,710–32,290 calibrated years before present) (Weigle 1974; Owens and Denny 1979). Cedar wood from 10 m (33 ft) beneath the north end of adjoining Chincoteague Island has been dated to 28,700 ± 850 radiocarbon years before present (33,960–30,910 calibrated years before present) (Halsey 1976). Peat north of Ocean City at and below the 30-foot horizon includes spores of mosses, clubmosses, spikemosses, and ferns, and pollen of conifers and angiosperms (Weigle 1974), and similar fossils would be expected in the analogous peat layer beneath ASIS. Shells beneath peat under the Chincoteague National Wildlife Refuge, at the southern end of Assateague Island, have been dated to 28,750 ± 1,100 radiocarbon years before present (34,570–30,480 calibrated years before present) (Owens and Denny 1979). At greater depths, but still probably within the Sinepuxent Formation, unspecified material dated to 92,000 +18,000/-14,000 years ago was found 18 m (60 ft) below sea level at Assateague Point (Goettle 1981).

Pollen and spores are common fossils in peat, and are useful for local climate reconstructions. The peat beneath ASIS could yield such fossils. Pollen and spore assemblages from various times in the Pleistocene not represented beneath ASIS have been described from elsewhere on the Delmarva Peninsula, recording the vegetation that inhabited the region (Sirkin 1974; Sirkin et al. 1977; Nickman and Demarest 1982; Toscano et al. 1989; Ramsey 2010).

As a whole, the Sinepuxent Formation within and outside of ASIS has yielded dinoflagellates, peat, fern spores (McLaughlin et al. 2008), conifer and angiosperm pollen, bivalves (Owens and Denny

1979), and ostracodes (Mixon 1985). The pollen record indicates a cool to cold temperate climate, with a salt marsh influence appearing over time (Owens and Denny 1978). The Beaverdam Formation is less fossiliferous than the Sinepuxent Formation. It has yielded peat, spores, pollen, leaf impressions, and invertebrate burrows (Owens and Denny 1978, 1979). The pollen record of this formation shows the presence of *Ephedra*, conifers, and angiosperms, and indicates warm temperate to warmer climates (Owens and Denny 1978). Deposits thought to represent the Yorktown Formation in the area have produced foraminifera (Mixon 1985), angiosperm and conifer pollen (Owens and Denny 1978), wood fragments, corals, bivalves, gastropods, scaphopods, barnacles, and ostracodes (Mixon 1985). The fossils of these formations would only be uncovered within ASIS through drilling operations.

Unnamed Holocene Deposits

Unconsolidated barrier island sediments can be more than 13 m (50 ft) thick at the south end of Assateague Island (Mixon 1985). Owens and Denny (1978) divided the surficial deposits of Assateague Island into two broad groups: barrier sand and tidal marsh deposits. Barrier sand deposits are composed of light-colored, fine to very coarse, moderately to well sorted feldspar-rich quartz sand, often featuring cross-bedding as a result of wave action. Abundant shell fragments are present in the sand. This type of deposit can be up to 6 m (20 ft) thick. Tidal marsh deposits are composed of silt and clay with degraded organic matter. These deposits are exposed on the west side of the island and also underlie the barrier sand. They tend to be 5 m (15 ft) thick or less. Marsh deposits beneath the barrier sand on the island have been dated to 1,800 ± 200 years old, showing the relative youth of both types of deposits. This is not surprising, because barrier islands are dynamic settings. Morton et al. (2008) and Krantz (2010) provided much more detailed maps of the island's various types of surficial deposits. There is at least one significant disconformity in the deposits, regarded as younger than 2,000 years old by Goettle (1981).

The Holocene sediments of Assateague Island and ASIS are sporadically fossiliferous. Peat and mollusks can be confidently attributed to ASIS. The land segment between Chincoteague and Sinepuxent bays (partially in Assateague State Park and partially in ASIS) is over bay fill that includes mollusks dating between 4,419 and 2,018 calibrated years before present, and some peat from the past 200 years (Seminack and Buynevich 2013). Goettle (1981) took 11 vibracores and three short cores from locations in and around the south end of Assateague Island, where the land belongs to Chincoteague Wildlife Refuge but the waters surrounding it are within ASIS. These cores sampled Pleistocene and Holocene deposits, and yielded fossils of foraminifera and mollusks. All but one of the vibracore sites were on land on Assateague or Chincoteague islands. Unusually deep (24 m [78 ft] below sea level) tidal marsh deposits with plant fragments beneath the south end of the island have been dated to 8,595 ± 140 radiocarbon years before present (9,528–8,882 calibrated years before present) (Goettle 1981). Shelly sands are present in washover deposits, and bioturbation (burrowing that has destroyed sedimentary structures) in back barrier bay deposits, in the Fishing Point area of Assateague Island (Slingerland 1989). These reports are typical; per Finkelstein and Ferland (1987), typical organic remains in the barrier/back barrier system of the Delmarva Peninsula include foraminifera, peat, pieces of *Spartina* (cordgrass), bivalves, and ostracodes from about the past 4,600 years.

Park Collections

ASIS maintains a small collection of fossils, as noted above. They include 12 accessioned specimens: ASIS-01650 and 01651, “tableate” corals; 01652, a cup coral and tetracoral; ASIS-00008, 00109, and 01673, bivalve shells; ASIS-01653, an ammonite; ASIS-00004, 00005, 00006, and 01664, crabs; and ASIS-00336, a funnel-shaped casting. The Toms Cove Visitor Center has two more fossils, another crab and a possible sea lion jaw, that had not been accessioned as of 2003 (Kenworthy and Santucci 2003). Additional specimens have probably been added, given the influx of offshore fossils in the wake of Hurricane Irene, and reported donations of offshore vertebrate fossils by clam dredgers (Whaley et al. 2012).

Cultural Resource Contexts

The short geologic and human history of ASIS reduces the likelihood of for the occurrence of fossils in a cultural resource context, particularly those associated with ancient archeological sites. It is possible that somewhere on the island there may be fossils in archeological contexts, such as fossil shark teeth, which sometimes are found associated with shell middens and may have been used as scrapers (Visaggi and Godfrey 2010). Examples have been found at George Washington Birthplace National Monument, about 135 km (85 miles) west-northwest of the nearest part of ASIS (Kenworthy and Santucci 2006). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- Seashore staff should be encouraged to observe exposed sedimentary deposits for fossil material while conducting their usual duties. To promote this, they should also 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, seashore staff should take advantage of them, if funding and time permit.

- Staff should photodocument any occurrences of paleontological resources that may be observed in situ. In most NPS units, fossils and their associated geologic context (surrounding rock/sediment) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts. However, the rapid coastal erosion at ASIS make collection more important. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. 2009).

- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist. Any fossil with 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.

- Pleistocene and Holocene fossils and deposits are of interest because they can be used to describe the effects of past climate and sea level changes, and to predict natural responses to future changes. If studies of these topics are desired at ASIS, the peat beds beneath the island are perhaps the most likely sources of relevant fossils, like pollen.
- The ASIS fossil collections should be evaluated by a paleontologist. In particular, the identities of the ammonite, tabulate? coral, and sea lion fossils should be confirmed. If incorrect, they can be corrected. If correct, they have interesting stories to tell. The ammonite and tabulates imply reworking from Mesozoic and Paleozoic rocks, and sea lions are absent from the North Atlantic.
- Unauthorized collection of fossils probably occurs at ASIS. Visitors are permitted to collect up to one gallon of unoccupied shells, and it can be difficult to distinguish between young fossil and modern shells (Schupp 2013). Brunner et al. (2010) also discusses the issue of unauthorized collection of coastal fossils.
- It could be of interest to develop interpretive products to educate visitors about fossils found at ASIS, and what they should do if they find them. Because there are many more visitor eyes than staff eyes, there is great potential for visitors to make substantial contributions to what is known about ASIS paleontology. Encouraging reporting of fossils would need to be weighed against the increased risk of unauthorized collection.
- Contact the NPS Geologic Resources Division for technical assistance with paleontological resource management issues.

References Cited

Anonymous. 1866. Miscellaneous scientific intelligence. American Journal of Science 42(124):135–138.

Brunner, J., J. Kenworthy, and V. Santucci. 2010. Unauthorized fossil collecting from National Park Service shorelines: servicewide policy and perspectives. Pages 319–323 *in* S. Weber, editor. Rethinking protected areas in a changing world: proceedings of the 2009 George Wright Society Conference. The George Wright Society, Hancock, Michigan. Available at http://www.georgewright.org/0956brunner.pdf (accessed February 2014).

Carruthers, T., K. Beckert, B. Dennison, J. Thomas, T. Saxby, M. Williams, T. Fisher, J. Kumer, C. Schupp, B. Sturgis, and C. Zimmerman. 2011. Assateague Island National Seashore natural resource condition assessment: Maryland, Virginia. Natural Resource Report NPS/ASIS/NRR—2011/405. National Park Service, Fort Collins, Colorado.

Collins, G. S., and K. Wünnermann. 2005. How big was the Chesapeake Bay impact? Insights from numerical modeling. *Geology* 33(12):925–928.

De Kay, J. E. 1842. Zoology of New-York, or the New-York fauna; Part I. Mammalia. W. & A. White & J. Visscher, Albany, New York. Available at https://archive.org/details/zoologyofnewyork01deka (accessed February 2014).

Dillow, J. J. A., W. S. L. Banks, and M. J. Smigaj. 2002. Ground-water quality and discharge to Chincoteague and Sinepuxent bays adjacent to Assateague Island National Seashore, Maryland. U.S. Geological Survey, Baltimore, Maryland. Water-Resources Investigations Report 02-4029. Available at http://pubs.usgs.gov/wri/wri024029/ (accessed March 2014).

Eshelman, R., and F. Grady. 1986. Quaternary vertebrate localities of Virginia and their avian and mammalian fauna. Pages 43–70 *in* J. N. McDonald and S. O. Bird, editors. The Quaternary of Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 75. Available at http://www.dmme.virginia.gov/commercedocs/PUB_75.pdf (accessed January 2014).

Field, M. E., and D. B. Duane. 1976. Post-Pleistocene history of the United States inner continental shelf: significance to origin of barrier islands. *Geological Society of America Bulletin* 87(5):691-702

Finkelstein, K., and M. A. Ferland. 1987. Back-barrier response to sea-level rise, Eastern Shore of Virginia. Pages 145–155 *in* D. Nummedal, O. H. Pilkey, and J. D. Howard, editors. Sea-level fluctuation and coastal evolution. Society of Economic Paleontologists and Mineralogists, Tulsa, Oklahoma. Special Publication 41.

Fraley, F. 1874. [Stated meeting, April 17th, 1874]. Proceedings of the American Philosophical Society 14:16–18. Available at http://biodiversitylibrary.org/page/31205519 (accessed March 2014).

Goettle, M. S. 1981. Geological development of the southern portion of Assateague Island, Virginia. *Northeastern Geology* 3(3–4):278–282.

Halsey, S. D. 1976. Late Pleistocene and Holocene geologic history and morphologic development of the Chincoteague-Assateague area of Maryland-Virginia with implications to the origin of barrier islands. Pages 44–57 *in* S. D. Halsey, B. McCaslin, W. L. Carey, and W. D. Romey, editors. Women in geology: proceedings of the first northeastern women's geoscientists conference. Ash Lad Press, Canton, New York.

Halsey, S. D. 1978. Late Quaternary geologic history and morphologic development of the barrier island system along the Delmarva Peninsula of the Mid-Atlantic Bight. Dissertation. University of Delaware, Wilmington, Delaware.

Hasley, S. D., S. C. Farrell, J. J. Hammond, and J. C. Kraft. 1977. Preliminary investigations of former coastal features preserved along the mid-Wisconsinan(?) shoreline of New Jersey and Delmarva. Abstracts with Programs - *Geological Society of America* 9(3):271–272.

Hay, O. P. 1923. The Pleistocene of North America and its vertebrated animals from the states east of the Mississippi River and from the Canadian provinces east of longitude 95 degrees. Carnegie Institution of Washington, Washington, D.C. Publication 322. Available at https://archive.org/details/pleistoceneofnor00hayouoft (accessed January 2014).

Hobbs, C. H., III. 2004. Geological history of Chesapeake Bay. *Quaternary Science Reviews* 23(5–6):641–661.

Horton, B. P., W. R. Peltier, S. J. Culver, R. Drummond, S. E. Engelhart, A. C. Kemp, D. Mallinson, E. R. Thieler , S. R. Riggs, D. V. Ames, and K. H. Thomson. 2009. Holocene sea-level changes along the North Carolina Coastline and their implications for glacial isostatic adjustment models. *Quaternary Science Reviews* 28:1725–1736.

Johnson, G. H., S. E. Kruse, A. W. Vaughn, J. K. Lucey, C. H. Hobbs, III, and D. S. Powars. 1998. Postimpact deformation associated with the late Eocene Chesapeake Bay impact structure in southeastern Virginia. *Geology* 26(6):507–510.

Kenworthy, J. P., and V. L. Santucci. 2003. Assateague Island National Seashore. Pages 7–9 *in* J. P. Kenworthy and V. L. Santucci. Paleontological resource inventory and monitoring: Northeast Coastal and Barrier Network. TIC# D-340. National Park Service, Denver, Colorado.

Kenworthy, J. P., and V. L. Santucci. 2006. A preliminary investigation of National Park Service paleontological resources in cultural resource contexts, Part 1: general overview. Pages 70–76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf (accessed January 2014).

Krantz, D. E. 2010. A hydrogeomorphic map of Assateague Island National Seashore, Maryland and Virginia. Natural resource report NPS/NRPC/GRD/NRR—2010/215. National Park Service, Fort Collins, Colorado. Available at http://www.nature.nps.gov/geology/inventory/publications/reports/asis_hydro_rpt.pdf (accessed March 2014).

Kraft, J. C. 1976. Radiocarbon dates in the Delaware coastal zone. Delaware sea grant report DEL-SG-19-76. College of Marine Studies, University of Delaware, Newark, Delaware, USA.

Leatherman, S. P., and E. Maurmeyer. 1989. Coastal and marine geology of the United States: coastal geomorphology of the Maryland and Delaware barrier islands. Field trips for the 28th International Geological Congress. American Geophysical Union, Washington, DC. Field Trip T217. Available at http://www.agu.org/books/ft/v217/FT217.pdf (accessed February 2014).

McCary, B. C. 1986. Early man in Virginia. Pages 71–78 *in* J. N. McDonald and S. O. Bird, editors. The Quaternary of Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 75. Available at http://www.dmme.virginia.gov/commercedocs/PUB_75.pdf (accessed January 2014).

McLaughlin, P. P., K. G. Miller, J. V. Browning, K. W. Ramsey, R. N. Benson, J. L. Tomlinson, and P. J. Sugarman. 2008. Stratigraphy and correlation of the Oligocene to Pleistocene section at Bethany Beach, Delaware. Delaware Geological Survey, Newark, Delaware. Report of Investigations 75. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/ri75.pdf (accessed February 2014).

Mitchill, S. L., J. A. Smith, and W. Cooper. 1827. Discovery of a fossil walrus in Virginia. *Annals of the Lyceum of Natural History of New York* 2(9/11):271–272. Available at http://biodiversitylibrary.org/page/15911334 (accessed February 2014).

Mixon, R. B. 1985. Stratigraphic and geomorphic framework of uppermost Cenozoic deposits in the southern Delmarva Peninsula, Virginia and Maryland. U.S. Geological Survey, Washington, DC. Professional Paper 1067-G. Available at http://pubs.er.usgs.gov/publication/pp1067G (accessed February 2014).

Mixon, R. B., B. J. Szabo, and Owens, J. P. 1982. U-series dating of mollusks and corals, and age of Pleistocene deposits, Chesapeake Bay area, Virginia and Maryland. U.S. Geological Survey, Washington, DC. Professional Paper 1067-E. Available at http://pubs.er.usgs.gov/publication/pp1067E (accessed January 2014).

Morton, R. A., J. E. Bracone, and B. Cooke. 2008. Geomorphology and depositional sub-environments of Assateague Island, Maryland-Virginia. U.S. Geological Survey, Reston, Virginia. Open-File Report 2007-1388. Scale 1:21,552. Available at http://pubs.usgs.gov/of/2007/1388/ (accessed March 2014).

National Park Service (NPS), Geologic Resources Inventory Program. 2009. Digital geomorphic map of Assateague Island National Seashore, Virginia and Maryland (NPS, GRD, GRI, ASIS, ASIS digital map). NPS Geologic Resources Inventory Program, Lakewood, Colorado. Geospatial Dataset-1047585. Available at https://irma.nps.gov/App/Reference/Profile?Code=1047585 (accessed February 2014).

National Park Service (NPS), Geologic Resources Inventory Program. 2011. Unpublished digital hydrogeomorphic map of Assateague Island National Seashore, Maryland and Virginia (NPS, GRD, GRI, ASIS, ASIG digital map) adapted from Krantz, 2010, NPS/NRPC/GRD/NRR - 2010/215. NPS Geologic Resources Inventory Program, Lakewood, Colorado. Geospatial Dataset-2181547. Available at https://irma.nps.gov/App/Reference/Profile/2181547 (accessed May 2014).

Newberry, J. S. 1873. [Meeting for October 27th, 1873]. Proceedings of the Lyceum of Natural History in the City of New York 1873(3):71. Available at http://biodiversitylibrary.org/page/14338913 (accessed February 2014).

Nickmann, R. J., and J. M. Demarest, II. 1982. Pollen analysis of some mid-Pleistocene interglacial lagoonal sediments from southern Delaware. *Quaternary Research* 17(1):93–104.

Owens, J. P., and C. S. Denny. 1978. Geologic map of Worcester County. Maryland Geological Survey, Baltimore, Maryland. Scale 1:62,500.

Owens, J. P., and C. S. Denny. 1979. Upper Cenozoic deposits of the central Delmarva Peninsula, Maryland and Delaware. U.S. Geological Survey, Washington, DC. Professional Paper 1067-A. Available at http://pubs.er.usgs.gov/publication/pp1067A (accessed February 2014).

Poag, C. W. 1997. The Chesapeake Bay bolide impact: a convulsive event in Atlantic Coastal Plain evolution. *Sedimentary Geology* 108(1–4):45–90.

Powars, D. S., and T. S. Bruce. 1999. The effects of the Chesapeake Bay impact crater on the geological framework and correlation of hydrogeologic units of the lower York-James Peninsula, Virginia. U.S. Geological Survey, Reston, Virginia. Professional Paper 1612. Available at http://pubs.er.usgs.gov/publication/pp1612 (accessed January 2014).

Ramsey, K. W. 2010. Stratigraphy, correlation, and depositional environments of the middle to late Pleistocene interglacial deposits of southern Delaware. Delaware Geological Survey, Newark, Delaware. Report of Investigations 76. Available at http://udspace.udel.edu/handle/19716/5416 (accessed March 2014).

Richards, H. G. 1936. Fauna of the Pleistocene Pamlico Formation of the southern Atlantic Coastal Plain. *Geological Society of America Bulletin* 47:1611–1656.

Richards, H. G. 1962. Studies on the marine Pleistocene. Transactions of the American Philosophical Society 52(3). Available at http://babel.hathitrust.org/cgi/pt?id=mdp.39076001805097 (accessed March 2014).

Sallenger, A. H., K. S. Doran, and P. A. Howd. 2012. Hotspot of accelerated sea-level rise on the Atlantic coast of North America. *Nature Climate Change* 2:884–888.

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado.

Schupp, C. 2013. Assateague Island National Seashore: geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2013/708. National Park Service, Denver, Colorado. Available at http://nature.nps.gov/geology/inventory/publications/reports/asis_gri_rpt_view.pdf (accessed February 2014).

Seminack, C. T., and I. V. Buynevich. 2013. Sedimentological and geophysical signatures of a relict tidal inlet complex along a wave-dominated barrier: Assateague Island, Maryland, U.S.A. *Journal of Sedimentary Research* 83(2):104–116.

Sirkin, L. A. 1974. Microflora in the Sangamon and younger beds of the Delmarva Peninsula, Delaware, Maryland and Virginia. *Abstracts with Programs - Geological Society of America* 6(1):74.

Sirkin, L. A., C. S. Denny, and M. Rubin. 1977. Late Pleistocene environment of the central Delmarva Peninsula, Delaware-Maryland. *Geological Society of America Bulletin* 88(1):139–142.

Slingerland, R. 1989. Passive margin deposits at Chincoteague Island, VA: the Holocene transgression and resulting deposits. Pages 75–76 *in* R. Slingerland, and K. P. Furlong, leaders. Sedimentation and basin analysis in siliciclastic rock sequences: Volume 2, Sedimentology and thermal-mechanical history of basins in the Central Appalachian Orogen. Field trips for the 28th international geological congress. American Geophysical Union, Washington, DC. Field Trip T158.

Spencer, R. S., and L. D. Campbell. 1987. The fauna and paleoecology of the late Pleistocene marine sediments of southeastern Virginia. *Bulletins of American Paleontology* 92(327). Available at http://www.biodiversitylibrary.org/item/105198 (accessed February 2014).

Thornberry-Ehrlich, T. L. 2005. Assateague Island National Seashore geologic resource evaluation management issues scoping summary. National Park Service, Geologic Resources Division, Denver, Colorado. Available at http://nature.nps.gov/geology/inventory/publications/s_summaries/ASIS_scoping_summary_20050929.pdf (accessed February 2014).

Toscano, M. A., R. T. Kerhin, L. L. York, T. M. Cronin, S. J. Williams. 1989. Quaternary stratigraphy of the inner continental shelf of Maryland. Maryland Geological Survey, Baltimore, Maryland. Report of Investigations 50.

Underwood, S. G., and M. W. Hiland. 1995. Historical development of Ocean City Inlet ebb shoal and its effect on northern Assateague Island. Prepared for the U.S. Army Engineer Waterways Experiment Station and the National Park Service.

Visaggi, C. C., and S. J. Godfrey. 2010. Variation in composition and abundance of Miocene shark teeth from Calvert Cliffs, Maryland. *Journal of Vertebrate Paleontology* 30(1):26–35.

Weigle, J. M. 1974. Availability of fresh ground water in northeastern Worcester County, Maryland. Maryland Geological Survey, Baltimore, Maryland. Report of Investigations 24.

Whaley, P. W., C. S. Hulslander, and B. Garrett. 2012. Celebrating National Fossil Day and fossils in an area where fossils are very rare. *Abstracts with Programs - Geological Society of America* 44(7):102.

Additional References

Belknap, D. F., and J. C. Kraft. 1985. Influence of antecedent geology on stratigraphic preservation potential and evolution of Delaware's barrier systems. *Marine Geology* 63:235–262.

Belknap, D. F., J. W. Wehmiller, R. B. Mixon, J. P. Owens, and B. J. Szabo. 1977. Amino acid geochronology applied to Pleistocene Coastal Plain stratigraphy: preliminary results. *Abstracts with Programs - Geological Society of America* 9(2):118.

Buzas, M. A., and S. J. Culver. 1994. Species pool and dynamics of marine paleocommunities. *Science* 264(5164):1439–1441.

Colman, S. M., C. R. Berquist, and C. H. Hobbs, III. 1988. Structure, age and origin of the bay-mouth shoal deposits, Chesapeake Bay, Virginia. *Marine Geology* 83:95–113.

Colquhoun, D. J., G. H. Johnson, P. C. Peebles, P. F. Huddlestun, and T. Scott. 1991. Quaternary geology of the Atlantic Coastal Plain. Pages 629–650 *in* R. B. Morrison, editor. Quaternary nonglacial geology: conterminous U.S. The geology of North America K-2. Geological Society of America, Boulder, Colorado.

Cronin, T. M., L. M. Bybell, R. Z. Poore, B. W. Blackwelder, J. C. Liddicoat, and J. E. Hazel. 1984. Age and correlation of emerged Pliocene and Pleistocene deposits, U.S. Atlantic Coastal Plain. *Palaeogeography, Palaeoclimatology, Palaeoecology* 47(1–2):21–51.

Cronin, T. M., M. Robertson, D. Willard, and J. Halka. 2004. Stratigraphy and age of Pocomoke Sound sediments. Chapter 4 in T. M. Cronin, editor. Pocomoke Sound sedimentary and ecosystem history. U.S. Geological Survey, Reston, Virginia. Open-File Report 2004-1350. Available at http://pubs.usgs.gov/of/2004/1350/ (accessed February 2014).

Ellwood, B. B. 1996. Geology and America's National Park areas. Prentice Hall, Upper Saddle River, New Jersey.

Finkelstein, K., and M. S. Kearney. 1988. Late Pleistocene barrier-island sequence along the southern Delmarva Peninsula: implications for middle Wisconsin sea levels. *Geology* 16(1):41–45.

Goettle, M. S. 1978. Geological development of the southern portion of Assateague Island, Virginia. Thesis. University of Delaware, Newark, Delaware.

Harris, P. M. 1973. Holocene sediment and stratigraphy of marshes at Chincoteague Inlet, Virginia. Thesis. West Virginia University, Morgantown, West Virginia.

Hunt, R. K., J. P. Kenworthy, and V. L. Santucci. 2006. A preliminary inventory of fossil fish from National Park Service units. Pages 63–69 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://www.nature.nps.gov/GEOLOGY/paleontology/pub/fossil_conference_7/8%20Hunt%202.pdf (accessed February 2014).

Lowery, D. L. 2009. Geoarchaeological investigations at selected coastal archaeological sites on the Delmarva Peninsula: the long term interrelationship between climate, geology, and culture. Dissertation. University of Delaware, Newark, Delaware.

Mayor, A. 2005. Fossil legends of the first Americans. Princeton University Press, Princeton, New Jersey.

Nikitina, D. L., J. E. Pizzuto, R. A. Schwimmer, and K. W. Ramsey. 2000. An updated Holocene sea-level curve for the Delaware coast. *Marine Geology* 171(1-4):7–20.

Olsen, S. J. 1971. Zooarchaeology: animal bones in archaeology and their interpretation. Addison-Wesley Publishing Company, New York City, New York..

Owens, J. P., and C. S. Denny. 1974. Provisional stratigraphic sequences in the Maryland-Delaware parts of the lower Delmarva Peninsula. *Abstracts with Programs - Geological Society of America* 5(1):61–62.

Roberts, J. K. 1942. Annotated geological bibliography of Virginia. University of Virginia bibliographical series 2.

Ruhle, J. L. 1965. Geologic literature of the Coastal Plain of Virginia, 1783-1962. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Information Circular 9. Available at http://www.dmme.virginia.gov/commercedocs/IC_9.pdf (accessed January 2014).

Scott, T. W., D. J. P. Swift, G. R. Whittecar, and G. A. Brook. 2010. Glacio-isostatic influences on Virginia's late Pleistocene coastal plain deposits. *Geomorphology* 116(1–2):175–188.

Thompson, P. R. 1983. Foraminiferal evidence for sources and timing of mass-flow deposits south of Baltimore Canyon. *AAPG Bulletin* 67(3):557.

Whitmore, F. C., Jr., K. O. Emery, H. B. S. Cooke, and D. J. P. Swift. 1967. Elephant teeth from the Atlantic Continental Shelf. *Science* 156(3781):1477–1481.

Data Sets

Assateague Island National Seashore Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Assateague Island National Seashore Collections
1965–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by ASIS staff; status: Active.

Assateague Island National Seashore Digital Geologic Map
2009–present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online. https://irma.nps.gov/App/Reference/Profile?Code=1047585.

Cape Cod National Seashore

Cape Cod National Seashore (CACO), in eastern Massachusetts, protects an area 64 km (40 miles) long in outer Cape Cod, from Provincetown at the tip of the cape in the north to Chatham in the south. This area features diverse natural and cultural resources. The natural setting includes beaches, dunes, gravelly cliffs, marshes, and glacial kettle ponds (CACO Figure 1). Cultural resources include numerous archeological sites, historic lighthouses and a life-saving station, and the Marconi Station, where the first trans-Atlantic wireless communication occurred in 1903. CACO was authorized August 7, 1961 and established June 1, 1966. Its boundaries changed November 10, 1978 and October 26, 1998. Today the national seashore encompasses 17,647.73 ha (43,608.48 acres), 11,121.89 ha (27,482.73 acres) of which are federal, and 11,210 ha (27,700 acres) of which are land, the rest being water.



CACO Figure 1. CACO is composed in large part of unconsolidated glacial sediments, which erode rapidly (NPS).

Geologic Background

CACO is located in eastern Barnstable County, Massachusetts. Using the common metaphor that compares Cape Cod to an arm, CACO comprises the outer surface of the forearm and most of the wrist and clenched fist (CACO Figure 2). Cape Cod is often described in terms of "outer" and "inner", or "upper" and "lower". CACO and the rest of the "forearm" are described as "outer" and "lower", while the rest of the Cape is described as "inner" or "upper". Cape Cod is essentially a creation of the most recent glacial episode, the Wisconsinan (or Wisconsin) glaciation of about 75,000 to 11,000 years ago, later modified by the rising Atlantic Ocean. Exposed bedrock is nowhere to be found on the Cape, but glacial and coastal features are well-developed. The Cape features the longest unbroken unconsolidated glacial coastline in New England (Fisher 1987).

Descriptions of the geology of CACO are often focused on the coastal geology and the processes that will eventually erode the seashore out of existence. The paleontology of CACO has also been described in a number of documents. Publications that discuss the paleontology and general geology of CACO include Finch (undated), Crosby (1879), Upham (1879), Davis (1896), Shaler (1898), Hollick (1902), Woodworth and Wigglesworth (1934), Sayles (1939), Sayles and Knox (1943), Hyyppä (1955), Zeigler et al. (1960, 1964), Strahler (1966), Chamberlain (1967), Hartshorn et al. (1967), Koteff et al. (1967), Oldale (1968, 1970, 1976a/undated update, 1976b, 1979, 1982, 1988, 1992, 2001), Oldale et al. (1971, 1993), Fisher (1972), Leo et al. (1973), Gleba (1978), Leatherman (1979), O'Keefe and Patterson (1980), Winkler (1982, 1985, 1988, 1989, 1992, 1997), McManamon and Borstel (1984), Borstel (1984a), Oldale and Barlow (1986), Fisher (1987), Fisher and Leatherman (1987), Leatherman (1987), Goldsmith and Weed (1991), Winkler and Sanford (1994, 1995), Uchupi et al. (1996), Portnoy et al. (2001), Kenworthy and Santucci (2003), Mulligan and Uchupi (2004), Poppe et al. (2006), Stone and DiGiacomo-Cohen (2006), Uchupi and Mulligan (2006), Bratton (2007), Graham (2008), NPS (2009), Spiess (2011), and Maio et al. (2013). The NPS Geologic Resources Division coordinated a Geologic Resource Inventory workshop for CACO in June 2008 (Graham 2008), and in 2009 produced a digital geologic map for the seashore (NPS 2009). The initial paleontological resource inventory and summary was prepared by Kenworthy and Santucci (2003).

The bedrock of outer Cape Cod can only be reached through drilling (Koteff and Cotton 1962; Leo et al. 1973; Goldsmith and Weed 1991). It has been found between about 112 and 150 m (367 and 492 ft) below the surface (Leo et al. 1973), and includes metamorphosed limestone, phyllite schist (Koteff and Cotton 1962), granite, and gabbro (Leo et al. 1973). Granite below Chatham has been dated to 584 +9/-8 Ma (million years ago) (Leo et al. 1973). These igneous and metamorphic rocks pertain to the Avalon terrane (Leo et al. 1973). A terrane is a distinct block of crustal rock that has been separated from its original plate and become attached to another. The Avalon terrane represents part of a microcontinent called Avalonia, which had been part of the southern supercontinent Gondwana before detaching from it during the Ordovician (see the Appendix for a geologic time scale); the rest of Avalonia is now part of western Europe (Torsvik and Cocks 2013). Several large terranes have been identified in eastern North America. They became part of this continent during the Paleozoic, when a series of island arcs and continental fragments collided with the continent as a prelude to the assembly of the supercontinent Pangaea in the Pennsylvanian.

Pangaea existed through the Permian into the Triassic, when it began to rift apart. Rift basins were created by the separation of North America from Africa and Europe during the Late Triassic and Early Jurassic. These basins are scattered along the eastern margin of North America and contain volcanic and sedimentary rocks, having been the sites of rift lakes similar to those found today in eastern Africa. Buried examples are present beneath CACO and the vicinity. One rift, known as the Nantucket Basin, is about 100 km (60 miles) long and trends northeast off of Cape Cod (Goldsmith and Weed 1991). A smaller rift is present beneath the "wrist" of Cape Cod (including CACO), oriented east–west at 42° N (Uchupi et al. 1996).

Explorations of the subsurface of Martha's Vineyard and Nantucket, and an exposure of glacially thrusted Cretaceous and Neogene deposits at Gay Head on Martha's Vineyard, show that eastern Massachusetts was a site of coastal plain deposition at several times from the Late Cretaceous to the Pliocene (Folger et al. 1978; Goldsmith and Weed 1991; Oldale 2001). Coastal plain sediments may have been present as far north as Boston, but glacial ice has removed them north of the islands (Oldale 2001). Similar coastal plain sediments are present in the subsurface of Fire Island National Seashore (FIIS), Gateway National Recreation Area (GATE), and Sagamore Hill National Historic Site (SAHI); see the individual chapters in this report for more information. Uchupi et al. (1996) depicted isolated erosional remnants of Cretaceous–Cenozoic coastal plain sediments north of Nantucket Sound, including in Cape Cod Bay, but noted that they could consist, at least in part, of pre-Wisconsinan glacial deposits. No coastal plain sediments have been encountered in the subsurface of outer Cape Cod; reported Eocene deposits identified by fossils are more



CACO Figure 2. Geography of CACO (NPS).

likely Pleistocene sediments with redeposited Eocene fossils (Uchupi et al. 1996).

The geography and surficial geology of Cape Cod are of ocean-modified glacial debris, deposited less than 25,000 years ago at the end of the Wisconsinan glaciation. There is evidence on Martha's Vineyard and elsewhere in New England for at least one major glacial episode before the Wisconsinan (Oldale and Colman 1992), but each glaciation destroyed much of the evidence for preceding glaciations, so only the Wisconsinan glaciation is widely represented. The great continental ice sheet that traversed northern North America during the Wisconsinan is known as the Laurentide ice sheet. It appeared around 75,000 years ago but only began its major advance into New England around 25,000 years ago (Oldale 2001). The ice sheet reached its maximum extent in eastern New England between about 21,000 and 20,000 radiocarbon years before present, then retreated to near the present south shore of Cape Cod around 19,000 radiocarbon years before present, pausing before retreating fully (Uchupi and Mulligan 2006). A thickness of some 1,700 m (5,600 ft) of ice covered New England during the height of the Wisconsinan (Portnoy et al. 2001). Three glacial lobes covered the Cape Cod region. On the west was the Buzzards Bay Lobe. Inner Cape Cod was covered by the Cape Cod Bay Lobe. Outer Cape Cod formed along the boundary between the Cape Cod Bay Lobe and the South Channel Lobe to the east (Oldale 2001).

Note that radiocarbon dates are not the same as calendar dates, and must be calibrated to approximate calendar years. Uncalibrated radiocarbon dates in publications are often denoted by "radiocarbon years before present" (^{14}C yr BP, with the year 1950 as "present") or a similar formulation. However, they are not always specifically identified as radiocarbon dates. Dates that are not labeled with "calibrated years" or something similar should be assumed to be uncalibrated radiocarbon dates. Dates here were calibrated using Calib 7.0 (http://calib.qub.ac.uk/calib/) where appropriate.

Two systems of moraines (accumulations of glacial debris) were created by this glaciation. The older system, created at the maximum extent of the glaciation, includes the more southerly coastal moraines, such as those on Martha's Vineyard and Nantucket, and continues to Long Island in the form of the Ronkonkoma Moraine. The younger system includes the more northerly moraines on Cape Cod proper, primarily the Buzzards Bay and Sandwich moraines, and is also represented on Long Island, as the Harbor Hill Moraine (Oldale 1979). The moraines on Cape Cod did not form by "conveyor belts" of debris dropped by ice at a stillstand, but from brief rapid advances during an overall retreat. Underlying beds were shoved forward as discrete sheets or blocks of material, forming what are known as thrust moraines (Oldale and O'Hara 1984). Outer Cape Cod was formed from outwash plains deposited by meltwater streams transporting debris from the South Channel Lobe on the east between about 17,000 and 14,000 years before present; thus, the plains slope to the west (Portnoy et al. 2001).

Several large meltwater lakes formed on and around Cape Cod during the retreat of the glacial lobes. These lakes had geologically short lifespans of a thousand years or less (Oldale 2001). A large lake formed in what is now Nantucket Sound after the first period of retreat. As the glaciers retreated further, a proglacial lake called Lake Wampanoag formed across inner Cape Cod. This lake eventually broke through its confines and drained into the Nantucket Sound lake, causing that lake to fail as well. Lake Wampanoag is thought to have existed sometime between 19,000 and 17,000

radiocarbon years before present, spreading north over time (Uchupi and Mulligan 2006). A second proglacial lake formed in Cape Cod Bay as the Cape Cod Bay Lobe continued to retreat, and persisted to around 16,000 radiocarbon years before present (Mulligan and Uchupi 2004). It is known under various names, generally some formulation similar to Lake Cape Cod Bay. This lake eventually drained out through several areas around Cape Cod, including the Eastham area (Oldale 1979; Uchupi et al. 1996). A subglacial lake existed beneath the ice covering the Eastham area at about the same time as Lake Cape Cod Bay (Mulligan and Uchupi 2004). The various outwash plains of outer Cape Cod prograded into Lake Cape Cod Bay (Poppe et al. 2006). Shorter-lived lakes, such as one at Wellfleet, formed on outer Cape Cod (Uchupi et al. 1996).

The glaciers departed Cape Cod between 15,000 and 14,000 radiocarbon years before present (Oldale 1979). Occasional brief readvances punctuated the withdrawal (Uchupi et al. 1996). In the immediate aftermath of their departure, marine flooding occurred because the land surface had been depressed by the mass of ice. This condition did not last long, because the crust then began to rebound, and eventually to subside again as it adjusted to the lack of ice (Oldale 1988). The early marine incursion into Cape Cod Bay was probably over by about 12,000 radiocarbon years before present (Uchupi et al. 1996). Possible slump deposits from earthquakes that occurred during this adjustment can be found in the sediments of northeastern Cape Cod Bay (Oldale 1988). The adjustment could be dramatic: Boston, across the bay, was 33 m (110 ft) below sea level immediately after deglaciation, then rebounded to at least 43 m (140 ft) above sea level within one to two thousand years, followed by more subsidence (the shape of the deformation can be described as a bulge that followed the retreating ice). The effects were not as dramatic at outer Cape Cod (Uchupi et al. 1996).

Massive blocks of ice were separated from the glacial lobes during their retreat. The slow melting of the blocks led to the formation of kettle ponds throughout the outer Cape (Portnoy et al. 2001). If insulated, melting could have taken several thousand years (Oldale 2001). Two kinds of kettle ponds are present in CACO and outer Cape Cod. The oldest are the original kettle ponds, which date to the latest Pleistocene. The second kind includes reactivated kettle ponds that filled when rising sea level caused the freshwater lens beneath Cape Cod to rise and enter previously emptied ponds (Winkler and Sanford 1995; Portnoy et al. 2001). Some of the kettle ponds along the coast have been breached by the rising sea (Oldale 2001; Bratton 2007). A third type of pond has formed among the dunes in Provincelands. These are not kettle ponds (Winkler and Sanford 1995). Instead, these ponds and bogs formed as interdunal ponds during the wetter period about 1,150 to 900 radiocarbon years before present (Winkler 1992).

During the Last Glacial Maximum of about 25,000 to 20,000 years ago, sea level was significantly lower; figures vary between sources. Uchupi et al. (1996) cited an estimate of 130 m (430 ft) lower than present at 18,000 radiocarbon years before present. Whatever the exact figure, the effect was to turn vast areas of the continental shelf into coastal plains (Portnoy et al. 2001). These coastal plains surrounding eastern Massachusetts supported forests of spruce, pine, and fir amid tundra plants and grasses, and swamps and marshes. Fish, reptiles, birds, bear, wolves, mastodons, mammoths, deer, moose, caribou, bison, and musk oxen lived in these areas, and their remains, along with peat, are sometimes dredged from the now-submerged lands (Oldale 2001). Sea level rose rapidly after

deglaciation, then slowed. Sea level is estimated at 20 m (66 ft) below present by about 8,000 radiocarbon years before present, 10 m (33 ft) at 6,000 radiocarbon years before present, and 7 m (23 ft) at 5,000 radiocarbon years before present (Uchupi et al. 1996).

As sea level rose, outer Cape Cod was reworked by coastal processes. Outer Cape Cod was once wider, and without the present smooth coastline or the sandy Provinceland Hook (Fisher 1987). It has been extensively modified over the past 9,500 years into its present form, with as much as 7 km (4 miles) lost east of the present coastline (Uchupi et al. 1996). The Provincetown Hook began forming about 6,000 years ago after the Georges Bank was submerged by the rising sea and littoral drift began flowing in part to the north, bringing sediment from the southern part of the outer Cape (Uchupi et al. 1996). The outermost part of the hook, Herring Cove Beach Spit, began forming over 1,500 years ago (Ekwurzel 1990). The salt marshes of outer Cape Cod began forming around 6,000 years ago (Oldale 2001). Nauset Spit is another young feature, about 4,000 years old (McManamon and Borstel 1984). Continued coastal erosion will eventually destroy outer Cape Cod. The sea scarp retreats at about 0.67 ± 0.3 m/year (2.2 ± 0.9 ft/year) (Leatherman 1987). Outer Cape Cod's remaining lifespan is postulated to be in the thousands of years, depending on the width of a particular segment (Fisher 1987; Oldale 2001).

Microfossils in the many bodies of water in CACO and the rest of outer Cape Cod have been used to describe in detail the environmental and climatic history since deglaciation. The basal portion of the sediment in the oldest kettle ponds is a debris layer representing the vegetation that grew on top of the buried melting ice blocks, before ponds were established. Succeeding pollen and spores show that a tundra–spruce parkland existed shortly after deglaciation, to about 12,000 years before present. The warming climate led to a boreal forest dominated by spruce, jack pine, and green alder, which persisted to about 10,500 years before present, when increasing moisture started a transition to a northern conifer forest dominated by white pine. The northern conifer forest lasted until about 9,500 years before present. The next approximately 9,000 years featured a warmer climate that alternated between drier and wetter phases. When more moisture was available, a mixed mesophytic forest of pitch pine, white pine, and oak was present, and when the climate was drier, white pine disappeared and pine barrens formed. The arrival of European settlers in the 17th century further altered the community (Winkler 1985, 1997; Winkler and Sanford 1995; Portnoy et al. 2001). Vegetation change on the outer Cape was not as great as on the mainland, and the communities included fewer mesic (moist climate) elements (McMananom and Borstel 1984). Charcoal in the ponds show that fires were most common between about 9,500 and 5,000 years before present, under a drier climate when pitch pine and oak were dominant (Winkler 1997). Droughts and resulting lowstands in Cape Cod lakes appear to correspond to times of low sea surface temperatures, when the western North Atlantic became cooler and fresher (Newby et al. 2009). Humans arrived at outer Cape Cod around 9,000 years ago (Finch undated). European colonization began in 1620 with the Pilgrims, who first landed in Provincetown Harbor.

The surficial geology of CACO is entirely composed of unconsolidated deposits. Most of the sediments were deposited during the recessional phase of the Wisconsinan glaciation, as outwash, in glacial lakes, and so forth, but the outermost portion (the Provincetown hook) is composed of

sediment moved by coastal processes in the past few thousand years (CACO Figure 3). Geologic maps of part or all of CACO include Koteff et al. (1967), Oldale (1968, 1970), Oldale et al. (1971), Oldale and Barlow (1986), Stone and DiGiacomo-Cohen (2006), and NPS (2009). The deposits found in CACO are extensively fossiliferous. Common fossil resources include transported wood fragments, marine shells, and fossiliferous cobbles from various sources in glacial deposits, and diatoms (phytoplankton with cell walls made of silica), charcoal, spores, pollen, and crustacean remains in lake and bog sediments. CACO also has yielded fossils from deep wells and microfossils from marine sediments, and has many examples of floral and faunal remains at archeological sites (CACO Table 1).

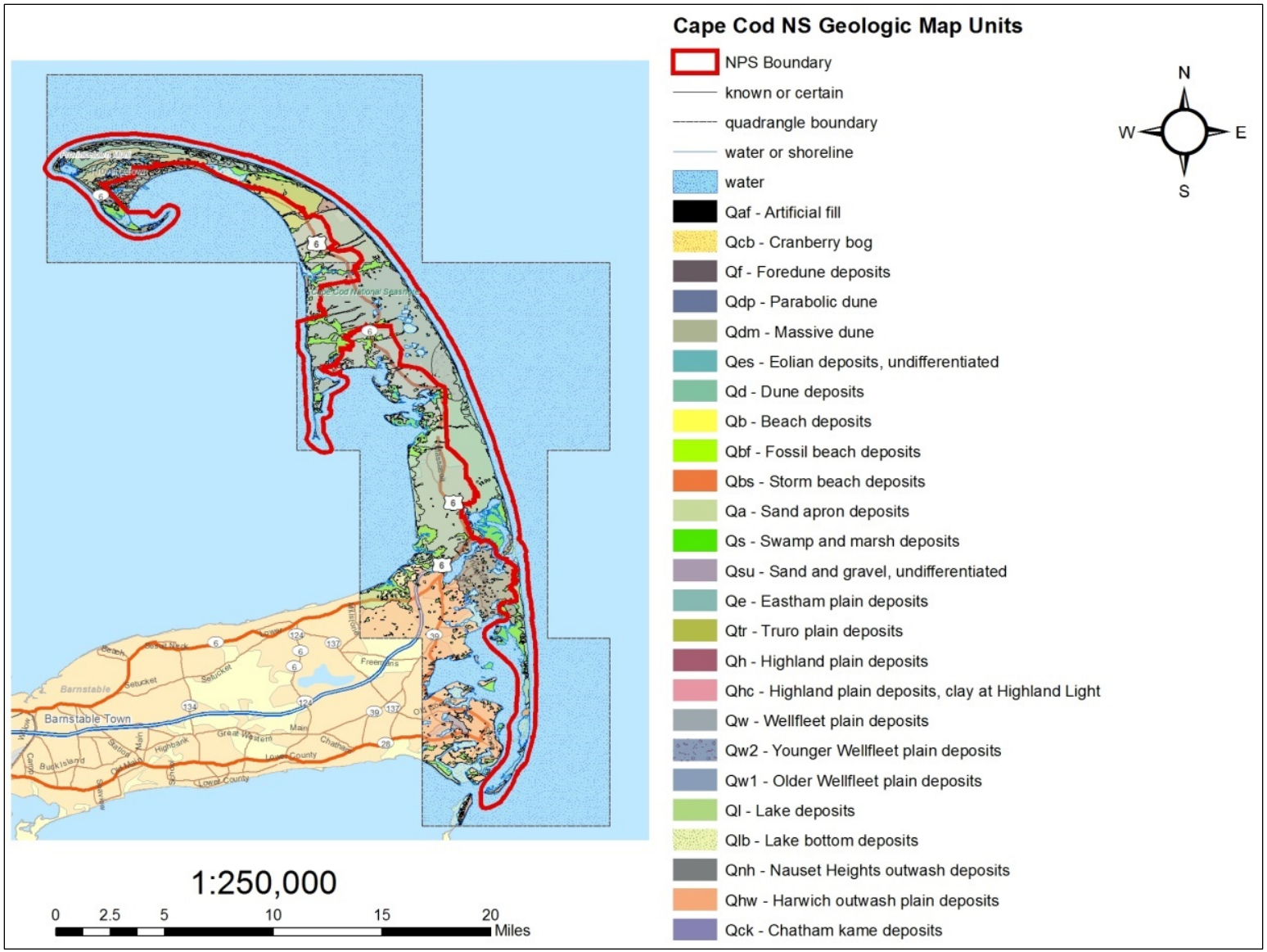
Sources of Paleontological Resources

The fossils of CACO present opportunities for education, interpretation, and scientific research in the seashore. Fossil management at CACO is unusual compared to most NPS units. The majority of its fossils have either been moved from other places by glaciers or are microfossils in lake sediments. The transported fossils are not technically in situ but are often portable, and are vulnerable to loss by coastal erosion. Management or documentation of these fossils present practical challenges. Unlike a formation, which crops out in defined areas, these transported specimens can be almost anywhere and occupy spaces on the scale of an inch. Lake microfossils are inaccessible to the public and are of minimal interest to collectors and vandals. They are of substantial interest for park management purposes, because they illustrate previous environmental and climatic conditions.

Subsurface (Various Ages of Fossils in Pleistocene Deposits)

Several deep wells and borings have been made within CACO. These subsurface explorations have frequently encountered fossils, such as microfossils. Because the fossiliferous sediments are buried hundreds of meters or feet below the surface, they are protected from erosion, theft, and vandalism, and only require management when brought to the surface. They are included here for completeness, and because they illustrate otherwise hidden aspects of CACO's geologic history.

Zeigler et al. (1960) reported on three wells at the north end of CACO, known in the literature as "Holden's Pond", "Race Point", and "Stark's Well". A fourth well, "Jim's II", has also entered the literature. They range from about 60 to 80 m (200 to 260 ft) in depth (Goldsmith and Weed 1991). Zeigler et al. (1960) described fossils recovered from the Holden's Pond and Stark's Well sites, finding them from 26 to 80 m (86 to 264 ft) below the surface at Holden's Pond, and 59 to 62 m (193 to 203 ft) below the surface at Stark's Well. These included lignite coal, Eocene-age spores and pollen, and foraminifera (single-celled organisms that secrete "shells", typically of calcium carbonate) interpreted as Eocene in age (Zeigler et al. 1960). Eocene pollen is also present in the other two wells (Zeigler et al. 1964), and carbonized wood has been found as well (Uchupi et al. 1996). Zeigler et al. (1960, 1964) regarded the microfossils as evidence of buried Eocene sediments. More recent publications (Goldsmith and Weed 1991; Uchupi et al. 1996) interpreted the fossils as having been eroded out of sediments elsewhere and transported to Cape Cod with other material by glaciers. Although the spores and pollen are still thought to be of Eocene age, the foraminifera are more likely from the Pliocene or Pleistocene (Uchupi et al. 1996).



CACO Figure 3. Schematic geological map of CACO. Map graphic adapted from digital geologic map data available at the following URL: https://irma.nps.gov/App/Reference/Profile?Code=1048646.

CACO Table 1. Summary of CACO stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text.

Formation	Age	Fossils Within CACO	Depositional Environment
Quaternary sediments	Pleistocene-Holocene	Glacial deposits (transported fossils): Cambrian hyoliths and trilobites; Lower Devonian brachiopods, bivalves, and trilobites; hyoliths and invertebrate burrows (*Skolithos*) of uncertain age; Eocene coral, bivalves, gastropods, and echinoid spines; Pleistocene peat, radiolarians, diatoms, wood fragments (including conifers), spores of mosses, ferns, and clubmosses, pollen of conifers and angiosperms, sponge spicules, bivalves, gastropods, and barnacles; undated lenses of peat or lignite and carbonized fragments; possibly also Cretaceous and/or Cenozoic petrified wood, shark teeth, and fish teeth (the glacially transported material with CACO probably includes more diverse fossils than presently known) Kettle ponds, bogs, marshes: peat, other organic debris, testate amoebae, diatoms, chrysophyte algae, dinoflagellates, the chlorophyte algae *Pediastrum*, charophyte algae oospores, charcoal, mosses, seeds and fragmentary macrofossils of conifers and angiosperms (twigs, needles, etc.), aquatic plants (angiosperms), spores of mosses, quillworts, clubmosses, and ferns, pollen of conifers and angiosperms, insect remains, cladoceran crustaceans, and possibly gastropods (latest Pleistocene–Holocene) Glaciomarine deposits: diatoms, spores of mosses, ferns, and clubmosses, and pollen of conifers and angiosperms (latest Pleistocene) Coastline: peat pebbles (uncertain age, probably late Pleistocene–Holocene) Archeological sites: seeds, nuts, bivalves, gastropods, bones of cartilaginous fish, ray-finned fish, amphibians, turtles, snakes, raptors, waterfowl, ground birds, unidentified birds, rodents, lagomorphs, canids, raccoons, skunks, mustelids, bear, seals, porpoises, and deer, and artifacts made of potentially fossiliferous material (middle–late Holocene)	Glacial outwash, shallow marine, glacial and nonglacial lakes, salt marshes, bogs, dune fields, beaches, and minor fluvial; glacial sediments include materials derived from a variety of settings across New England
Subsurface sediments	Pleistocene; fossils of various ages	Reworked Pliocene or Pleistocene foraminifera; Eocene spores and pollen; undated lignite and carbonized wood	Glacial outwash and shallow marine deposits; glacial sediments include materials derived from a variety of settings across New England

Peat is also encountered regularly in the shallow subsurface of CACO and outer Cape Cod. The Provincetown Hook has been the major study area for subsurface peat. Forty-one cores were taken from the Provincetown part of CACO to study the growth of this feature. Freshwater peats dated between roughly 890 and 550 radiocarbon years before present were found in these cores 0.6 to 2 m (2 to 7 ft) below the surface (Leatherman 1987). Slightly older peat has been found at Wood End in CACO, dating to 1,500 ± 150 radiocarbon years before present (1,730–1,170 calibrated years before present) (Ekwurzel 1990). Just offshore of Provincetown, probably outside of CACO, the record goes back even farther: freshwater peat found there dates to 12,320 ± 350 radiocarbon years before present (15,520–13,470 calibrated years before present) (Oldale 1982). Peat has also been found near the Coast Guard Beach Station on the east side of CACO, dating back to at least 815 ± 95 radiocarbon years before present (930–640 calibrated years before present) (Fisher and Leatherman 1987). At one point, a peat bed 3.7 m (12 ft) thick had been present at the beach near the station, but it may no longer exist; it eroded from that thickness as seen in summer 1916 to a thickness of 0.3 m (1 ft) in 1937 (Sayles and Knox 1943).

Other fossils have been recovered from the immediate vicinity. A boring at the end of Provincetown's central wharf, just outside of CACO, recovered shells of bivalves and gastropods as far down as 43 m (140 ft) (Upham 1879). Wells drilled in Provincetown frequently encounter shell fragments. (Woodworth and Wigglesworth 1934). In eastern Provincetown, a deep well bored in 1905 encountered a fossiliferous bed about 61 m (200 ft) down. Bivalves, gastropods, barnacles, and echinoids were found in this bed, which was correlated to the fossiliferous Sankaty Sand of Nantucket (Woodworth and Wigglesworth 1934). Woodworth and Wigglesworth also attributed a shell bed 26 m (84 ft) down at East Orleans to the Sankaty Sand, suggesting the bed was folded there which brought it higher, but these early correlations have generally been superseded. For reference, the Sankaty Sand of Nantucket has yielded an assemblage of foraminifera, boring sponges (Cushman 1904, 1906; Wilson 1905), corals (Oldale and Colman 1992), bryozoans, bivalves, gastropods, serpulid worm tubes, barnacles, crabs, hermit crabs (Cushman 1904, 1906; Wilson 1905), ostracodes (Oldale et al. 1982), and echinoids (Cushman 1904, 1906; Wilson 1905). The fossils date to the Sangamon interglacial preceding the Wisconsinan glaciation (Oldale and Colman 1992).

Quaternary Deposits (Uppermost Pleistocene–Holocene; Transported Fossils as Old as Cambrian)

The surficial geology of CACO is composed of a series of distinct outwash deposits derived from material transported by the South Channel Lobe. From oldest to youngest, these include the Nauset Heights deposits, the Wellfleet Plain deposits, the Highland Plain deposits, the Truro Plain deposits, and the Eastham Plain deposits (Oldale and Barlow 1986; CACO Figure 3). Various depositional settings and processes are represented. The Nauset Heights deposits are made up of ice contact deposits (Oldale and Barlow 1986). Lacustrine deposits are found in the Highland Plain (Koteff et al. 1967; Oldale 1979), Truro Plain, and Wellfleet Plain deposits, with deltas in the latter two indicating deposition in Lake Cape Cod Bay (Oldale and Barlow 1986). Fluvial bedding is found in the Eastham Plain deposits (Oldale and Barlow 1986). As described in the Geologic Background section, these deposits are younger than about 17,000 years old. There are two primary types of fossils in these sediments in CACO: glacially transported fossils and microfossils in lake sediments.

Transported fossils (Cambrian–Pleistocene)

Fossils reworked from elsewhere are commonly found in the sediments of CACO and Cape Cod, having been eroded by glaciers from a variety of different sources. Common examples from outer Cape Cod include fossiliferous cobbles, carbonized wood fragments, marine shell fragments (Zeigler et al. 1964), and Cenozoic fish teeth and petrified wood (Uchupi et al. 1996). Oldale (2001) presented photos of petrified wood of Cretaceous or Cenozoic age, Eocene-age shelly marl, and a Cenozoic shark tooth from the Wellfleet Plain deposits. Transported fossils within CACO are undoubtedly more diverse than presently known.

The oldest reports of fossils from CACO come from the geologist Warren Upham. In his first description, related via Crosby (1879), he described a class of pebble-to-boulder-sized rock fragments composed of white lime-rich (calcareous) sandstone. These white stones had abundant fossil remains, often fragmented, and sometimes replaced by molds and casts. They were brought to Upham's attention in 1877 by David F. Loring, the keeper of the Highland Light; Loring had collected a few pieces and given them away to others. Upham returned in 1878 and recovered a number of pieces during visits in June and October. The first locality was in a sea cliff less than 1 km (about 0.5 miles) south of the lighthouse. Additional specimens were found over 6 km (4 miles) to the south, where they came from a horizon 9 m (30 ft) above sea level in a cliff. Upham found that this type of material was essentially confined to only these locations. Fossils included traces of lignite and specimens of 25 species of marine invertebrates. Most were bivalves, but a coral, gastropods, and echinoid (sea urchin) spines were also found. The fossils were interpreted as Eocene in age (Crosby 1879). Upham (1879) provided additional details later that year.

Upham (1879) also reported on additional finds of more recent fossils, found along the bluffs on the east coast in the Truro area. "Broken and worn shells" were found in gravel at several locations, representing bivalves, gastropods, and barnacles. Productive areas included: about 1.6 km (1 mile) south of the head of the Pamet River, where a thin lens of peat or lignite (about 1 cm [0.5 in] thick and 1.5 m [5 ft] across) was found just above the shelly gravel; about 0.5 km (0.3 miles) north of the river's head; and two localities separated by about 0.5 km (0.3 miles), 1.6 km (1 mile) south of the Highland Light. Lignite was also present in thin lenses at the northernmost locality, with similar dimensions to the lens south of the Pamet River. Upham interpreted all of the outer Cape's fossils as having been eroded from pre-glacial deposits in Massachusetts Bay and transported by glaciers.

Several examples of transported Paleozoic fossils have been reported from CACO. Hollick (1902) described a boulder of red shale near the Highland Light that contained Cambrian-age fossils of hyoliths (extinct mollusks with triangular shells) and several genera of trilobites. The boulder was broken up so that specimens could be sent for identification. Gleba (1978) noted that the occurrence was similar to in situ fossils in Braintree, Massachusetts, over 60 km (37 miles) northwest of Race Point. Woodworth and Wigglesworth (1934) reported a greenish piece of quartzite from near Highland Light with a hyolith of uncertain but possibly Cambrian age, and another piece of quartzite from just north of the Weather Bureau station included examples of the simple invertebrate burrow *Skolithos*. Brachiopods, bivalves, and trilobites of early Devonian age were found in a piece of quartzitic sandstone discovered near the Highland Light in 1915; this stone and other Devonian clasts

had probably been part of a Carboniferous conglomerate before being transported again, by Pleistocene glaciers (Woodworth and Wigglesworth 1934).

Sayles and Knox (1943) described several beds on outer Cape Cod that they interpreted as glacial till and intertill beds. More recent research has reevaluated the beds as glacial drift with transported fossils (Oldale 1982), with the exception of some beds near the Highland Light that are postglacial marine units and thus in situ (Oldale 1979). The beds included a variety of microfossils including radiolarians, diatoms, spores of mosses, ferns, and clubmosses, pollen of conifers and angiosperms, and sponge spicules. Localities within CACO include the old Nauset Coast Guard Station (locality 12), the Nauset Light (13 and 13a), a site 0.8 km (0.5 miles) south of the Pamet River Coast Guard Station (16), the Highland Light (17), and a site 0.5 km (0.3 miles) south of the Highland Light (17a). Locality 11 at Nauset Heights is probably in CACO as well. "Till" 2 at the Nauset Coast Guard Station had the most diverse diatoms, and was the only site where radiolarians were specifically mentioned. Diatoms were also present at localities 11, 16, and 17. They are mostly of marine affinities, with no freshwater species. Pollen and spores were best represented at locality 17, but were also present at localities 12 and 16. Sponge spicules were found at 11, 12, 16, and 17, and are generally from deep marine forms. Bits of carbonized wood and other fragments that may represent seaweed were also commonly found in the beds (Sayles and Knox 1943). The Highland Light area is also discussed under "Other types of fossil occurrences" below.

Pleistocene wood fragments and marine shells are found at a number of places in CACO and the rest of the outer Cape. Several examples have been dated to various ages greater than 20,000 radiocarbon years before present (Zeigler et al. 1964; Koteff et al. 1967; Oldale 1968, 1979, 1982). Koteff et al. (1967) plotted the locations of numerous fossil shell localities in the North Truro quadrangle within CACO, and the localities of their radiocarbon dating sites. The fossil are found in the Wellfleet and Highland plain deposits, mostly along the Atlantic coast, and were probably transported from elsewhere by glaciers. The dated shells and wood predate 25,000 radiocarbon years before present (Koteff et al. 1967). Oldale (1968)'s map of the Wellfleet Quadrangle included several locations where radiocarbon-dated wood was found in CACO.

There is a decent possibility that fossils of extinct Pleistocene mammals will be found in the glacial deposits. Just outside of CACO at Town Cove in Orleans, the maxilla (upper jaw) of a bison calf was found in glacial drift (Allen 1920). The large distinctive teeth of mammoths and mastodons are probably the most likely types of these fossils to be found. Oldale (2001) included photos of both types of teeth, dredged from the Gulf of Maine off of Marblehead, Massachusetts, over 65 km (40 miles) northwest of Provincetown.

Microfossils in lake and bog sediments (uppermost Pleistocene–Holocene)

The ponds and bogs of CACO contain significant fossil records that detail the environmental and climate history of the outer Cape following deglaciation. Three general types of ponds can be differentiated. Group I includes kettle ponds with records beginning in the latest Pleistocene, between deglaciation and about 11,500 years before present. These ponds are found in the Truro and Wellfleet outwash plains, and include such ponds as Great Pond and Ryder Pond in the Truro part of CACO, and Duck Pond, Dyer Pond, and Great Pond (CACO Figure 4) in the Wellfleet part of CACO. Group

II ponds have shorter records, only going back to the middle or late Holocene. They are found north and west of the Group I ponds in the Herring River drainage basin and the Wellfleet outwash basin. They formed as sea level rose and pushed up the Cape's freshwater lens into previously dry basins. Examples of these ponds include Gull Pond and Higgins Pond in Truro, and Herring Pond in Wellfleet. Finally, Group III ponds are the most recent, having formed in the interdunal swales of the Provincelands Hook during roughly the past 1,000 years. They include Bennett Pond, within CACO, and the Provincetown Duck Pond, just outside of the border. Fossils found in the ponds include peat, diatoms, dinoflagellates (single-celled organisms that move using one or more whip-like flagella), the chlorophyte algae *Pediastrum*, oospores of charophyte algae, charcoal, seeds, conifer needles, willow twigs, aquatic plants, spores of ferns, quillworts, mosses, and clubmosses, pollen of conifers and angiosperms, insect remains, and cladoceran crustaceans ("water fleas") (Winkler and Sanford 1995; Portnoy et al. 2001). Gastropod shells are also reported from lakes on the outer Cape (Graham 2008), but no specific references have been encountered. Given the ubiquity of gastropods, fossil shells at any given site would not be surprising.



CACO Figure 4. Great Pond in Wellfleet is one of CACO's many kettle ponds. Like several other kettle ponds in CACO, it has a fossil record that goes back to the time of deglaciation (Oldale 1976a, USGS).

Duck Pond in Wellfleet is probably the most thoroughly described microfossil site in CACO. This kettle lake has a fossil record that begins over 12,000 years ago. Spores and pollen from the lake show how the local floral community changed through this period (Winkler 1985), as detailed in the geologic background section. Fossils from this site include diatoms, charcoal, mosses, spores of mosses, quillworts, and ferns, and pollen of conifers and angiosperms. The base of the section features a thin layer of organic debris, representing plant life that grew above the melting ice block that formed the pond. Identifiable moss macrofossils were found in this layer (Winkler 1985). Diatoms in the pond sediments have been used to study the pH history of the lake's waters (Winkler 1988), and charcoal from this and neighboring lakes has been used to study local fire history (Winkler 1997). Duck Pond is also mentioned in McManamon and Borstel (1984), Tzedakis (1992), and Newby et al. (2000). The Duck Pond in Wellfleet should not be confused with the Duck Pond in Provincetown, which has a much shorter fossil record and is just outside of CACO (Winkler 1992).

An example of an intermediate-age site in CACO is Pamet Cranberry Bog in Truro. The fossils of Pamet Cranberry Bog were described briefly in an abstract by O'Keefe and Patterson (1980). The fossil record of the bog extends to at least 6,980 ± 85 radiocarbon years before present (7,960–7,670 calibrated years before present), and includes peat, charcoal, moss spores, and conifer and angiosperm pollen. At this site, red maple predominated early on, with shrubs becoming common around 5,500 years ago. The surrounding uplands supported oak and pine (O'Keefe and Patterson 1980).

Bennett Pond in the Provincetown section of CACO is an example of the interdunal ponds of Group III. It has a record dating back to 910 ± 70 radiocarbon years before present (930–690 calibrated years before present), and has produced testate amoebae (amoebae with "shells", called tests), diatoms, chrysophyte algae (golden algae), moss spores, and conifer and angiosperm pollen (Winkler 1992).

Other pollen sites from eastern Massachusetts are described in Ogden (1959), Davis (1960, 1961), Suter (1985), Dunwiddie and MacDonald (1988), Tzedakis (1988), Dunwiddie (1989), and Newby et al. (1994, 2000, 2009). Although angiosperm and conifer pollen are the major topics of study, diatoms, algae (*Pediastrum* in particular), dinoflagellate cysts, various spores (of lycopods, quillworts, spikemosses, ferns, and mosses), seeds, fragments of plant macrofossils, fungi, cladocerans, and reworked ancient microfossils are also commonly found. Interpreting pollen in glacial settings is complicated by the fact that glacial meltwater transports pollen to areas of deposition, and redeposited pollen can be difficult to tell from primary pollen. Redeposited pollen is known at Cape Cod sites, having come from deposits eroded by ice (Davis 1961).

Other types of fossil occurrences (uppermost Pleistocene–Holocene)

A locality near the Highland Light in CACO has long attracted interest from geologists because of its distinctive three-layer stratigraphy. Previously, the sediments were correlated to three formations described from Long Island, in ascending order the Jameco Gravel, Gardiners Clay, and Jacob Sand (Fuller 1914; Woodworth and Wigglesworth 1934). More recent studies found them to be glaciomarine deposits left by the recession of the Wisconsinan glacial lobes (Oldale 1979): a body of sea water was briefly trapped here between the Cape Cod Bay Lobe on the west, the South Channel

Lobe on the east, and Wellfleet Plain on the south (Fisher and Leatherman 1987). Hyyppä (1955) described the diatoms and conifer and angiosperm pollen in the "Gardiners Clay" at some length, and noted that similar microfossils were present in the overlying and underlying deposits. Hyyppä reported similar fossils from clay at Indian Neck, outside of CACO. Peat, conifer fragments (Sayles and Knox 1943), and fossil shells have also been found near the Highland Light (Oldale 1982).

Submerged remains of trees and other plants are not uncommon around Cape Cod. Tree stumps have been reported from south of the entrance to Hatches Harbor at the northwest end of Provincetown Hook below high water. Offshore submerged forests have also been reported by fishermen (Woodworth and Wigglesworth 1934). The movement of dunes in the Provincetown Hook has sometimes buried vegetated areas, and later movement of the dunes can expose these "fossil forests" (Oldale 2001). These are probably of no great age, given the relative youth of the Provincetown Hook.

Pebbles of peat sometimes wash up on CACO beaches near the Highland Light and other places on the Cape (Woodworth and Wigglesworth 1934). There is some possibility that other types of offshore fossils will wash up on CACO beaches during storms, as happens at other coastal NPS units (see the Assateague Island National Seashore and Gateway National Recreation Area chapters of this report for examples). The nearby seafloor has been known as a source of fossils since the 19th century (Upham 1879; Shaler 1898). The best nearby record is from Georges Bank, where Miocene–Pliocene marine fossils and Pleistocene vertebrates have been recovered via fishing and dredging operations (Upham 1879; Gibson 1965; Stanley et al. 1967). Because of the apparent absence of Cenozoic coastal plain deposits around Cape Cod due to glacial activity, it is unlikely that Miocene–Pliocene marine fossils will be washed up on CACO. Fossils of extinct Pleistocene mammals are a more likely possibility, teeth of proboscideans being relatively common (Stanley et al. 1967; Whitmore et al. 1967; Oldale et al. 1987, Oldale 2001). Shaler (1898) reported that unspecified fossils had been dredged from north and east of Cape Cod.

Park Collections

As of the original CACO fossil resource summary, there were no fossils in park collections (Kenworthy and Santucci 2003). There are probably some specimens and certainly some records in other institutions, but the information is not clear. Upham gave some of the pieces of fossiliferous drift he recovered in 1878 to the Boston Society of Natural History (Crosby 1879; Upham 1879). The total quantity was about 9 kg (20 lb) (Upham 1879). The Boston Society of Natural History is now known as the Museum of Science in Boston. (This institution has also been known as the New England Museum of Natural History and the Boston Museum of Science.) Violetta Wolf (Museum of Science assistant curator) located documentation concerning BSNH 2369, 20 pieces of fossiliferous marl collected from the drift at Truro and accessioned in October 1878. This material was later donated to the Museum of Comparative Zoology (MCZ) (Harvard; Cambridge, Massachusetts) (V. Wolf, pers. comm., May 2014). Querying the MCZ online database produces no appropriate results, but this does not mean that the fossils are not there.

The current provenance of Hollick's fossiliferous Cambrian fragments is unknown. They are not in the collections of the Staten Island Museum (E. Johnson, Staten Island Museum director of science,

pers. comm., April 2014). Some of his paleobotanical fossils were sent to the Yale Peabody Museum and the National Museum of Natural History, but nothing resembling the Cambrian fossils are in their online databases, and at any rate it is uncertain that these fossils would have gone with the paleobotany collection because they are clearly not plants. It is not stated where Hyyppä's diatoms and other microfossils are reposited, if at all. Marjorie Winkler's work is associated with the Center for Climatic Research at the University of Wisconsin–Madison, so records and other relevant material should be found there. The Cape Cod Museum of Natural History in Brewster includes fossils, but its records were being digitized as of April 2014, so the exact details of its collections were not accessible (K. Roderick, Cape Cod Museum of Natural History curator, pers. comm., April 2014).

Cultural Resource Contexts

CACO has abundant archeological resources, and many include remains of the contemporary Holocene flora and fauna (McManamon 1984, 2011). Shell middens are found throughout the outer Cape. Shell middens can be 2 to 50 cm (1 to 20 in) thick and cover 5 to 700 m^2 (54 to 7,530 ft^2). The bivalve *Mercenaria mercenaria* (quahog) is a common component. Many middens have been affected by plowing (Borstel 1984b). Although the archeological record of Cape Cod goes back at least 9,000 years, the most ancient sites are uncommon. Sites become abundant beginning in the Late Archaic cultural period (5,500 to 3,000 years ago). Shell middens are generally younger than 3,500 years old, and most are younger than about 1,700 years old (Borstel 1984c). We can assume that a major factor in the distribution of ages is the loss of coastal areas during the Holocene as sea level rose. Shellfish were clearly an important resource, and the coastal areas that would have held middle Holocene and older shell middens have been eroded, their geographic positions now offshore.

Shell middens often preserve not only the remains of harvested bivalves and snails, but also artifacts and the remains of flora and vertebrates. The shell middens help to preserve these objects by causing soil alkalinity (Hancock 1984). Typical floral and vertebrate remains in CACO middens include seeds, nuts, and the bones of fish, birds, and mammals (Fitzgerald 1984). Vertebrates found at CACO archeological sites include skates, sharks, various ray-finned fish, amphibians, turtles, snakes, raptors, loons, auks, ducks, geese, grebes, cormorants, turkeys, grouse, unidentifiable birds, beavers and other rodents, lagomorphs, canids, raccoons, skunks, mustelids, bear, seals, porpoises, and deer, as well as a few European domestic animals at sites with historic components (Spiess 2011). Pot hunting has occurred at the numerous archeological sites of outer Cape Cod (Borstel 1984b), so there is some risk of paleontological material being destroyed or stolen in the course of such activity. Other archeological sites with faunal components in eastern Massachusetts are described in Waters (1962, 1965), Eteson (1982), Grimes et al. (1984), and Bradley and Spiess (1994).

Artifacts found in outer Cape Cod are made from diverse materials, supplied from various parts of New England by glaciers. Some of these artifacts are made of fossiliferous materials, particularly quartzite, which accounted for about 13.6% of artifacts in a survey of 51,309 examples by Borstel (1984a). About 0.5% were made of chert, another potentially fossiliferous material. Borstel (1984a) also noted one artifact made from petrified wood. Although specifics concerning artifacts that include identifiable fossils are lacking, their presence in CACO would not be surprising.

Additionally, shell-tempered pottery is known from the Cape (Borstel 1984c). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- Seashore staff should be encouraged to observe the beaches and exposed sedimentary deposits for fossil material while conducting their usual duties. To promote this, they should also 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, seashore staff should take advantage of them, if funding and time permit.
- Staff should photodocument and monitor any occurrences of paleontological resources that may be observed in situ. In most NPS units, fossils and their associated geologic context (surrounding rock/sediment) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts. However, the rapid coastal erosion at CACO makes collection more important. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. 2009).
- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist. Any fossil with 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.
- Quaternary fossils and deposits are of interest because they can be used to describe the effects of past climate and sea level changes, and to predict natural responses to future changes. Further study of these fossils and deposits in and around CACO is encouraged.
- It could be of interest to educate visitors about the glacially transported fossils and to encourage them to report fossils to staff. There are many more visitor eyes than staff eyes, and shoreline erosion is rapid. Encouraging reporting of fossils would need to be weighed against the increased risk of unauthorized collection. Some arrangement with another institution may also be necessary to house the fossils. Brunner et al. (2010) discuss some of the issues related to coastal fossil theft, which have some relevance to a discussion about transported fossils.
- Fossils and other materials transported by glaciers could serve as an unusual educational resource, because they illustrate where the glaciers had been as well as the geologic history of much of New England. The glacial deposits are like a “sampler platter” of the geology of the region, with rocks from the ancient crystalline basement, various exotic terranes, Triassic rift valleys, Cretaceous and Cenozoic coastal plains, and Pleistocene marine basins.

- It may be worth going through the Cape Cod Museum of Natural History collections, although a visit may have to wait until digitization of records is complete.
- Contact the NPS Geologic Resources Division for technical assistance with paleontological resource management issues.

References Cited

Allen, G. M. 1920. Bison remains from New England. *Journal of Mammalogy* 1(4):161–164. Available at http://www.jstor.org/stable/1373305 (accessed April 2014).

Borstel, C. L. 1984a. Stones for tool-making: local resources and archeological observations. Pages 277–337 *in* F. P. McManamon, editor. Chapters in the archeology of Cape Cod, I (part II): results of the Cape Cod National Seashore archaeological survey, 1979-1981. National Park Service, Boston, Massachusetts. Available at http://www.nps.gov/caco/historyculture/upload/Chapters-in-the-Archeology-of-Cape-Cod-I-Volume-2.pdf (accessed April 2014).

Borstel, C. L. 1984b. Stratigraphy and archaeological context of prehistoric sites of Cape Cod National Seashore. Pages 181–229 *in* F. P. McManamon, editor. Chapters in the archeology of Cape Cod, I (part I): results of the Cape Cod National Seashore archaeological survey, 1979-1981. National Park Service, Boston, Massachusetts. Available at http://www.nps.gov/caco/historyculture/upload/Chapters-in-the-Archeology-of-Cape-Cod-1-Volume-1.pdf (accessed April 2014).

Borstel, C. L. 1984c. Prehistoric site chronology: a preliminary report. Pages 231–299 *in* F. P. McManamon, editor. Chapters in the archeology of Cape Cod, I (part I): results of the Cape Cod National Seashore archaeological survey, 1979-1981. National Park Service, Boston, Massachusetts. Available at http://www.nps.gov/caco/historyculture/upload/Chapters-in-the-Archeology-of-Cape-Cod-1-Volume-1.pdf (accessed April 2014).

Bradley, J. W. and A. E. Spiess. 1994 . Two shell middens on Indian Neck, Wellfleet, Massachusetts: the excavations of Fred A. Luce. *Bulletin of the Massachusetts Archaeological Society* 55(2):45–60.

Bratton, J. F. 2007. Holocene sedimentation in a kettle pond breached by rising sea level on Cape Cod. *Abstracts with Programs - Geological Society of America* 39(1):70.

Brunner, J., J. Kenworthy, and V. Santucci. 2010. Unauthorized fossil collecting from National Park Service shorelines: servicewide policy and perspectives. Pages 319–323 *in* S. Weber, editor. Rethinking protected areas in a changing world: proceedings of the 2009 George Wright Society Conference. The George Wright Society, Hancock, Michigan. Available at http://www.georgewright.org/0956brunner.pdf (accessed February 2014).

Chamberlain, B. B. 1967. Cape Cod. *Natural History* 76(5):24–33.

Crosby, W. P. 1879. On the occurrence of fossiliferous boulders of the drift of Truro, on Cape Cod, Massachusetts. *Proceedings of the Boston Society of Natural History* 20:136–141. Available at http://biodiversitylibrary.org/page/41799905 (accessed April 2014).

Cushman, J. A. 1904. Notes on the Pleistocene fauna of Sankaty Head, Nantucket, Massachusetts. *American Geologist* 34:169–174. Available at http://books.google.com/books?id=_vcNAQAAIAAJ&pg=PA169 (accessed April 2014).

Cushman, J. A. 1906. The Pleistocene deposits of Sankoty Head, Nantucket, and their fossils. Nantucket Maria Mitchell Association, Publication 1(1):1–21. Available at https://archive.org/details/pleistocenedepos00cushrich (accessed April 2014).

Davis, M. B. 1960. A late-glacial pollen diagram from Taunton, Massachusetts. *Bulletin of the Torrey Botanical Club* 87:258–270.

Davis, M. B. 1961. The problem of rebedded pollen in late-glacial sediments at Taunton, Massachusetts. *American Journal of Science* 259:211–222.

Davis, W. M. 1896. The outline of Cape Cod. Proceedings of the American Academy of Arts and Science 31:303–332. Available at http://biodiversitylibrary.org/page/8866655 (accessed April 2014).

Dunwiddie, P. W. 1989. Forest and health: the shaping of the vegetation on Nantucket Island. *Journal of Forest History* 33:126–133.

Dunwiddie, P. W., and G. M. MacDonald. 1988. Vegetation change and coastal erosion: palynological and geochemical evidence from Nantucket Island, Massachusetts. Program and Abstracts - American Quaternary Association. Conference 10:64.

Ekwurzel, B. 1990. A complex bayside beach: Herring Cove Beach, Cape Cod, Massachusetts, USA. *Journal of Coastal Research* 6(4):879–891.

Eteson, M. O. 1982. The Hayward's Portanimicutt site (19-BU-324). *Bulletin of the Massachusetts Archaeological Society* 43(1):6–31.

Finch, R. Undated. Cape Cod, its natural and cultural history. U.S. National Park Service Handbook 148.

Fisher, J. J. 1972. Field guide to geology of the Cape Cod National Seashore. University of Rhode Island, Providence, Rhode Island. Guidebook for the 5th annual meeting of the American Association of Stratigraphic Palynologists.

Fisher, J. J. 1987. Shoreline development of the glacial Cape Cod coastline. Pages 279–305 *in* D. M. Fitzgerald and P. S. Rosen, editors. Glaciated coasts. Academic Press, San Diego, California.

Fisher, J. J., and S. P. Leatherman. 1987. Glacial and coastal geology, Cape Cod National Seashore, Massachusetts. Pages 213–220 *in* D. C. Roy, editor. Northeastern section of the Geological Society of America. Geological Society of America, Boulder, Colorado. Centennial Field Guide 5.

Fitzgerald, J. 1984. Floral and faunal archeological remains. Pages 43–81 *in* F. P. McManamon, editor. Chapters in the archeology of Cape Cod, I (part II): results of the Cape Cod National Seashore archaeological survey, 1979-1981. National Park Service, Boston, Massachusetts. Available at http://www.nps.gov/caco/historyculture/upload/Chapters-in-the-Archeology-of-Cape-Cod-I-Volume-2.pdf (accessed April 2014).

Folger, D. W., J. C. Hathaway, R. A. Christopher, P. C. Valentine, and C. W. Poag. 1978. Stratigraphic test well, Nantucket Island, Massachusetts. U.S. Geological Survey, Washington, DC. Circular 773. Available at http://pubs.er.usgs.gov/publication/cir773 (accessed April 2014).

Fuller, M. L. 1914. The geology of Long Island, New York, U.S. Geological Survey, Washington, DC. Professional Paper 82. Scale 1:125000. Available at http://pubs.er.usgs.gov/publication/pp82 (accessed March 2014).

Gibson, T. G. 1965. Eocene and Miocene rocks off the northeastern coast of the United States. *Deep-Sea Research and Oceanographic Abstracts* 12(6):975–981.

Gleba, P. P. 1978. Massachusetts mineral and fossil localities. Krueger Enterprises, Inc., Cambridge, Massachusetts. Available at http://www.geo.umass.edu/stategeologist/Gleba_Mass_Fossil-Min_Localities.pdf (accessed April 2014).

Goldsmith, R., and E. G. A. Weed. 1991. Stratigraphy of the Milford-Dedham Zone, eastern Massachusetts: an Avalonian terrane. Pages E1–E62 *in* N. L. Hatch, Jr., editor. The bedrock geology of Massachusetts. U.S. Geological Survey, Reston, Virginia. Professional Paper 1366 E–J. Available at http://pubs.er.usgs.gov/publication/pp1366EJ (accessed April 2014).

Graham, J. 2008. Geologic resource evaluation scoping summary: Cape Cod National Seashore, Massachusetts. National Park Service, Geologic Resources Division, Denver, Colorado. Available at http://www.nature.nps.gov/geology/inventory/publications/s_summaries/CACO_scoping_summary_20081223.pdf (accessed February 2014).

Grimes, J. R., W. Eldridge, B. Grimes, V. Vaccaro, F. Vaccaro, J. Vaccaro, N. Vaccaro, and A. Orsini. 1984. Bull Brook II. *Archaeology of eastern North America* 12:159–183.

Hancock, M. E. 1984. Shellfish distribution on prehistoric archeological sites, outer Cape Cod. Pages 83–120 *in* F. P. McManamon, editor. Chapters in the archeology of Cape Cod, I (part II): results of the Cape Cod National Seashore archaeological survey, 1979-1981. National Park Service, Boston, Massachusetts. Available at http://www.nps.gov/caco/historyculture/upload/Chapters-in-the-Archeology-of-Cape-Cod-I-Volume-2.pdf (accessed April 2014).

Hartshorn, J. H., R. N. Oldale, and C. Koteff. 1967. Preliminary report on the geology of the Cape Cod National Seashore. Pages 49–58 *in* O. C. Farquhar, editor. Economic geology in Massachusetts: proceedings. University of Massachusetts, Amherst, Massachusetts.

Hollick, C. A. 1902. Geological and botanical notes: Cape Cod and Chappaquidick Island, Massachusetts. *Bulletin of the New York Botanical Garden* 2:381–406. Available at http://biodiversitylibrary.org/page/5895678 (accessed April 2014).

Hyyppä, E. 1955. On the Pleistocene geology of southeastern New England. Bulletin de la Commission Géologique de Finlande 167.

Kenworthy, J. P., and V. L. Santucci. 2003. George Washington Birthplace National Monument. Pages 10–12 *in* J. P. Kenworthy and V. L. Santucci. Paleontological resource inventory and monitoring: Northeast Coastal and Barrier Network. TIC# D-340. National Park Service, Denver, Colorado.

Kenworthy, J. P., and V. L. Santucci. 2006. A preliminary investigation of National Park Service paleontological resources in cultural resource contexts, Part 1: general overview. Pages 70–76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf (accessed January 2014).

Koteff, C., and J. E. Cotton. 1962. Preliminary results of recent deep drilling on Cape Cod, Massachusetts. *Science* 137(3523):34.

Koteff, C., R. N. Oldale, and J. H. Hartshorn. 1967. Geologic map of the North Truro quadrangle, Barnstable County, Massachusetts. U.S. Geological Survey, Washington, DC. Geologic Quadrangle Map 599. Scale 1:24,000. Available at http://pubs.er.usgs.gov/publication/gq599 (accessed April 2014).

Leatherman, S. P., editor. 1979. Environmental geologic guide to Cape Cod National Seashore. University of Massachusetts, Amherst, Massachusetts. Field trip guidebook for the Eastern Section of the Society of Economic Paleontologists and Mineralogists.

Leatherman, S. P. 1987. Reworking of glacial outwash sediments along outer Cape Cod; development of Provincetown Spit. Pages 307–325 *in* D. M. Fitzgerald and P. S. Rosen, editors. Glaciated coasts. Academic Press, San Diego, California.

Leo, G. W., J. K. Mortensen, B. Barreiro, and J. D. Phillips. 1993. Petrology and U-Pb geochronology of buried Avalonian plutonic rocks on southeastern Cape Cod. *Atlantic Geology* 29(2):103–113.

Maio, C. V., A. Gontz, C. Weidman, and J. Donnelly. 2013. A drowned paleo-forest along a Cape Cod barrier beach: lessons from the past, Mashpee, Massachusetts, USA. *Abstracts with Programs - Geological Society of America* 45(1):114.

McManamon, F. P., editor. 1984. Chapters in the archeology of Cape Cod, I: Results of the Cape Cod National Seashore archaeological survey, 1979-1981. National Park Service, Boston, Massachusetts. Available at http://www.nps.gov/caco/historyculture/upload/Chapters-in-the-Archeology-of-Cape-Cod-1-Volume-1.pdf and http://www.nps.gov/caco/historyculture/upload/Chapters-in-the-Archeology-of-Cape-Cod-I-Volume-2.pdf (accessed April 2014).

McMananon, F. P., editor. 2011. Chapters in the archeology of Cape Cod, IV: faunal analysis and metallurgical analysis from the Cape Cod National Seashore archeological survey. Cape Cod National Seashore, National Park Service, Department of the Interior, Wellfleet, Massachusetts. Available at http://www.nps.gov/caco/historyculture/upload/ChaptersintheArcheologyofCapeCodVolumeIVforweb.pdf (accessed April 2014).

McManamon, F. P. and C. L. Borstel. 1984. The natural environment and natural resources. Pages 85–115 *in* F. P. McManamon, editor. Chapters in the archeology of Cape Cod, I (part I): results of the Cape Cod National Seashore archaeological survey, 1979-1981. National Park Service, Boston, Massachusetts. Available at http://www.nps.gov/caco/historyculture/upload/Chapters-in-the-Archeology-of-Cape-Cod-1-Volume-1.pdf (accessed April 2014).

Mulligan, A. E., and E. Uchupi. 2004. Wisconsinan glacial lake sediments in the subsurface of Cape Cod, Massachusetts. *Northeastern Geology and Environmental Sciences* 26(3):188–201.

National Park Service (NPS), Geologic Resources Inventory Program. 2009. Digital geologic map of Cape Cod National Seashore and vicinity, Massachusetts (NPS, GRD, GRI, CACO, CACO digital map). NPS Geologic Resources Inventory Program. Lakewood, Colorado. Geospatial Dataset-1048646. Available at https://irma.nps.gov/App/Reference/Profile?Code=1048646 (accessed March 2014).

Newby, P., P. Killoran, M. Waldorf, and T. Webb, III. 1994. 11,500 yrs of sediment, vegetation and water level changes at Makepeace Cedar Swamp, southeastern Massachusetts. Program and Abstracts - American Quaternary Association. Conference 13:145.

Newby, P. E., P. Killoran, M. R. Waldorf, B. N. Shuman, R. S. Webb, and T. Webb, III. 2000. 14,000 years of sediment, vegetation, and water-level changes at the Makepeace Cedar Swamp, southeastern Massachusetts. *Quaternary Research* 53(3):352–368.

Newby, P. E., J. P. Donnelly, B. N. Shuman, and D. MacDonald. 2009. Evidence of centennial scale drought from southeastern Massachusetts during the Pleistocene/Holocene transition. *Quaternary Science Reviews* 28(17–18):1675–1692.

O'Keefe, J. F., and W. A. Patterson, III. 1980. The vegetation history of the Pamet Cranberry Bog, North Truro, Massachusetts. Program and Abstracts - American Quaternary Association. Conference 6:150.

Ogden, J. G., III. 1959. A late-glacial pollen sequence from Martha's Vineyard, Massachusetts. *American Journal of Science* 257(5):366–381.

Oldale, R. N. 1968. Geologic map of the Wellfleet quadrangle, Barnstable County, Cape Cod, Massachusetts. U.S. Geological Survey, Washington, DC. Geologic Quadrangle Map 750. Scale 1:24,000. Available at http://pubs.er.usgs.gov/publication/gq750 (accessed April 2014).

Oldale, R. N. 1970. Geologic map of the Chatham quadrangle, Barnstable County, Cape Cod, Massachusetts. U.S. Geological Survey, Washington, DC. Geologic Quadrangle Map 911. Scale 1:24,000. Available at http://pubs.er.usgs.gov/publication/gq911 (accessed April 2014).

Oldale, R. N. 1976a/undated update. Geologic history of Cape Cod, Massachusetts. U.S. Geological Survey, Washington, DC. General Interest Publication. Available at http://pubs.er.usgs.gov/publication/7000013 or http://pubs.usgs.gov/gip/capecod/ (accessed April 2014).

Oldale, R. N. 1976b. Generalized geologic map of Cape Cod. U.S. Geological Survey, Washington, DC. Open-File Report 76-765.

Oldale, R. N. 1979. Glacial deposits and features of outer Cape Cod. Pages 41–54 *in* S. P. Leatherman, editor. Environmental geologic guide to Cape Cod National Seashore. University of Massachusetts, Amherst, Massachusetts. Field trip guidebook for the Eastern Section of the Society of Economic Paleontologists and Mineralogists.

Oldale, R. N. 1982. Pleistocene stratigraphy of Nantucket, Martha's Vineyard, the Elizabeth Islands, and Cape Cod, Massachusetts. Pages 1–34 *in* G. J. Larson and B. D. Stone, editors. Late Wisconsinan glaciation of New England. Kendall-Hunt Publishing Co., Dubuque, Iowa.

Oldale, R. N. 1988. A late Wisconsinan marine incursion into Cape Cod Bay, Massachusetts. *Quaternary Research* 30(3):237–250.

Oldale, R. N. 1992. Cape Cod and the Islands, the geologic story. Parnassus Imprints, East Orleans, Massachusetts.

Oldale, R. N. 2001. Cape Cod, Martha's Vineyard, and Nantucket: the geologic story. On Cape Publications, Yarmouth Port, Massachusetts. Available at http://woodshole.er.usgs.gov/staffpages/boldale/geology.pdf (accessed April 2014). Revised version of Oldale, R. N. 1992. Cape Cod and the Islands, the geologic story. Parnassus Imprints, East Orleans, Massachusetts.

Oldale, R. N., and R. A. Barlow. 1986. Geologic map of Cape Cod and the Islands, Massachusetts. U.S. Geological Survey, Reston, Virginia. Miscellaneous Investigations Series Map 1763. Scale 1:100,000. Available at http://pubs.er.usgs.gov/publication/i1763 (accessed April 2014).

Oldale, R. N., and S. M. Colman. 1992. On the age of the penultimate full glaciation of New England. Pages 163–170 *in* P. U. Clark and P. D. Lea, editors. The last interglacial-glacial transition in North America. Geological Society of America, Boulder, Colorado. Special Paper 270.

Oldale, R. N., and C. J. O'Hara. 1984. Glaciotectonic origin of the Massachusetts coastal end moraines and a fluctuating late Wisconsinan ice margin. *Geological Society of America Bulletin* 95(1):61–74.

Oldale, R. N., C. Koteff, and J. H. Hartshorn. 1971. Geologic map of the Orleans quadrangle, Barnstable County, Cape Cod, Massachusetts. U.S. Geological Survey, Washington, DC. Geologic Quadrangle Map 931. Scale 1:24,000. Available at http://pubs.er.usgs.gov/publication/gq931 (accessed April 2014).

Oldale, R. N., P. C. Valentine, T. M. Cronin, E. C. Spiker, B. W. Blackwelder, D. F. Belknap, J. F. Wehmiller, and B. J. Szabo. 1982. Stratigraphy, structure, absolute age, and paleontology of the upper Pleistocene deposits at Sankaty Head, Nantucket Island, Massachusetts. *Geology* 10(5):246–252.

Oldale, R. N., F. C. Whitmore, Jr., and J. R. Grimes. 1987. Elephant teeth from the Western Gulf of Maine, and their implications. *National Geographic Research* 3:439–446.

Oldale, R. N., J. V. O'Connor, B. B. Tormey, and R. S. Williams, Jr. 1993. A geologic overview of Cape Cod and a geologic transect of Wellfleet from the Atlantic Ocean to Cape Cod Bay. U.S. Geological Survey, Reston, Virginia. Open-File Report 93-618. Available at http://pubs.er.usgs.gov/publication/ofr93618 (accessed April 2014).

Poppe, L. J., D. S. Foster, and W. W. Danforth. 2006. Character and distribution of exposed glaciodeltaic deposits off outer Cape Cod, Massachusetts, and their effects on hydrogeology and benthic habitats. *Geo-Marine Letters* 26(1):51–57.

Portnoy, J. W., M. G. Winkler, P. R. Sanford, and C. N. Farris. 2001. Kettle Pond Data Atlas: paleoecology and modern water quality. Cape Cod National Seashore, National Park Service, U.S. Department of the Interior. Available at http://www.nps.gov/caco/naturescience/upload/Pondatlasfinal.pdf (accessed April 2014).

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado.

Sayles, R. W. 1939. Upper till, two boulder clays, and interglacial flora on Cape Cod. *Geological Society of America Bulletin* 50(12, part 2):1931–1932.

Sayles, R. W., and A. S. Knox. 1943. Fossiliferous tills and intertill beds of Cape Cod, Massachusetts. *Geological Society of America Bulletin* 54(10):1569–1612.

Shaler, N. S. 1898. Geology of the Cape Cod district. U.S. Geological Survey, Washington, DC. Eighteenth Annual Report, Part 2:497–593. Available at https://archive.org/details/geologycapecodd00shalgoog (accessed April 2014).

Spiess, A. 2011. Cape Cod National Seashore archeological survey faunal analysis. Pages 13–61 *in* F. P. McMananon, editor. Chapters in the archeology of Cape Cod, IV: faunal analysis and metallurgical analysis from the Cape Cod National Seashore archeological survey. Cape Cod National Seashore, National Park Service, Department of the Interior, Wellfleet, Massachusetts. Available at http://www.nps.gov/caco/historyculture/upload/ChaptersintheArcheologyofCapeCodVolumeIVforweb.pdf (accessed April 2014).

Stanley, D. J., D. J. P. Swift, and H. G. Richards. 1967. Fossiliferous concretions on Georges Bank. *Journal of Sedimentary Petrology* 37(4):1070–1083.

Stone, B. D., and M. L. DiGiacomo-Cohen. 2006. Surficial geologic map of the Pocasset-Provincetown-Cuttyhunk-Nantucket 24-Quadrangle area of Cape Cod and islands, southeast Massachusetts. U.S. Geological Survey, Reston, Virginia. Open-File Report 2006-1260-E. Available at http://pubs.usgs.gov/of/2006/1260/E/ (accessed April 2014).

Strahler, A. N. 1966. A geologist's view of Cape Cod. Natural History Press, Garden City, New York.

Suter, S. M. 1985. Late-glacial and Holocene vegetation history in southeastern Massachusetts: a 14,000 year pollen record. *Current Research in the Pleistocene* 2:87–89.

Torsvik, T. H. and L. R. M. Cocks. 2013. New global palaeogeographical reconstructions for the Early Palaeozoic and their generation. Pages 5–24 in D. A. T. Harper and T. Servais, editors. Early Palaeozoic biogeography and palaeogeography. The Geological Society of London, London, U.K. Memoir 38.

Tzedakis, P. C. 1988. Paleoecological investigation of a mesic site on Cape Cod, Massachusetts. Program and Abstracts - American Quaternary Association. Conference 10:158.

Tzedakis, P. C. 1992. Effects of soils on the Holocene history of forest communities, Cape Cod, Massachusetts, U.S.A. *Geographie Physique et Quaternaire* 46(1):113–124.

Uchupi, E., and A. E. Mulligan. 2006. Late Pleistocene stratigraphy of upper Cape Cod and Nantucket Sound, Massachusetts. *Marine Geology* 227(1–2):93–118.

Uchupi, E., G. S. Giese, D. G. Aubrey, and D. J. Kim. 1996. The late Quaternary construction of Cape Cod, Massachusetts: a reconsideration of the W. M. Davis model. Geological Society of America, Boulder, Colorado. Special Paper 309.

Upham, W. 1879. The formation of Cape Cod. *American Naturalist* 13:489–502, 552–565. Available at http://biodiversitylibrary.org/page/41038546 (accessed April 2014).

Waters, J. H. 1962. Some animals used as food by successive cultural groups in New England. *Bulletin of the Archaeological Society of Connecticut* 31:29–46.

Waters, J. H. 1965. Animal remains from some New England Woodland sites. *Bulletin of the Archaeological Society of Connecticut* 33:5–11.

Whitmore, F. C., Jr., K. O. Emery, H. B. S. Cooke, and D. J. P. Swift. 1967. Elephant teeth from the Atlantic Continental Shelf. *Science* 156(3781):1477–1481.

Wilson, J. H. 1905. The Pleistocene formations of Sankaty Head, Nantucket. *Journal of Geology* 13:713-734. Available at http://www.jstor.org/stable/30066332 (accessed April 2014).

Winkler, M. G. 1982. Late-glacial and postglacial vegetation history of Cape Cod and the paleolimnology of Duck Pond, South Wellfleet, Massachusetts. Thesis. University of Wisconsin-Madison, Madison, Wisconsin.

Winkler, M. G. 1985. A 12,000 year history of vegetation and climate for Cape Cod, Massachusetts. *Quaternary Research* 23(3):301–312.

Winkler, M. G. 1988. Paleolimnology of a Cape Cod kettle pond: diatoms and reconstructed pH. *Ecological Monographs* 58(3):197–214.

Winkler, M. G. 1989. Geologic, chronologic, biologic, and chemical evolution of the acid kettle ponds within the Cape Cod National Seashore. Report to the National Park Service, North Atlantic Region.

Winkler, M. G. 1992. Development of parabolic dunes and interdunal wetlands in the Provincelands, Cape Cod National Seashore. Pages 57–64 *in* C. H. Fletcher, III and J. F. Wehmiller, editors. Quaternary coasts of the United States: marine and lacustrine systems. Society of Economic Paleontologists and Mineralogists, Tulsa, Oklahoma Special Publication 48.

Winkler, M. G. 1997. Late Quaternary climate, fire, and vegetation dynamics. Pages 329–346 *in* J. S. Clark, H. Cachier, J. G. Goldammer, and D. J. Stocks, editors. Sediment records of biomass burning and global change. Springer-Verlag, Berlin, Germany.

Winkler, M. G., and P. R. Sanford. 1994. Coastal Massachusetts pond development: edaphic, climatic, and sea level impacts since deglaciation. Program and Abstracts - American Quaternary Association. Conference 13:258.

Winkler, M. G., and P. R. Sanford. 1995. Coastal Massachusetts pond development: edaphic, climatic, and sea level impacts since deglaciation. *Journal of Paleolimnology* 14:311–336.

Woodworth, J. B., and E. Wigglesworth. 1934. Geography and geology of the region including Cape Cod, the Elizabeth Islands, Nantucket, Marthas Vineyard, No Mans Land, and Block Island. Museum of Comparative Zoology Memoirs 52. Available at http://www.biodiversitylibrary.org/bibliography/49347#/summary (accessed April 2014).

Zeigler, J. M., W. S. Hoffmeister, G. Giese, and H. Tasha. 1960. Discovery of Eocene sediments in subsurface of Cape Cod. *Science* 132(3437):1397–1398.

Zeigler, J. M., S. D. Tuttle, H. J. Tasha, and G. S. Giese. 1964. Pleistocene geology of outer Cape Cod, Massachusetts. *Geological Society of America Bulletin* 75(8):705–714.

Additional References

Aubrey, D. G., D. C. Twichell, and S. L. Pfirman. 1982. Holocene sedimentation in the shallow nearshore zone off Nauset Inlet, Cape Cod, Massachusetts. *Marine Geology* 47(3–4):243–259.

Byers, D. S. 1954. Bull Brook—a fluted point site in Ipswich, Massachusetts. *American Antiquity* 19(4):343–351.

Byers, D. S. 1959. Radiocarbon dates for the Bull Brook site, Massachusetts. *American Antiquity* 24(4, Part 1):427–429.

Cross, V. A., J. F. Bratton, J. Crusius, J. A. Colman, and T. D. McCobb. 2008. Submarine hydrogeological data from Cape Cod National Seashore. U.S. Geological Survey, Reston, Virginia. Open-File Report 2006-1169. Available at http://pubs.er.usgs.gov/publication/ofr20061169 (accessed April 2014).

Ellwood, B. B. 1996. Geology and America's National Park areas. Prentice Hall, Upper Saddle River, New Jersey.

Frey, D. G. 1964. Remains of animals in Quaternary lake and bog sediments and their interpretation. Archiv für Hydrobiologie, Egebnisse der Limnologie 2.

Hancock, M. E. 1984. Analysis of shellfish remains: seasonality information. Pages 121–156 *in* F. P. McManamon, editor. Chapters in the archeology of Cape Cod, I (part II): results of the Cape Cod National Seashore archaeological survey, 1979-1981. National Park Service, Boston, Massachusetts. Available at http://www.nps.gov/caco/historyculture/upload/Chapters-in-the-Archeology-of-Cape-Cod-I-Volume-2.pdf (accessed April 2014).

Hay, O. P. 1923. The Pleistocene of North America and its vertebrated animals from the states east of the Mississippi River and from the Canadian provinces east of longitude 95 degrees. Carnegie Institution of Washington, Washington, D.C. Publication 322. Available at https://archive.org/details/pleistoceneofnor00hayouoft (accessed January 2014).

Hunt, R. K., J. P. Kenworthy, and V. L. Santucci. 2006. A preliminary inventory of fossil fish from National Park Service units. Pages 63–69 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://www.nature.nps.gov/GEOLOGY/paleontology/pub/fossil_conference_7/8%20Hunt%202.pdf (accessed February 2014).

Kaye, C. A. 1967. Fossiliferous bauxite in glacial drift, Martha's Vineyard, Massachusetts. *Science* 157(3792):1035–1037.

Larson, G. J., and B. D. Stone, editors. 1982. Late Wisconsinan glaciation of New England. Kendall-Hunt Publishing Co., Dubuque, Iowa.

Mather, K. F., R. P. Goldthwait, and L. R. Thiesmeyer. 1942. Pleistocene geology of western Cape Cod, Massachusetts. *Geological Society of America Bulletin* 53(8):1127–1174.

Mayor, A. 2005. Fossil legends of the first Americans. Princeton University Press, Princeton, New Jersey.

Ockay, C., and J. F. Hubert. 1989. Petrology of Pleistocene and Holocene sands of outer Cape Cod. *Abstracts with Programs - Geological Society of America* 21(2):55.

Oldale, R. N., investigator. 1980. Glacial stratigraphy of Cape Cod, Nantucket, and Martha's Vineyard, Massachusetts. U.S. Geological Survey, Washington, DC. Professional Paper 1175:65–66. Available at http://pubs.er.usgs.gov/publication/pp1175 (accessed April 2014).

Olsen, S. J. 1971. Zooarchaeology: animal bones in archaeology and their interpretation. Addison-Wesley Publishing Company, New York City, New York.

Schafer, J. P., and J. H. Hartshorn. 1965. The Quaternary of New England. Pages 113–128 *in* H. E. Wright, Jr. and D. G. Frey, editors. The Quaternary of the United States. Princeton University Press, Princeton, New Jersey.

Skehan, J. W. 2001. Roadside geology of Massachusetts. Mountain Press Publishing Company, Missoula, Montana.

Wilson, J. H. 1906. The glacial history of Nantucket and Cape Cod. Columbia University Geological Series 1. Available at http://books.google.com/books?id=S9q7AAAAIAAJ (accessed April 2014).

Winkler, M. G. 1985. Charcoal analysis for paleoenvironmental interpretation: a chemical assay. *Quaternary Research* 23:313–326.

Winkler, M. G. 1985. Diatom evidence of environmental changes in wetlands: Cape Cod National Seashore. Report to the North Atlantic Regional Office, National Park Service.

Winkler, M. G. 1994. Development of the Gull Pond chain of lakes and the Herring River Basin, Cape Cod National Seashore. Technical report to the National Park Service, North Atlantic Region. NPS/NAROSS/NRTR/95-27.

Winkler, M. G. 1997. Late Quaternary climate, fire, and vegetation dynamics. Pages 329–346 *in* J. S. Clark, H. Cachier, J. G. Goldammer, and B. J. Stocks, editors. Sediment records of biomass burning and global change. Springer-Verlag, Berlin, Germany.

Winkler, M. G. 1997. The development of Ryder Pond in the Cape Cod National Seashore and determination of the causes of recent Ryder pondwater chemistry changes. Technical Report to the National Park Service, North Atlantic Regional Office. NPS/NESO-RNR/NRTR/97-01.

Data Sets

Cape Cod National Seashore Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Cape Cod National Seashore Digital Geologic Map
2009–present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online. https://irma.nps.gov/App/Reference/Profile?Code=1048646.

Cape Cod Museum of Natural History
20th century–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by CCMNH staff; status: Active.

Museum of Comparative Zoology (former collections of the Boston Society of Natural History)
Post-1878–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by MCZ staff; status: Active?

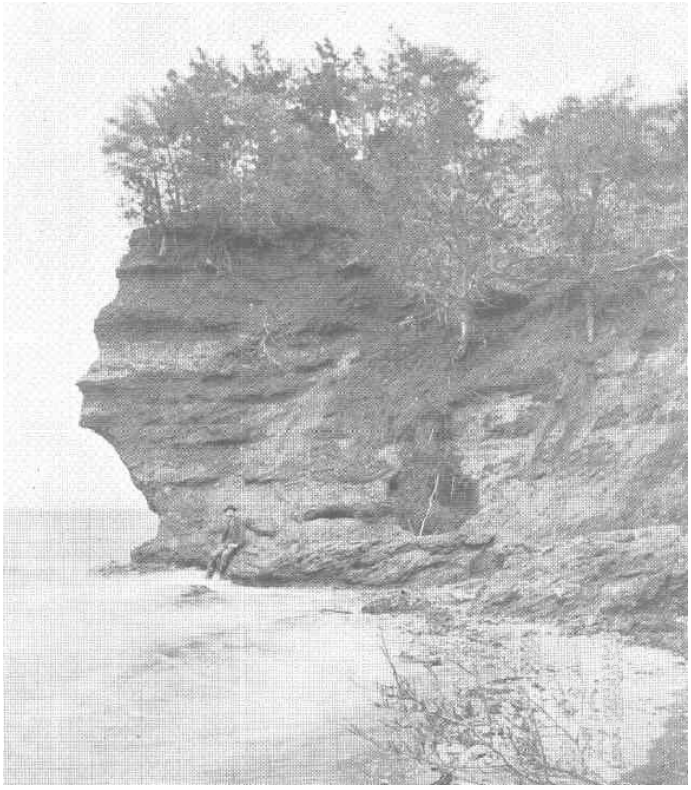
Museum of Science (originally Boston Society of Natural History)
1878–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by BSNH staff; status: Active.

University of Wisconsin–Madison Center for Climatic Research
1982–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by UW–Madison staff; status: Active.

Colonial National Historical Park

Colonial National Historical Park (COLO) in southeastern Virginia links several important sites from the colonial period of American history. At the southwest end is Jamestown, site of the first permanent English settlement in the Americas (1607). At the east end is Yorktown, site of the famous Revolutionary War engagement (1781) that led to the surrender of the British Army and the beginning of the negotiations that ended the war and secured American independence. The two are connected by the 37-km (27-mile) Colonial Parkway, which passes through Williamsburg, another important colonial-era site (it was the capital of Virginia from 1699 to 1776, succeeding Jamestown). The Jamestown portion is sometimes identified as Historic Jamestowne (JAME), and the Yorktown section is sometimes identified as Yorktown Battlefield (YONB). The area is also noted for Civil War history; Yorktown and Williamsburg were sites of Civil War battles in 1862 during the Peninsula Campaign, and Yorktown National Cemetery was established for Civil War burials. There are also two detached units: Green Spring Plantation west of Jamestown, and Cape Henry Memorial (CAME) in Virginia Beach, which commemorates the first landing of the Jamestown expedition in 1607.

COLO also has an important place in the history of American paleontology. Objects now recognized as fossils have been reported from the COLO area for hundreds of years, particularly in the bluffs and cliffs along the York River (COLO Figure 1), and it is likely that the first illustrated fossil from North America came from the Yorktown Formation of the Yorktown area.



COLO Figure 1. A cliff in the Yorktown Formation near Yorktown on the York River (Clark et al. 1912). Most of the York River shore is now covered in riprap.

Colonial National Monument was authorized July 3, 1930 and established December 30, 1930. It was redesignated as Colonial National Historical Park June 5, 1936. It has had numerous boundary changes: August 22, 1933; June 5, 1936; June 15, 1938; December 24, 1942; April 22, 1944; December 23, 1944; May 12, 1948; September 23, 1950; May 13, 1953; March 29, 1956; August 29, 1967; and November 12, 1996. Today, COLO encompasses 3,511.42 ha (8,676.91 acres), of which all but 27.39 ha (67.69 acres) are federal.

Geologic Background

Aside from the detached CAME unit, COLO follows an approximately east-west line across the central York–James Peninsula (or Virginia Peninsula) of Virginia, so named because it is bracketed on the north by the York River and on the south by the James River (COLO Figure 2). Both rivers are also estuaries in this area, draining into the nearby Chesapeake Bay, itself a much larger estuary leading into the Atlantic Ocean. All of COLO is within the coastal plain of Virginia. The majority of COLO is in James City County and York County, with small parcels in Surry County and the independent city of Virginia Beach (CAME). The geology and paleontology of COLO and Yorktown have been described in numerous publications, although the pace has slowed since construction and shore protection have obscured many areas of outcrops. Important references include Lincoln (1783), Mitchill (1818), Say (1824), Rogers and Rogers (1837), Clark et al. (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), and Ward (1993). The NPS Geologic Resources Division coordinated a Geologic Resource Inventory workshop for COLO in August 2005 (Thornberry-Ehrlich 2005). The initial paleontological resource inventory and summary was prepared by Kenworthy and Santucci (2003).

Eastern Virginia has been tectonically quiet since North America rifted from Africa and Europe in the early Mesozoic (see the Appendix for a geologic time scale). There has been one major disruption of the rocks and sediments since then: around 35 Ma, a meteor impacted the future Chesapeake Bay (Poag 1997; Johnson et al. 1998; Powars and Bruce 1999). The resulting crater was up to 90 km (56 miles) across and 1.3 km (0.8 miles) deep, with an area of 6,400 km^2 (2,500 $miles^2$) (Poag 1997) (but see Collins and Wünnermann [2005], which interprets the original structure as less than half that size). The outer rim of the structure passes through Yorktown. The Cretaceous, Paleocene, and Eocene sediments where the meteor struck were completely disrupted, forming a breccia that puzzled researchers for decades. A lens of salty water entered the breccia, explaining the salinity of the groundwater in the area. The crater formed a topographic low that persisted into the Pleistocene, creating a distinct depositional basin and influencing the geography of Chesapeake Bay and the courses of the York and James rivers (Poag 1997). Blocks of sediment slumped into the crater over tens of millions of years, leading to angular unconformities (flat-lying sediments deposited over tilted sediments). Shoals formed on the up-rotated ends of these slumping blocks (Johnson et al. 1998).

The deposits exposed within COLO generally formed in shallow marine, estuarine, and fluvial settings between approximately 11 Ma (million years ago) and the present. The Late Miocene-age Eastover Formation and Pliocene-age Yorktown Formation are dominantly marine, while the various Pleistocene units correspond to brief episodes of heightened sea levels that turned rivers into estuaries and, in some cases, shallow seas. The depositional setting of the Eastover and Yorktown formations was a mosaic of marine shelf, marginal marine, and nonmarine deposits, with deposition shifting from the Salisbury Embayment associated with Maryland and Virginia to the Albemarle Embayment associated with North Carolina (Newell and Rader 1985). The Eastover Formation, deposited in two distinct episodes, includes an older cooler open marine phase and a younger subtropical shallow marine phase (Ward and Blackwelder 1980). The Yorktown Formation is also the result of multiple marine transgressions over the land and includes deposits from many different

settings, including open shallow marine, restricted marine (lagoons or bays), shell reefs, barrier bars, and others (Ward and Blackwelder 1980; Campbell 1993).

Units deposited after the Yorktown Formation present complicated stratigraphy, and terminology is subject to frequent revisions. Many older references use a system of terrace-formations, named after coastal plain marine references (Johnson et al. 1981). The post-Yorktown Formation deposits have complex cut-and-fill relationships, and nowhere is there a complete sequence. Each period of deposition, and thus each formation, is separated from the others by a period of erosion (Bick and Coch 1969). Between marine transgressions, lower sea levels led to deep paleochannels and eroded surfaces. Complex sequences of scarps and fills formed, featuring a handful of similar fluvial-estuarine-restricted marine units. One interesting characteristic is that the youngest deposits are found at the lowest elevations, close to sea level along the rivers, because of the cut-and-fill nature of the seal-level-driven erosion and deposition. The nature of deposition also means that the distribution of these units is complex, and depends greatly on the extent of erosion before and after a unit was deposited.

An important environmental factor at work during the deposition of the sediments in and around COLO is the onset of glaciation. Changes in the size of the polar ice sheets affected the climate and sea level, and thus what organisms were present and when and where deposition occurred. In the marine environment, warming during the Pliocene led to the appearance of subtropical faunas, recorded in the Yorktown Formation (Williams et al. 2009). Cooling after this led to significant local extinctions over the Pleistocene (Stanley 1986). The marine climate was further affected by tectonics; ocean circulation was cut off at Central America and the Mediterranean during deposition of the Eastover and Yorktown formations (Whitmore 1994). On land, the climate varied from warmer than the present (6 to 5 Ma, for example) to cooler than the present (2.3 to 2.0 Ma, for example, approximately the time of the Bacons Castle Formation) (Groot 1991). During the deposition of the Bacons Castle Formation, shorelines transitioned from being controlled by tectonics to being controlled by the effects of glaciation on sea level. At the end of the transition, a more modern drainage system and coastline appeared. Previously, the coast had been straighter, but the new lower sea level and increased sediment supply gave it a much different form (Ramsey 1992). Sea level rose during interglacials and fell during glacial episodes. After the end of the last glacial episode, humans arrived in eastern Virginia. People have been present at Jamestown and the vicinity for at least 10,000 years (NPS 2001).

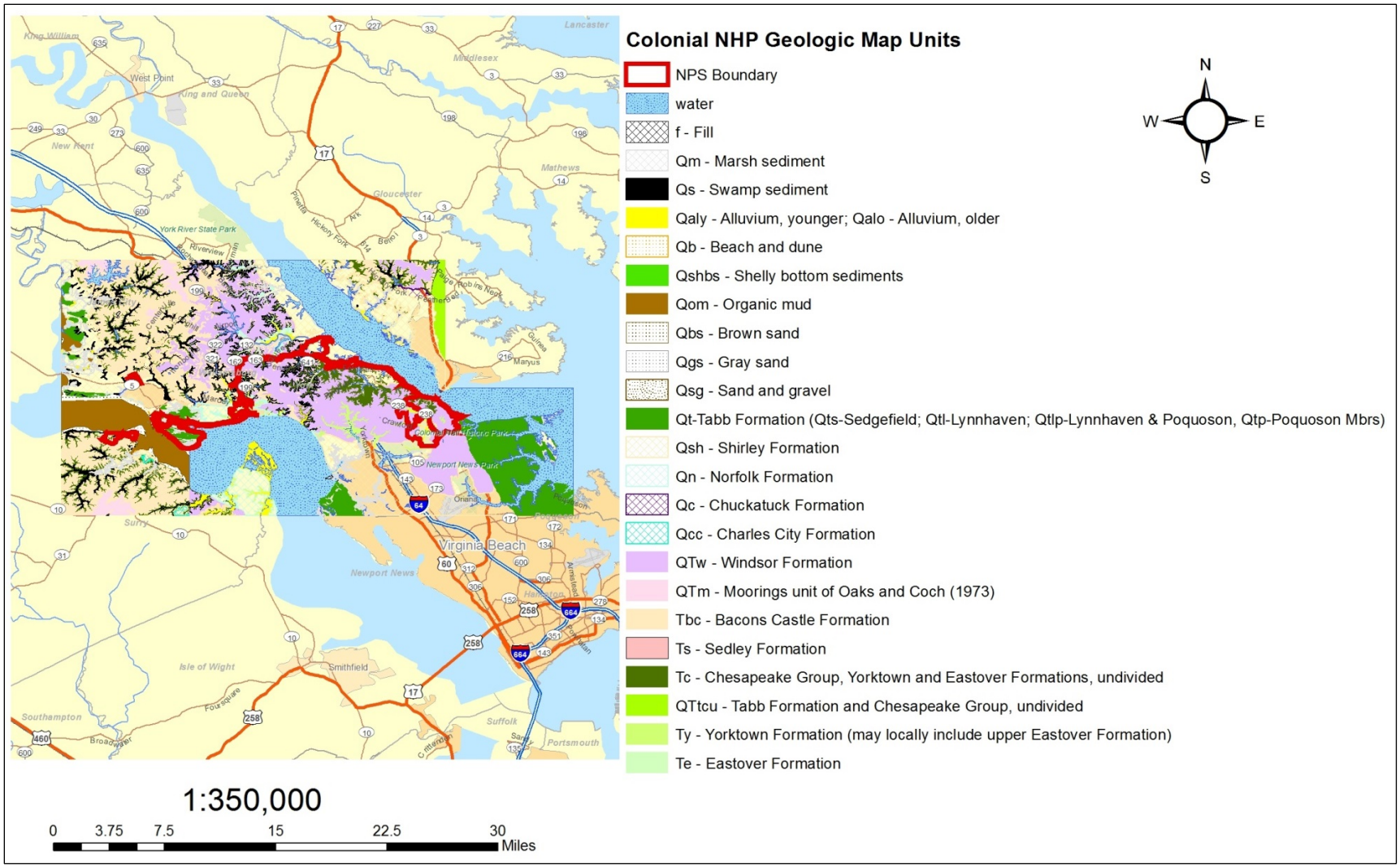
Geological formations exposed within COLO include, in ascending order, the following: the Eastover Formation (Upper Miocene) and Yorktown Formation (Pliocene) of the Chesapeake Group; the Bacons Castle Formation (lower Pleistocene); the Windsor Formation (lower or middle Pleistocene); the Chuckatuck Formation (lower or middle Pleistocene); the Shirley Formation (middle Pleistocene); the Tabb Formation (upper Pleistocene); and unnamed Quaternary sediments (upper Pleistocene–Holocene) (COLO Figure 3) (Bick and Coch 1969; Johnson 1972; Johnson and Berquist 1989; Mixon et al. 1989). Two formations have been omitted as outdated: the Sedley Formation, now considered a weathering horizon at the top of the Yorktown Formation, and the Norfolk Formation, now considered a combination of deposits belonging to the Shirley and Tabb

formations in the COLO area. The Eastover Formation, Yorktown Formation, and unnamed Quaternary deposits are fossiliferous within COLO. Well cuttings of subsurface deposits are also fossiliferous (COLO Table 1). Most of the fossils are bivalve and gastropod shells, with scientifically notable collections of foraminifera (single-celled organisms that secrete “shells”, typically of calcium carbonate) and ostracodes (seed shrimp), and significant quantities of other types of fossils. The most recent fossils are mostly pollen and spores that describe the climate and environment of the Jamestown area during and after the last glacial period.

Two caveats should be applied to the maps and geological descriptions. First, the late Cenozoic deposits of coastal Virginia are complex and many attempts have been made to sort them out, with limited success. Second, many references to the Late or Upper Pliocene would now be considered references to the early or lower Pleistocene (divisions of the Pleistocene have not been formalized). In 2009 the age of the Pliocene–Pleistocene boundary was placed much older (2.588 Ma versus 1.806 Ma) to better accommodate the record of glaciation. This affects, for example, the Bacons Castle Formation.



COLO Figure 2. Geography of COLO (NPS). The detached Cape Henry Memorial (CAME) is not included.



COLO Figure 3. Schematic geological map of COLO (NPS).

COLO Table 1. Summary of COLO stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text.

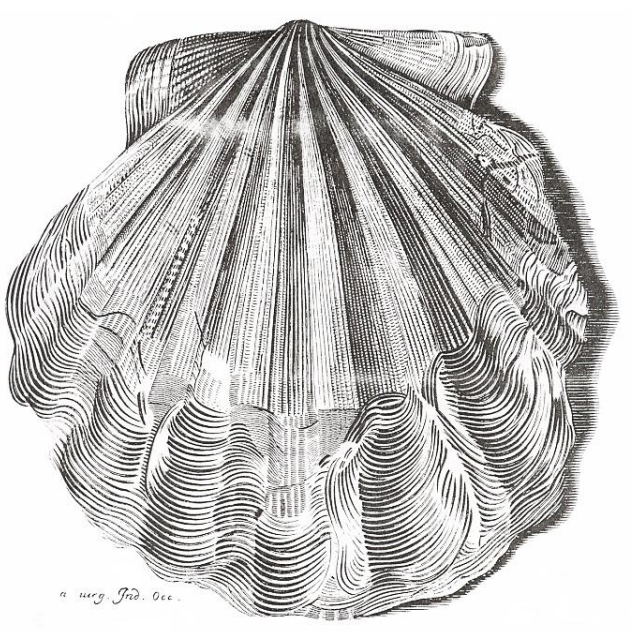
Formation	Age	Fossils Within COLO	Depositional Environment
Unnamed Quaternary sediments	late Pleistocene-Holocene	Foraminifera, spores, conifer and angiosperm pollen, and pine and angiosperm phytoliths (Jamestown Island, about 37 thousand years ago to the present); late Pleistocene bivalves and gastropods (York River); potentially a mastodon	Fluvial, estuarine, marsh, swamp, and beach
Tabb Formation	late Pleistocene	None to date? Some of the fossils in the above section may pertain to the upper Tabb Formation	Fluvial, estuarine, and marginal and restricted marine
Shirley Formation	middle Pleistocene	None to date; plant fragments and peat are most likely	Complex, with fluvial, estuarine, and nearshore marine most common
Chuckatuck Formation (present per Mixon et al. 1989)	early or middle Pleistocene	None to date; plant matter (in peat) and burrows are most likely	Fluvial, estuarine, and restricted marine
Windsor Formation	early or middle Pleistocene	None to date; fossils are not common in this formation	Fluvial, estuarine, tidal flat, and restricted marine
Bacons Castle Formation	early Pleistocene	None to date; invertebrate burrows are most likely	Fluvial, estuarine, tidal flat, and possibly marine
Yorktown Formation	Early–Late Pliocene	Foraminifera, sponges, corals, bryozoans, brachiopods, bivalves, scaphopods, gastropods, mollusk fragments, annelid worm tubes, barnacles, ostracodes, unspecified arthropod fragments, echinoids, decapod burrows, invertebrate borings on other fossils, shark teeth, whale bones, unspecified mammal bones, 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
Eastover Formation	Late Miocene	Foraminifera, bivalves, and ostracodes; mollusks also reworked into Yorktown Formation	Shallow marine
Subsurface (includes Chesapeake Group and Chickahominy Formation)	Various; includes Pliocene, Miocene and Late Eocene units	Shells	Various; predominantly shallow marine

Sources of Paleontological Resources

The fossils of COLO present opportunities for education, interpretation, and scientific research in the park. Professional geologists and amateur fossil collectors have long obtained specimens from Yorktown and along the York River. Unauthorized collectors may still be doing so at the present. Burns (1991), in a guide to Mid-Atlantic fossil sites, included a site at the mouth of Indian Field Creek, which is within COLO.

The shell beds of the Virginia Coastal Plain were noted almost immediately by the English settlers, who used them to make lime for mortar. They were described briefly in writings by William Strachey, the first secretary of Jamestown. Early naturalists John Clayton and John Banister, active in the 1680s, occasionally encountered what we would recognize as fossil bones and teeth, and Banister described a shell bed 32 to 48 km (20 to 30 miles) up the James River (Ray 1983), probably not far below Jamestown. The fossils of Yorktown received wider notice beginning in the 1780s, in the aftermath of the American Revolutionary War. General Benjamin Lincoln, who served at the siege of Yorktown, briefly detailed the fossil beds. He reported the presence of cockles, clams, and other shells in several different shell-rich layers in the steep banks (Lincoln 1783). The German naturalist Johann David Schöpf, who had been serving as a doctor to the German contingent with the British Army, visited Yorktown in 1783 and noted the shell beds there and at a mill race between Yorktown and Williamsburg, where he also observed probable fragments of whale bones (Ray 1983). Perhaps the earliest detailed geologic description of the COLO area is Rogers and Rogers (1837), which includes information on several fossil sites.

Fossils from the Yorktown Formation of the COLO area probably first appeared in the literature in the 1680s, although not recognized as such. Yorktown Formation mollusks were first illustrated in Martin Lister's "Historiae Conchyliorum", published in an idiosyncratic fashion primarily between 1685 and 1692. At the time, the specimens were not recognized as fossils, and were not even known to come from Virginia. Although credit for first recognizing any of the specimens as fossils from North America appears to go to a 1786 auction catalog, this does not appear to have made an impression (Ray 1987). Thomas Say (1824) was the first to recognize and describe any of Lister's fossils in a scientific document. He named the bivalve *Pecten* (now *Chesapecten*) *jeffersonius* and considered a specimen illustrated in Lister's work to be an example of the species (COLO Figure 4).



COLO Figure 4. Martin Lister's 1687 illustration of a fossil shell later known as Chesapecten jeffersonius, as reproduced in Ward and Blackwelder (1975).

This specimen was originally illustrated in a 1687 edition of Lister's work, on Plate 167, with the caption "A virg Ind Occ". It is thought that the specimen was originally labeled "A virg", which Lister misinterpreted as a reference to the Virgin Islands ("Ind Occ" means Indies Occidentale, or West Indies) (Ward and Blackwelder 1975).

At least two other fossils are represented in Lister's figures: another bivalve now known as *Mercenaria tridacnoide* and a snail of the genus *Ecphora*, sometimes identified as *E. quadricostata*. The snail has sometimes been reported as the first North American fossil to be illustrated, but this is inaccurate; the illustration appears to have first been published in 1770, in a long-posthumous edition of Lister's work (Ray 1987). The *Chesapecten jeffersonius* specimen instead has pride of priority as the first illustrated North American fossil (Ward and Blackwelder 1975; Ray 1987).

It is likely that Lister's source for the bivalve fossils was John Banister. The snail was probably collected later from Maryland (Ray 1987). Based on the distribution of *C. jeffersonius* fossils, Lister's specimen may have come from the King Creek area, mostly within the U.S. Naval Weapons Station. Some of the land around the mouth of the creek is within COLO along and near the Colonial Parkway. An alternative discovery site is the Indian Field Creek area; the mouth of this creek is also crossed by the Parkway. In either case, there is a chance that the original fossil came from COLO (L. Ward, Virginia Natural History Museum, pers. comm. in Kenworthy and Santucci 2003). *C. jeffersonius* was designated the state fossil of Virginia in 1993 in recognition of its historical significance and abundance (Kenworthy and Santucci 2003). It is possible that Lister's specimens are still at the Ashmolean Museum of Oxford or in other collections, but they have not yet been found (Ray 1987).

Further geographic confusion occurred in the early 19th century. John Finch collected fossils from Yorktown and near City Point in Petersburg and distributed them to several scientists, including Say (Ward and Blackwelder 1975). Other authors, including Timothy Abbott Conrad (1833) and Isaac Lea (1833) also published on fossils collected by Finch (Campbell 1993). For unclear reasons, these authors thought that Finch's collections were from the St. Mary's River of Maryland, but they were probably from the Eastover and Yorktown formations in and around Yorktown (Ward 1991). Conrad was the most prolific of the early authors, naming numerous species over a period of several decades (Campbell 1993).

Subsurface (Various Ages)

In areas like coastal Virginia, where there are fossiliferous marine formations in the subsurface, it is not uncommon for well projects to bring fossils to the surface in cores and cuttings. Because the fossiliferous sediments are buried hundreds of meters or feet below the surface, they are protected from erosion, theft, and vandalism, and only require management when brought to the surface. They are included here for completeness.

Cederstrom (1957) mentioned several wells drilled within COLO and provided detailed information about an example from Yorktown. At this site, shells were encountered at several levels in the Chesapeake Group between 4.6 and 59 m (15 and 195 ft) down, in a unit identified as the Chickahominy Formation between 108 and 130 m (356 and 425 ft) down, and in unnamed sediments

between 197 and 235 m (645 and 772 ft) down. Fossils were also recovered from a well adjacent to Jamestown, probably just outside of COLO. This site yielded shells between 34 and 43 m (110 and 140 ft) down in the Chesapeake Group, foraminifera from the Chickahominy Formation between 56 and 69 m (182 and 226 ft) down, foraminifera around 73 m (240 ft) down in the Nanjemoy Formation, and shells between 85 and 88 m (280 and 289 ft) down in the Mattaponi Formation (Cederstrom 1957). Later research found that the Mattaponi Formation is an invalid unit; in the Yorktown area and other areas near and within the Chesapeake Bay crater, it actually represents tsunami breccia deposits created from Cretaceous–Eocene sediments and rocks disrupted by the meteor impact (Poag 1997; Powars and Bruce 1999). Richards (1947) reported bivalves and gastropods from a well at Yorktown, but the location is not specified, so the site may be outside of COLO.

Well corings and cuttings have been very productive in the COLO area. Cushman and Cederstrom (1945) described a number of foraminifera from the Chickahominy Formation, contacted at depths of more than 100 m (330 ft) beneath the adjoining Navy Mine Depot (now the Naval Weapons Station. Later, Cederstrom (1957) included a detailed column from a well dug in the naval property. This well penetrated more than 180 m (600 ft) and produced many fossils, including foraminifera, shells, shark teeth, and fish bones and scales, terminating in Cederstrom's Mattaponi Formation.

Chesapeake Group: Eastover Formation (Upper Miocene)

The deposits of the Eastover Formation have long been recognized in southeastern Virginia, but until the 1980s they were generally known as the St. Mary's/Marys Formation or "Virginia St. Mary's", after a unit found in Maryland. They were given their present name by Ward and Blackwelder (1980). Older descriptions sometimes included some of the sediments in other formations, including the underlying Calvert and Choptank formations and the overlying Yorktown Formation (Ward and Blackwelder 1980). The Eastover Formation includes sand, silt, and clay, and is divided into the Claremont Manor Member and overlying Cobham Bay Member. The Claremont Manor Member is composed of beds of poorly sorted silty and clayey sand fining up to clay, typically green-gray when fresh and iron-stained tan after weathering. The Cobham Bay Member is composed of fine well-sorted shell-rich sand with local deposits of clay. Its sediments are typically gray-blue when fresh, and weather to yellowish orange. Overall, the Eastover Formation is about 5 to 28 m (16 to 92 ft) thick. The Claremont Manor Member reaches up to 24 m (79 ft) thick, but is usually much thinner; a 9 m (30 ft) deposit is considered thick. The Cobham Bay Member ranges from 1 to 12 m (0.3 to 39 ft) thick, typically a bit shy of 4 m (13 ft) (Ward and Blackwelder 1980). Thicker deposits, up to about 64 m (210 ft), can be found within the basin formed by the Chesapeake Bay crater (Powars and Bruce 1999). It can be found in many areas of COLO.

The contact of the Eastover Formation with older units is disconformable (representing a significant break in deposition), and this contact is often marked by bones and teeth (Ward and Blackwelder 1980). The upper contact with the Yorktown Formation is also disconformable (Ward and Blackwelder 1980), and the first advance of the Yorktown sea eroded part of the Eastover Formation (Newell and Rader 1985). However, this contact can be difficult to find, because the formations have similar sediments near the contact and fossils are commonly leached (Johnson et al. 1981). The

contact can appear conformable (Bick and Coch 1969), and the two formations are occasionally lumped together (Teifke 1973a, 1973b). The contact between the Claremont Manor and Cobham Bay members is also described as disconformable (Ward and Blackwelder 1980; Ward and Powars 2004). Deposition of the Eastover Formation occurred during the Late Miocene (Tortonian stage) (Ward and Blackwelder 1980). The Claremont Manor Member has proven difficult to date. It may be as old as 11 Ma (Fierstine 1998). The Cobham Bay Member dates from 8.9 ± 0.4 to 6.6 ± 0.05 Ma (Whitmore 1994). The depositional environment of the Claremont Manor Member is interpreted as open marine, with cooler water than the Cobham Bay Member. The depositional environment of the Cobham Bay Member is interpreted as shallow open marine (Ward and Blackwelder 1980).

The Eastover Formation is fossiliferous, although not as abundantly fossiliferous as the overlying Yorktown Formation. The shell deposits have historically been used for agricultural purposes (Clark and Miller 1906). The Eastover Formation has yielded fossils within COLO. McLean (1966) reported a microfossil site (Locality H) on the Colonial Parkway a little less than 1 km (0.5 miles) south of Halfway Creek, 3 km (2 miles) south of Williamsburg. Foraminifera and ostracodes were found here. To the south, the Swann's Point parcel has yielded the characteristic bivalve *Isognomon* (Hazel 1971). Harris (reprinted in Ward [1993]) found *Isognomon* along the York River, showing the presence of the Eastover Formation below Indian River Creek. Reworked (eroded and then redeposited in younger deposits) Eastover Formation mollusks have also been reported at Felgate's Creek (Mansfield 1943). The formation is also quite productive at Cobham Wharf near COLO in the bay south of Jamestown, where many bivalves and gastropods have weathered out of the deposits and are found on the beach (Ruhle 1962a). In 2013, a partial skeleton of a baleen whale was discovered and recovered from this formation along the York River in Navy property adjacent to COLO. It has been nicknamed "Cornwallis" (McClain 2014).

The fossil assemblage of the Eastover Formation includes foraminifera (McLean 1966), diatoms (Andrews 1986), palynomorphs (organic microfossils like pollen and spores) including dinoflagellates (single-celled organisms that move using one or more whip-like flagella), moss and fern spores, conifer and angiosperm pollen, and reworked older material (Groot 1991), brachiopods (lamp shells), bivalves, scaphopods (tusk shells), gastropods, barnacles (Clark et al. 1912), crabs (Blow and Bailey 1992), ostracodes (McLean 1966; Forester 1980), echinoids (sea urchins), burrows (Ward and Blackwelder 1980), sharks (Kimmel and Purdy 1984), a few types of bony fish (Kimmel and Purdy 1984; Fierstine 1998), auks (Wijnker and Olson 2009), cetaceans including baleen whales, extinct toothed whales (Whitmore 1985), and river dolphins (Geisler et al. 2012), and vertebrate scrap. The pearly tabular bivalve *Isognomon maxillata* is characteristic of the Eastover Formation (Bick and Coch 1969; Powars and Bruce 1999).

The two members differ in abundance and types of fossils. Major constituents of the Claremont Manor Member assemblage include bivalves, gastropods, echinoids, burrows, vertebrate bones and teeth. Preservation is poor, with natural molds and casts common. The best fossils are found along the James River from Claremont to Cobham Wharf, and mostly consist of mollusks (Ward and Blackwelder 1980). The mollusks are poorly preserved, and the assemblage is low-diversity (Ward and Powars 2004). Shells are much more abundant in the Cobham Bay Member, with bivalves,

gastropods, and ostracodes common. Pearlaceous bivalves are present in this member, which helps to differentiate it from the generally similar overlying Yorktown Formation (Ward and Blackwelder 1980). Individual beds in the Cobham Bay Member can be largely composed of bivalve shells (Johnson et al. 1981). Mollusks are more diverse in this member, and show open-shelf warm water affiliation (Ward and Powars 2004). Eastover Formation bivalve and gastropod shells frequently are at least partially leached, which can create shell "ghosts" (Dischinger 1987; Johnson and Berquist 1989). Molds and chalky residues can also be present (Johnson and Berquist 1989).

Chesapeake Group: Yorktown Formation (Lower–Upper Pliocene)

As the name suggests, the Yorktown Formation was first described from Yorktown (Clark and Miller 1906; Clark et al. 1912; Mansfield 1943; Ward and Blackwelder 1980). Unfortunately, the Yorktown cliffs are now covered by riprap, preventing access (Ward and Blackwelder 1980). Early usage of the formation name sometimes incorporated beds from what are now recognized as different formations, such as the Eastover Formation (Ward and Blackwelder 1980). Descriptions of the Yorktown Formation's lithology vary by location. Bick and Coch (1969), describing the Williamsburg, Hog Island, and Bacons Castle quadrangles, distinguished four units and the Sedley Formation (now considered part of the Yorktown Formation; see below). In this area, the basal 3 m (10 ft) of the Yorktown Formation is composed of sandy fossiliferous beds with abundant *Pecten* shells. Above this is about 4.6 m (15 ft) of highly fossiliferous beds with abundant *Chama congregata* shells. The next unit is 1 to 3 m (3 to 10 ft) of highly fossiliferous beds. The upper part of their Yorktown Formation is 3 m (10 ft) of clay with a thin intercalated bed of shell debris. Their overlying Sedley Formation approaches 10 m (35 ft) thick south of the James River but only half of that north of the river, and is composed of brown sand and clay.

Johnson (1972), describing the Yorktown, Poquoson West, and Poquoson East quadrangles, used facies (distinct rocks or packages of sediment deposited under specific conditions) instead of vertical beds and included a weathered zone instead of the Sedley Formation. The facies include silty sand, shelly sand, cross-bedded coquina, sandy silt, coquina, and *Chama* facies, the latter not exposed at the surface. The configuration is interpreted as an offshore bar in the Yorktown–Chuckatuck area (cross-bedded coquina facies) with a lagoon on the west (sandy silt facies) and marine waters of 15 to 38 m (50 to 125 ft) depth on the east (shelly sand and silty sand facies). At some point, the bar broke down and the coquina and *Chama* facies were deposited above them in a warm shallow sea. Eventually, the marine waters regressed, and erosion and aggradation followed (Johnson 1972).

The Sedley Formation, formerly thought to be a distinct fluvial-estuarine formation lying above the Yorktown Formation (Bick and Coch 1969), is now considered to be a weathered and leached horizon at the top of the Yorktown Formation (Johnson et al. 1981; Johnson and Berquist 1989). It had been thought to consist of a lower section of weathered sediments and an upper section known informally as the "chocolate bed" for its distinctive color, with some overlying tidal beds. The "chocolate bed" goes from clay-rich to muddy sand going up, and marks the top of the marine Yorktown. Combined with the tidal beds, this appears to be a shallowing, regressive sequence (Johnson et al. 1981). Leached shells and a few burrows have been found in the "Sedley Formation"

(Johnson et al. 1981); its characteristics probably represent subaerial and subterranean dissolution of shell beds (Johnson and Berquist 1989).

Several formal divisions of the Yorktown Formation have been proposed. Mansfield (1943) divided the formation into two faunal zones, Zone 1 (lower) and Zone 2 (upper). Zone 1, the *Pecten clintonius* zone, is present at Bellefield. Zone 2, the *Turritella alticostata* zone, was further divided into several subunits. The lowest part includes beds a-d. The middle part, the fragmental beds, includes beds e-f, and has been observed at the Yorktown bluffs. All units from a to f have been found at Yorktown The upper part is composed of gray to blue sands, found between Indian Field Creek and just above Yorktown (Mansfield 1943). In more recent terminology, the Sunken Meadow Member is in Zone 1 and the Rushmere, Morgarts Beach, and Moore House members are in Zone 2 (Campbell 1993).

Ward and Blackwelder (1980) divided the Yorktown Formation into four members, in ascending order the Sunken Meadow, Rushmere, Morgarts Beach, and Moore House members. The Sunken Meadow Member is considered to be the lower Yorktown Formation, and the other three make up the upper part of the formation. The Sunken Meadow Member is composed of coarse to medium poorly sorted shelly sand. Its upper contact may include a brief break in deposition before the Rushmere Member, but a long disconformity is not apparent. The Rushmere Member is composed of well-sorted fine shelly sand. It has a conformable to gradational relationship with the Morgarts Beach Member, composed of very fine sand to silty clay, with characteristic small bivalves (*Mulina congesta*). At the top is the Moore House Member, which usually has an abrupt contact with the Morgarts Beach Member. It is composed of sandy shell hash, and is only found east of the Surry Scarp. The Sunken Meadow Member is interpreted as having been deposited on a shallow shelf, under mild temperate water of normal marine salinity. Warmer water arrived during deposition of the upper members. The Rushmere Member includes the greatest marine transgression, to just beyond the Fall Line (Ward and Blackwelder 1980). This is the highest local sea stand between the Middle Eocene and the present (Krantz 1990). The Rushmere Member is interpreted as resulting from deposition on a shallow open marine shelf. The Morgarts Beach Member is interpreted as lagoon deposits behind offshore bars. The Moore House Member at the top of the formation, named for Moore House in COLO, includes some brackish deposits at the very top, showing the marine regression that ended deposition of the formation (Ward and Blackwelder 1980). Campbell (1993) regarded the four-member scheme as unworkable, being based on an outmoded conception of the Yorktown Formation as one marine transgression-regression cycle, with members based on commonly recurring types of deposits that cannot be mapped the same way the member names are applied. He instead substituted a modified version of Mansfield (1943)’s two zone scheme. This reassessment does not appear to have been widely followed.

The Yorktown Formation is sometimes described as resulting from a single transgression (Ward and Blackwelder 1980; Blackwelder 1981; Bailey 1987), but as noted this is outdated (Campbell 1993). Some authors describe it as including three transgressions (Johnson and Ramsey 1987; Groot 1991; Krantz 1990; Campbell 1997; Williams et al. 2009) or more (Campbell 1993). Shallower facies, such as fluvial and tidal deposits, have been reported to the north, away from the marine settings (Mixon

et al. 1994), and bivalves and stable isotopes indicate brackish-water conditions prevailed briefly late in deposition in the Williamsburg area (O'Donnell et al. 2003). Although its thickness is sometimes described as thick as 45 to 60 m (150 to 200 ft), in the COLO area the Yorktown Formation is only about 12 to 14 m (39 to 45 ft) thick (Bick and Coch 1969). It reaches an unusually great thickness of about 16.8 m (55 ft) near Yorktown (Ward and Blackwelder 1980). The upper contact with the Bacons Castle Formation is disconformable (Johnson and Ramsey 1987). Deposition of the Yorktown Formation spanned the Early and Late Pliocene. Published dates vary, but they are generally within the 4.5 to 2.5 Ma figure given by Campbell (1993).

The climate featured warm seas and low seasonality (Stanley 1986; Williams et al. 2009). Mild temperate seas prevailed during deposition of the Sunken Meadow Member, becoming warm temperate for the other members (Krantz 1990), increasing into subtropical temperatures late in deposition (Stanley 1986). Subtropical faunas expanded north during this warm period (roughly 3.29 to 2.97 Ma) (Williams et al. 2009). The warm-adapted mollusks died off following deposition of the Yorktown Formation as the climate cooled (Stanley 1986). Warm-temperate conditions are no longer found in the modern Western Atlantic (Campbell 1993).

Yorktown Formation fossils: COLO and the vicinity

The Yorktown Formation is famous for its abundant fossils. It is among the best formations for collecting fossils on the Atlantic Coastal Plain (Bevan 1957). The most common fossils include corals, bivalves, scaphopods, gastropod, and barnacles, all of which are characteristic of the city of Yorktown; 30 common species are illustrated in Roberts (1932). Yorktown and the James River have been regarded as hosting the most fossiliferous beds of the formation for more than a century (Clark and Miller 1906; Clark et al. 1912; Roberts 1932), but efforts to protect the York River bluffs have covered many of the outcrops on the south bank of the York River (Ward and Blackwelder 1980; Kenworthy and Santucci 2003). Others were destroyed during construction (Mansfield 1943). Visual guides to the common fossils can be found in Roberts (1932) and Campbell (1993). Like the Eastover Formation, the shells of the Yorktown Formation have been used for agricultural purposes (Rogers and Rogers 1837), and the shell marl has historically been an important resource (Clark et al. 1912). Other uses include temporary road surfaces (Roberts 1932). Coquina (beds made up mostly or entirely of shells) has sometimes been quarried for building material (Roberts 1932).

Overall, the Yorktown Formation within COLO has yielded foraminifera, sponges, corals, bryozoans (moss animals), brachiopods, bivalves, scaphopods, gastropods, annelid worm tubes, barnacles, ostracodes, unspecified arthropod fragments, echinoids, decapod crustacean burrows, invertebrate borings on other fossils, shark teeth, whale bones, unspecified mammal bones, and probably walrus bones. Specific mentions of localities in the literature that are either definitely or plausibly within COLO include the following, listed in chronological order and in separate paragraphs for readability:

The shells at Bellefield, the coquina, 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 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;

Gilbert 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' 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 (COLO Tables 2, 3), including Bellefield, Temple Place (apparently Moore House per Ward [1993]), and the York River;

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 et al. (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. At that time, the best area was between 1.6 and 3.6 km (1 and 2.25 miles) below Yorktown along the river, where 90 species of mostly bivalves and gastropods had been reported. This general locality, which also included coquina, includes Moore House and its surroundings. Other sites of note that are either within or adjacent to COLO along the York River include: the beach 0.4 km (0.25 miles) above Yorktown, where small bivalves like *Leda* and *Yoldia* are most common; near Bellefield, in Navy property and at the mouth of Felgate's Creek, where the coral *Septastrea*, 65 species of shells, barnacles, shark fossils, and whale vertebrae had been found (including a 3 m [10 ft] thick bed with 35 fossil species); and Camp Penniman, where foraminifera, large pectinid bivalves, shark teeth, and whale bones had been found on the beach. On the south side of the peninsula, Roberts reported that the James River beaches of Carter's Grove and King's Mill (east of the Colonial Parkway) were productive, with the King's Mill site noted for foraminifera;

Cushman and Cahill (1933) investigated foraminifera from the Yorktown Formation, naming the species *Massilina mansfieldi* from a specimen (USNM 371735) found at a locality about 2 km (1.25

miles) below Yorktown and half a mile below a prominent projection, probably in the vicinity of Moore House;

Mansfield (1943) described a site about 4 km (2.5 miles) above Yorktown, almost certainly in COLO, that yielded bivalves and gastropods. He also reported that various bivalves and gastropods had been found at Yorktown and Felgate's Creek, and bivalves (in the *Chama* bed) were found about 2.4 km (1.5 miles) 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 fine sandy beds just above Yorktown, *Diplodonta berryi* (ANSP 16013 per Richards [1968]) from a high undercut bluff of the York River below Yorktown, and *Petricola rogeri* (ANSP 16015) from a blue clay lens about midway between the undercut bluff and Moore House;

Malkin (1953)'s ostracode locality 20 was 1.9 km (1.2 miles) southeast of Yorktown along the York River, 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, 3 km (2 miles) below Yorktown, was probably nearby but not within COLO. Malkin named several ostracode species from these localities (COLO Table 2);

McLean (1956) reported foraminifera from Felgaters [sic] Creek, Moore House Beach, and the bluffs of Yorktown. Bivalve and gastropods were also present at Felgaters [sic] Creek, and bivalves, gastropods, and barnacles were also present at Moore House Beach. McLean named several foraminifera species from these localities (COLO Table 2);

McLean (1957) reported ostracodes from Felgaters [sic] Creek, Moore House Beach, and the bluffs of Yorktown, naming *Murrayina barclayi* (ANSP 22588) from Moore House Beach;

Hazel (1971)'s ostracode locality 13 (Sample 41, USGS 24717) is within the Swann's Point parcel of COLO;

Johnson (1972) included several localities relevant to COLO. Site D, 90 m (300 ft) above Moore House, 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* are locally common. The coquina facies, extensively exposed between the U.S. Naval Weapons Station and the U.S. Coast Guard Reserve Training Center (largely

within COLO), is dominated by bivalves, often bored by sponges and spirobid 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, including the mouth of Felgate's Creek, two miles above Yorktown, and Moore House;

Ward and Blackwelder (1980) reported foraminifera, bryozoans, bivalves, gastropods, and ostracodes at Moore House;

Gibson (1983) reported on foraminifera collected from Yorktown;

Wilson (1983) reported that the unusual barnacle *Mclellania* had been found at Moore House;

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). The site, now closed, formerly permitted fossil collecting. 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 ("ear bones") (Sabol 1960), and gull bones (Olson and Rasmussen 2001) have been found. Cobham Wharf is also described in 183 Cronin et al. (1989).

Yorktown Formation fossils: overall

A number of different types of fossils are known from the Yorktown Formation over its entire depositional area. Plants are represented by spores of mosses, ferns, and clubmosses, conifer and angiosperm pollen (Groot 1991; Sirkin and Owen 1998), resin, and wood representing forms such as pines, cypresses, junipers, and locust trees. The wood is sometimes bored or colonized by barnacles

(Hueber 1983). Aside from pollen and spores, palynomorphs are also represented by dinoflagellates and reworked Cretaceous palynomorphs (Groot 1991; Sirkin and Owen 1998). Pollen is often poorly preserved (Groot 1991).

The Yorktown Formation marine fossil assemblage includes calcareous nannofossils (tiny plates from plankton) (Campbell 1997), foraminifera, radiolarians (another type of single-celled "shelled" organisms), diatoms (phytoplankton with cell walls of silica), other microfossils (Roberts 1932), sponges, hydrozoans (relatives of jellyfish and corals) (Johnson 1972), corals, bryozoans, brachiopods, bivalves, scaphopods, gastropods (Roberts 1932; Johnson 1972), cephalopod statoliths (mineralized deposits that form in some invertebrate ears and are used for equilibrium; Clarke and Fitch [1975]), annelid worm tubes, barnacles, ostracodes, other crustaceans, echinoids (Roberts 1932; Johnson 1972), invertebrate burrows and borings (Johnson 1972), 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 invertebrates are commonly represented by shark teeth (Roberts 1932; Johnson 1972) and vertebrae (Johnson 1972). Documents covering some of these individual groups include: calcareous nannofossils (Akers and Koppel 1974; Blackwelder 1981; Cronin et al. 1984, 1989; Campbell 1997); foraminifera (Bagg 1898; Cushman and Cahill 1933; McLean 1956); 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 [some are from the Eastover Formation; Hazel 1983]; 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, Fierstine 2001; Purdy et al. 2001); and various whales and dolphins (Baum and Wheeler 1977; Whitmore 1994; Gibson and Geisler 2009). The trace fossils include 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).

There are also aerial and terrestrial vertebrates, but most of the diversity of vertebrates comes from the famous Lee Creek Mine in Aurora, North Carolina, about 200 km (125 miles) south of Jamestown. Vertebrates found here include sharks, rays, ray-finned fish, turtles, possible crocodilians, over 100 species of birds (mostly waterfowl), xenarthrans, felids, ursids, canids, seals, walruses, whales, gomphotheres (elephant relatives), horses, tapirs, rhinos, peccaries, protoceratids (extinct ungulates), palaeomerycids (extinct ungulates), pronghorns, and camels. The terrestrial forms are all from the Sunken Meadow Member (Ward 2007). Birds are generally rare in the formation, except at the Lee Creek Mine (Olson 1985); a list of the various forms found there can be found in Olson and Rasmussen (2001).

Leaching of fossils is very common. Most affected are shells that were originally aragonitic and are of average thickness, like those of the bivalve *Chama* and gastropod *Crepidula*. The thicker shells of *Mercenaria* are less affected. Shells of the bivalve *Plicatula* originally had layers of aragonite and calcite, but after leaching the aragonite layer becomes corroded. The leached minerals fill voids

lower in the formation, helping to form the more resistant coquina (Waite and Condit 1969). Aragonitic shells become chalky or uncrystallized, or even dissolve entirely, while calcitic shells are unaltered or become chalky. There are different degrees of chalkiness. Sometimes a fossil remains hard, while sometimes it becomes soft and pasty (Herman 1991). Rogers and Rogers (1837) provide an early description of the leaching process.

Other Quaternary Deposits (Upper Pleistocene–Holocene)

A variety of deposits postdate the Tabb Formation (see below) in the COLO area. Types of deposits mapped within COLO include marsh sediment, swamp sediment, alluvium of varying ages, beach and dune sand, and organic mud. Most of the Holocene deposits in the area are from tidal marshes (Bick and Coch 1969). These deposits are fossiliferous within COLO: a variety of paleoecologically useful fossils have been recovered from Jamestown Island (Sager et al. 1994; Johnson and Hobbs 2001). Microfossils and conifer and angiosperm pollen were reported from vibracores taken from three creeks in and around Jamestown Island, from northwest to southeast Back Creek, Kingsmill Creek, and Passmore Creek. Estuarine deposition began after 5,000 years ago, and marshes formed by 3,000 years ago (Sager et al. 1994). Jamestown fossils from the same localities were more fully described by Johnson and Hobbs (2001). Most of their fossils were phytoliths (bits of silica secreted in the tissues of some plants) and pollen, although foraminifera and spores were also found. The fossil record of the island spans approximately the past 37,000 years, and is nearly complete over that time frame. At Back Creek Marsh, phytoliths representing four grass families, oak, and pine have been found, dating back approximately 5,000 years (Johnson and Hobbs 2001).

Pleistocene fossils have also been reported along the York River. G. D. Harris, as described in Ward's (1993) reprint of his unpublished manuscript about the geology of the Yorktown area, encountered a dark "soil" with abundant bivalves and gastropods a short distance above Yorktown that Ward attributed to late Pleistocene estuarine deposition. The coastal Pleistocene unit along the York River in COLO was mapped most recently as the Shirley Formation (Mixon et al. 1989), but previously was mapped (at greater resolution) as the Norfolk Formation (Johnson 1972). As noted, the Norfolk Formation was later divided into the Shirley and Tabb formations, and the age of the Tabb Formation is more consistent with the age of the fossils. Therefore, it was thought best to include the record here, instead of with one of the two possible formation. Common species include the bivalves *Crassostrea virginica*, *Mercenaria mercenaria*, *Ensis directus*, and the gastropod *Littorina irrorata* (Ward 1993).

The late Pleistocene–Holocene deposits present in COLO have the potential to yield many other types of fossils, based on comparable deposits in the area. Shell fragments are common in Holocene-age channel deposits in the COLO area. Some of them are reworked from older deposits (Bick and Coch 1969). Plant fragments (Roberts 1932) and peat are also present (Johnson 1972; Johnson and Berquist 1989). Peat and swamp deposits can contain a variety of plant material, including wood and woody debris, seeds, and leaves. Typical plants represented include cypress, black gum, sweet gum, other hygrophilous trees, arum, and cordgrass (Johnson and Berquist 1989). The best record of plants of this age in the area can be found in the Great Dismal Swamp, centered about 75 km (45 miles) south of Yorktown. Unsurprisingly, the Great Dismal Swamp has peat deposits with a variety of

palynomorphs, plant macrofossils, and other fossils. The swamp began forming as recently as the end of the last glacial episode. Freshwater marshes formed along streams passing through the area and moved inland as sea level rose. About half of the Great Dismal Swamp was mantled by peat by about 6,000 years ago, with the rest covered by about 3,500 years ago (Whitehead 1972). Organisms represented include diatoms, mosses, clubmosses, ferns, conifers, angiosperms, fungi, sponges (Cocke et al. 1934). Peat also formed in Chesapeake Bay before it was submerged (Oaks and Whitehead 1979). Cores of more recent sediments from the bay (2,300 years ago to the present) include foraminifera, dinoflagellates, angiosperm and conifer pollen, and bivalve shells (Willard et al. 2003).

Although inconspicuous fossils like pollen and phytoliths are far more abundant, the late Pleistocene is most famous for large extinct mammals such as mammoths and mastodons. Hay (1923) and Eshelman and Grady (1986) provide inventories of Quaternary vertebrate fossil sites in Virginia. Using the more recent Eshelman and Grady publication, cross-referenced with the online Neotoma (http://www.neotomadb.org/) and Faunmap databases (http://www.ucmp.berkeley.edu/faunmap/) (ideally, they provide the same data, but this is not necessarily true in practice), there are a handful of Pleistocene vertebrate localities within about 100 km (60 miles) of COLO. The nearest is a nebulous "near Williamsburg" site with mastodon fossils, described below; Eshelman and Grady (1986) make note of two localities "near Williamsburg," but do not assign any fossils to the second. Most of the sites have only one or two specimens or taxa reported. These include: Chesapeake, about 55 km (34 miles) southeast of Yorktown (horse); City Point, 46 km (29 miles) west-northwest of Jamestown (mastodon); Stratford Hall, about 105 km (65 miles) north of Williamsburg (horse); a site near Virginia Beach, about 65 km (40 miles) southeast of Yorktown (bison); and Deep Creek Pit, about 56 km (35 miles) south-southeast of Yorktown (mastodon and horse). More diverse fossils are found at Eclipse, about 38 km (24 miles) south of Yorktown (loons, gannets, and auks) and the Womack Pit, approximately 60 km (35 miles) southeast of Yorktown (grebes, gannets, cormorants, brants, gulls, auks, murres, walruses, gray seals, and indeterminate carnivorans and cetaceans). Finally, there are two general "locations" of interest. Fossils of giant beavers, walruses, and gray whales have been found on coastal barrier islands in Accomack County to the northeast, and boats frequently pull up Pleistocene mammal bones from the drowned coastal plains offshore of Virginia, including specimens of mammoths, mastodons, musk oxen, and bison (Eshelman and Grady 1986). As suggested by the preceding information, the most likely potential finds of Pleistocene vertebrates in the COLO area are bones of large vertebrates, particularly mammoths, mastodons, horses, and bison.

The Williamsburg-area mastodon was first reported in 1811 (Anonymous 1811). The details vary from report to report, but apparently the bones were found 10 km (6 miles) below (Anonymous 1811) or east (Mitchill 1818) of Williamsburg on the south bank of the York River. It is unclear where the former location would be, but the latter is potentially within COLO, in the vicinity of Bellefield Plantation and the mouth of Indian Field Creek. Anonymous (1811) reported that the site was a few yards within high water near the home of Gawin Corbin. The specimen included two tusks, two vertebrae, a pelvis, a femur, and partial jaws with seven associated teeth (Mitchill 1818); given the presence of teeth, it is surprising that Mitchill identified it as a mammoth but Hay (1923) reported it

as a mastodon. Hay (1923) reported that the bones were probably destroyed in a fire at the College of William and Mary in 1850.

More recent vertebrate fossils have been found in conjunction with archeological sites. Faunmap and Neotoma report five such sites, all younger than about 3,000 years. They generally have yielded a mix of mollusks, reptiles, birds, rodents, canids, raccoons, and deer. The nearest to COLO are sites on College Creek and Powhatan Creek between Jamestown and Williamsburg (Reinhart 1976, 1978; Barber 1978).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within COLO. However, they are known to preserve fossils elsewhere, and future field investigations within the park may locate fossils in one or more of them.

Bacons Castle Formation (Lower Pleistocene)

The Bacons Castle Formation is a heterogeneous unit deposited in a variety of settings. On the York–James Peninsula, it consists of two interfingering facies designated as members. An interbedded and interlaminated sand and mud facies is known as the Barhamsville Member, and a facies composed of gravel fining up to sandy mud is known as the Varina Grove Member. The Barhamsville Member is interpreted as the deposits of tidal flat complexes, and the Varina Grove Member is thought to be the deposits of rivers and estuaries. The two are sometimes capped by true marine deposits. Deposition began on an eroded surface with paleovalleys, and progressed during a marine transgression, during which sea level reached up to 45 m (150 ft) above present (Johnson and Ramsey 1987). It is the formation closest to the surface in many upland areas, especially at elevations above 34 m (110 ft), and it forms a plain at 37 m (120 ft) (Bick and Coch 1969). In older parlance, which used the names of various marine terraces as formations, the Bacons Castle Formation corresponds to the Sunderland Terrace/Formation (Bick and Coch 1969). Estimates of its thickness vary from 14 m (45 ft) (Mixon et al. 1994) to 21 m (70 ft) (Mixon et al. 1989; Johnson and Berquist 1989).

Deposition of the Bacons Castle Formation occurred approximately 2.3 to 2.0 Ma (Ramsey 1992), now regarded as early Pleistocene but previously included in the Late Pliocene. It was a time when sea level transitioned from being controlled by tectonics to being controlled by changes in the size of ice sheets (Ramsey 1992). The climate was cooler than at present; the presence of spruce pollen in the Bacons Castle Formation is notable, and suggests a New England-like climate on land (Groot 1991).

The Bacons Castle Formation is not noted for its fossils (Bick and Coch 1969; Ramsey 1992), and no fossils have been reported from COLO or the vicinity. Fossil shells are reportedly absent, but some peat is present in old paleochannels, and worm and decapod crustacean burrows are common (Johnson and Berquist 1989). Palynomorphs including dinoflagellates and microforaminifera, clubmoss and fern spores, and conifer and angiosperm pollen have been recovered from the formation in the vicinity of Richmond (Groot 1991). Johnson and Berquist (1989) also mention otherwise undescribed plant fossils in the Richmond area, which could include or be the same as Groot (1991)’s fossils. Mollusks have also been reported from this formation in Maryland, but it

likely that the sediments are of a different age than the Virginia deposits (Groot 1991). Reworked foraminifera are sometimes found (Bick and Coch 1969).

Windsor Formation (Lower or Middle Pleistocene)

The Windsor Formation is similar in origin and sediment types to the Bacons Castle Formation, but formed during a later marine transgression. In the COLO area, it consists of sand, silt, and clay. Cross-bedded sand from fluvial and estuarine settings is found at the base, followed by clay deposited in littoral settings, and then poorly sorted sand, silt, and clay deposited in a bay. The lower part is similar to the underlying Bacons Castle Formation, but is finer-grained (Bick and Coch 1969). The uppermost part can also include lagoonal, tidal flat, and tidal channel deposits, indicating part of a marine regression (Johnson 1972). The contact with the overlying Shirley (or Norfolk) Formation is disconformable (Bick and Coch 1969). Depositional environments correspond somewhat to modern geography: fluvial and estuarine deposits are common around the modern James River (Johnson and Berquist 1989). The formation was deposited during an interglacial stage, with higher sea levels than present (Bick and Coch 1969) (note that subsequent uplift makes sea levels look higher than they were). The rising sea level produced bay deposits east of the Surry Scarp (Johnson and Berquist 1989). Windsor Formation plains are found at 21 m (70 ft) and 27 m (90 ft) above sea level (Bick and Coch 1969). It has a maximum thickness of about 12 m (40 ft) (Mixon et al. 1989).

The Windsor Formation was formerly associated with the Wicomico Terrace/Formation (Bick and Coch 1969; Johnson and Berquist 1989). Deposits from several other formations, including the Bacons Castle and Chuckatuck formations, have occasionally been included in it (Johnson and Berquist 1989); some of the deposits included by Bick and Coch (1969) were transferred to other units by Johnson and Berquist (1989). It has not been precisely dated. Ramsey (1992) regarded its age as about 1.5 Ma. The lack of resolution is due in part to its poor fossil record. To date, fossils reported from the Windsor Formation include foraminifera (Bick and Coch 1969), fossils of the angiosperm *Pterocarya* (Colquhoun et al. 1991), decapod burrows (probably ghost shrimp) (Johnson 1972; Colquhoun et al. 1991), 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 part of the formation (Colquhoun et al. 1991). To date, no fossils have been reported in this formation within COLO.

Chuckatuck Formation (Lower or Middle Pleistocene)

The Chuckatuck Formation is another in the series of areally restricted Pleistocene formations of COLO and the vicinity. It is not included in the GRI map, but it is mapped in the eastern Yorktown area by Mixon et al. (1989). Formerly, its deposits were included in other units, including the Windsor Formation (Johnson and Berquist 1989). Deposition occurred during a marine transgression (Johnson and Berquist 1989), and deposits follow a similar pattern to the other Pleistocene formations of the area, with the bulk of the formation consisting of fluvial-estuarine and restricted marine deposition over an eroded surface (Mixon et al. 1989). It is composed of gray, yellowish-orange, and reddish-brown sand, silt, and clay, with some peat. It includes two facies: a fluvial-estuarine facies of coarse channel-fill deposits, cross-bedded and planar-bedded sand deposits above them, and clayey silt and silty to sandy clay at the top; and a bay facies with a basal gravelly sand, a

thin pebbly sand level above that, followed by a thicker section of silty sand and sandy silt. The formation forms plains at about 15 to 18 m (50 to 60 ft) above sea level. It is up to 8 m (26 ft) thick (Mixon et al. 1989).

The age of the Chuckatuck Formation is uncertain, but it is older than the Shirley Formation, which is in part 184,000 ± 20,000 years old (Mixon et al. 1989). It is similar to the Shirley Formation, but is finer-grained and is found at higher elevations (Johnson and Berquist 1989). Both its upper and lower contacts are unconformable (Johnson and Berquist 1989). It is only locally fossiliferous, and fossils have not been reported from COLO. Peat is sometimes present in the channel fill deposits of the fluvial-estuarine facies, and ghost shrimp burrows are present in the pebbly sand of the bay facies (Mixon et al. 1989). Plant fossils found in the formation include woody fragments and other material representing deciduous trees and shrubs such as hickory, sweet gum, and myrtle. They indicate that the climate was at least as warm as the present (Johnson and Berquist 1989).

Shirley Formation (Middle Pleistocene)

The Shirley Formation is another in the series of fluvial-estuarine Pleistocene coastal formations. Along with the younger Tabb Formation, its deposits were once mapped as part of the now-deprecated Norfolk Formation (Sedgefield and Lynnhaven members) (Peebles et al. 1984; Johnson and Berquist 1989). Specifically, the Shirley Formation was sometimes mapped as the clayey sand, silty sand, and coarse sand facies of the Norfolk Formation (Peebles et al. 1984). The GRI map for COLO was generated from base maps with different usages, and the reader can observe in the vicinity of lower Mill Creek that the map of the west side used the Shirley Formation, and the map of the east side used the Norfolk Formation. Previous to the Norfolk Formation, the Shirley Formation deposits were included in the Talbot Terrace/Formation (Colquhoun et al. 1991). Generally, the Shirley Formation consists of a pebbly base, a lower-middle section of peat and organic-rich silt and clay, and an upper section of gray clayey sandy silt and silty clay (Johnson and Ramsey 1987). It was deposited on a dissected coastal plain with relief of 23 m (75 ft) or more (Colquhoun et al. 1991), and is up to 24 m (80 ft) thick in paleochannels (Peebles et al. 1984; Johnson and Ramsey 1987). The upper contact with the Tabb Formation is disconformable (Johnson and Berquist 1989). Most of its deposition occurred in fluvial-estuarine, bay, and nearshore marine settings (Johnson and Ramsey 1987), but marsh, barrier, bay, and eolian deposition have also been recognized (Johnson and Berquist 1989). Bick and Coch (1969), using the “Norfolk Formation” name, regarded it as an interglacial formation deposited when the sea was about 14 to 15 m (45 to 50 ft) higher than present (subsequent uplift not calculated), forming a plain about 14 m (45 ft) above the present sea level. The geography was similar to today, except the York and James river estuaries were significantly wider (Bick and Coch 1969).

The Shirley Formation dates to the middle Pleistocene. Mixon et al. (1982) provided a date of 184,000 ± 20,000 years on a coral from the Norfolk Formation, which Mixon et al. (1989) transferred to the Shirley Formation. The Shirley Formation as mapped on the York–James Peninsula is believed to date to Aminozone IIc, approximately 400 to 250 thousand years ago (Mirecki et al. 1995). Fossils are not common in this formation, and have not been reported from COLO. Elsewhere, the peat and organic-rich beds include tree stumps and fossils of beech, cypress, hickory, oak, sweet gum, and

walnut. Bivalves and burrows are sometimes found in sand and silt beds (Peebles et al. 1984; Johnson and Ramsey 1987). Corals (Mixon et al. 1989) and gastropods have also been reported (Peebles et al. 1984). Valentine (1971) described ostracodes from the Norfolk Formation around Norfolk, but it is not clear if they would pertain to the Shirley Formation or another unit. The flora indicate a warm temperate climate (Colquhoun et al. 1991).

Tabb Formation (Upper Pleistocene)

As mentioned above, the Tabb Formation consists in part of deposits formerly mapped as the Norfolk Formation. It is composed of three distinct fluvial-estuarine sequences, described in ascending order as the Sedgefield, Lynnhaven, and Poquoson members (Johnson and Ramsey 1987). All three are composed of fining-upward sequences, beginning with sand beds including some pebbly to larger grains, and grading up into clayey or silty sand and sandy silt. The Sedgefield Member is up to 15 m (50 ft) thick, the Lynnhaven Member is up to 6 m (20 ft) thick, and the Poquoson Member is up to 5 m (15 ft) thick. Both the Sedgefield and Lynnhaven members have local paleochannel fill deposits that can include plant fragments or peat (Mixon et al. 1989). The three members of the Tabb Formation correspond to the Pamlico Terrace (7.6 to 9.1 m [25 to 30 ft]), the Princess Anne Terrace (5.5 m [18 ft]) and the Silver Bluff Terrace (3.6 m [12 ft]) (Colquhoun et al. 1991). The Sedgefield and Lynnhaven members make up most of the surficial deposits east of the Suffolk Scarp (Peebles et al. 1984).

Deposition occurred in a variety of fluvial, estuarine, bay, barrier, and nearshore marine settings (Johnson and Berquist 1989). The marine fossils of the Sedgefield Member suggest shallow nearshore settings from the intertidal zone to about 15 m (50 ft) of water (Scott et al. 2010). These late Pleistocene deposits may also indicate substantial uplift, perhaps due to crustal adjustments in response to glaciation to the north: they are found at maximum elevations of 3 to 12 m (10 to 40 ft), but they formed when sea levels were about 40 m (130 ft) lower than present (Scott et al. 2010). The Sedgefield Member is thought to date at least in part to Aminozone IIa, approximately 130,000 to 80,000 years ago (Mirecki et al. 1995; Scott et al. 2010). It has yielded a coral series with an average age of 71,000 ± 7,000 years old (Mixon et al. 1982; Mixon et al. 1989), and other corals, bivalves, and vertebrae have been dated to between about 120,000 to 60,000 years old (Scott et al. 2010). The Poquoson Member has wood that is older than radiocarbon dating. It and the underlying Lynnhaven Member are thought to have been deposited during Marine Isotope Stage 3, about 50,000 to 33,000 years ago. The Lynnhaven Member is thought to date to the early part of the stage, and the Poquoson Member is thought to date to the middle, representing two sea-level oscillations (Scott et al. 2010).

It is not clear if the Tabb Formation is fossiliferous within COLO. Johnson and Hobbs (2001) described it and the informal Kennon Formation as making up the surficial deposits of Jamestown Island. They extracted a number of microfossils from the deposits, going back to 37,000 years, which is younger than the postulated age of the Tabb Formation. Therefore, the fossil record is discussed under “Other Quaternary deposits”. Elsewhere, each member of the Tabb Formation is fossiliferous, with the Sedgefield Member being the most productive. The Sedgefield fossil assemblage is dominated by the bivalves *Crassostrea* and *Mercenaria* (Johnson et al. 1981). Foraminifera (Johnson et al. 1981), peat, stumps (in channel fill; Mixon et al. [1989]), wood (Colquhoun et al. 1991),

sponges (Johnson et al. 1981), corals (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), and vertebrae (Scott et al. 2010) have also been found. Fossils from this member are sometimes leached (Peebles et al. 1984). The Lynnhaven Member has plant material in channel fill (Mixon et al. 1989) and some burrows (Johnson and Berquist 1989). Peat and wood have been reported from the Poquoson Member (Scott et al. 2010).

Park Collections

COLO does not have fossils in its collections at this time (D. Guyer, COLO natural resource specialist, February 2014). However, it had a collection of fossils in the 1930s. Gerard Banks, a ranger-naturalist at COLO, collected specimens of at least 109 species in the summer of 1932, mostly bivalves and gastropods, and including other forms as well (apparently examples of all expected species outside of Bivalvia and Gastropoda had been located except for two mammals, a brachiopod, and a possible barnacle). Recent shells were also found and included for comparative purposes. A display had been arranged for the material at the Somerwell house, at that time the headquarters of COLO. The assistance of Joseph K. Roberts of the University of Virginia and Julia Gardner of the National Museum of Natural History had been arranged to identify the material (Banks 1932). This appears to have been discussed by COLO superintendent William M. Robinson, Jr., presenting an abstract in 1933. The information is not in Robinson (1933)'s abstract, but Roberts' (1942) annotation of the reference mentioned that a museum that had been started to display fossils from the York River bluffs of Yorktown. Roberts was present at the meeting where Robinson presented, so it possible that Roberts based his annotation on something Robinson said but did not include in the abstract, or on his interaction with Banks. No such display was noted in Phillips and Brennan (1983). Guyer (pers. comm., February 2014) reported that there had been a natural history collection including animal skeletons at Jamestown, "but it was removed in the 1980s because the specimens were treated with arsenic", and that any fossils that may have still been in the collections may have been removed at that time as well.

Fossils from COLO, or plausibly from COLO, can be found at several institutions in the United States and Europe. Collections featuring illustrated or named specimens definitely from COLO can be found at: the 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); the National Museum of Natural History (USNM) in Washington, D.C. (Dall 1892, 1900, 1903; Schuchert 1905; Cushman and Cahill 1933; Malkin 1953; Swain 1974; Wilson 1983; Dowsett and Wiggs 1992; Ward 1993 [Harris' 1890 collections]); and the Paleontological Research Institution (PRI) in Ithaca, New York (McLean 1956, 1957, 1966). Duplicate specimens from Malkin (1953)'s work were sent to Columbia University in New York City and Louisiana State University (LSU) in Baton Rouge, Louisiana (Henry V. Howe collections). Per McLean (1957), Denise Mongin collected ostracodes from Moore House Beach and brought these fossils to the Laboratorie de Geologie of the Institut Catholique in Paris, France. Fossils probably from COLO discussed in Johnson (1972) were reportedly curated by the Virginia Division of Mineral Resources (now the Division of Geology and Mineral Resources) in Charlottesville. Kenworthy and Santucci (2003)

reported that these fossils were at the College of William and Mary in Williamsburg, but they could still be reposited by the Virginia Division of Geology and Mineral Resources, which maintains an office at the college. The fossil collections of the Division of Geology and Mineral Resources are incompletely catalogued, but Michael Enomoto of the Division was able to locate six lots of specimens found within or adjacent to the Yorktown Battlefield part of COLO on short notice. The specimens included: a lot of bryozoans (VDMR F-00137), one gastropod (*Ecphora quadricostatus*) (VDMR F-00144), and two shipworm tubes (bivalve *Kuphus calamus*) (VDMR F-00145) from near British Redoubt #10; and a mass of barnacles (VDMR F-00146) (COLO Figure 5), two bivalves (*Dosinia acetabulum*), and a lot of snails (*Turritella alticostata*) (VDMR F-00148) (COLO Figure 6) from near Moore House (M. Enomoto, pers. comm., May 2014).



COLO Figure 5. Barnacle mass, VDMR F-00146 (photo courtesy Virginia Department of Geology and Mineral Resources).



COLO Figure 6. *Turritella alticostata*, VDMR F-00148 (photo courtesy Virginia Department of Geology and Mineral Resources).

Collections that came from nonspecific areas like Williamsburg and Yorktown, and thus potentially include COLO material, can be traced to the American Museum of Natural History (AMNH) in New York City, New York, the Natural History Museum (BMNH or NHM) in London, England, and the Museum of Comparative Zoology (MCZ) of Harvard in Cambridge, Massachusetts (Campbell 1993). The MCZ material was originally reposited at the Massachusetts Institute of Technology and passed through the Boston Society of Natural History before arriving at the current repository (Jones 1978; V. Wolf, Museum of Science assistant curator, pers. comm., May 2014). The

USGS transferred most of its fossils to the USNM, but records still exist regarding collections mentioned in several publications (Hazel 1971; Ward and Blackwelder 1975, 1980; Gibson 1983; Ward 1993).

An article in the Daily Press (Anonymous 1938) discussed the local collecting activities of a geologist named George Barclay, who collected various fossils from the shores of the James and York rivers during the mid-1930s for museums. Barclay obtained fossils from the Eastover

Formation (identified as “the St. Mary’s formation” in the article) from Scotland Wharf to Claremont on the James River and the Yorktown Formation from Wimberley’s Creek (modern name not known) to Queen’s Creek on the York River. He sent specimens to a number of institutions, including the AMNH, the BMNH, 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, the College of William and 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, the institutions are not included in the data sets.

An accounting of taxa named from COLO (COLO Table 2) and potentially named from COLO (COLO Table 3) provide a more complete inventory of these forms, but doubtless some are missing. As Campbell (1993) noted, more than 2,000 names have been proposed for mollusk species from the Yorktown Formation and its equivalent to the south, the Duplin Formation, and sorting through the taxonomy of Yorktown Formation fossils is a difficult task. Relying on the literature can be problematic: many of the works on the paleontology of the Yorktown Formation have important errors, particularly in taxonomic identifications, localities, and stratigraphy (Campbell 1993). Species named from “the James River,” a provenance most common in Conrad (1834), are omitted. Conrad (1833; 1839) frequently referred to specimens from the Smithfield area on the river, making it likely that these came from the same area. Additionally, there do not appear to be historic collecting areas of note within modern COLO boundaries on the James River, unlike Yorktown on the York River. Most of the forms in COLO Table 3 were either described from a general Yorktown locality (most of the Conrad citations), or are part of the John Finch collections that are probably from Yorktown (Green, Lea, and Say citations). A few forms in the table are from “Williamsburg” in general (primarily Rogers and Rogers 1837 and 1839), although it is likely that they were obtained outside of COLO boundaries.

COLO Table 2. Fossil taxa named from specimens found within COLO ("Yorktown" refers to the formation, not the location). The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column.

Taxon	Publication	Catalog Number	Provenance	Notes
Venus plena var. *inflata*	Dall 1903	USNM 163419	Pliocene, Yorktown	Bivalve
Diplodonta berryi	McGavock 1944	ANSP 16013	Pliocene, Yorktown	Bivalve
Diplodonta conradi	McGavock 1944	ANSP 16014	Pliocene, Yorktown	Bivalve
Petricola rogersi	McGavock 1944	ANSP 16015	Pliocene, Yorktown	Bivalve
Petricola (*Rupellaria*) *harrisii*	Dall 1900	USNM 145020	Pliocene, Yorktown	Bivalve
Venus plena var. *nucea*	Dall 1903	USNM 163418	Pliocene, Yorktown	Bivalve
Calliostoma harrisii	Dall 1892	USNM 113052	Pliocene, Yorktown	Gastropod
Ilyanassa (*Paranassa*) *isogramma*	Dall 1892	USNM 124948	Pliocene, Yorktown	Gastropod
Teinostoma pseudaeorbis	Dall 1892	USNM 112653	Pliocene, Yorktown	Gastropod
Murrayina barclayi	McLean 1957	PRI 22588	Pliocene, Yorktown	Ostracode
Cytherideis echolsae	Malkin 1953	Syntypes USNM 256023, 311872, 311873, and 311874	Pliocene, Yorktown	Ostracode
Clithrocytheridea virginiensis	Malkin 1953	Syntypes USNM 256020, 311894, 311960, 311961, and 311962	Pliocene, Yorktown	Ostracode
Paracytheridea similis	Malkin 1953	Syntypes USNM 256038 and 311939	Pliocene, Yorktown	Ostracode
Paracytheridea shattucki curta	Malkin 1953	Syntypes USNM 256037, 311893, and 311976 (not all from COLO)	Pliocene, Yorktown	Ostracode
Eocytheropteron yorktownensis	Malkin 1953	Syntypes USNM 256025, 311940, 311941, and 311959 (not all from COLO)	Pliocene, Yorktown	Ostracode
Hemicythere schmidtae	Malkin 1953	Syntypes USNM 256033, 311936, 311937, 311970, and 311971 (not all from COLO)	Pliocene, Yorktown	Ostracode
Quinqueloculina triloculiniforma	McLean 1956	PRI 22111	Pliocene, Yorktown	Foraminifera
Dentalina kaicherae	McLean 1956	PRI 22145	Pliocene, Yorktown	Foraminifera
Lagena pseudosulcata	McLean 1956	PRI 22174	Pliocene, Yorktown	Foraminifera
Elphidium kaicherae	McLean 1956	PRI 22282	Pliocene, Yorktown	Foraminifera
Bolivina lafayettei	McLean 1956	PRI 22299	Pliocene, Yorktown	Foraminifera
Loxostomum wilsoni	McLean 1956	PRI 22301	Pliocene, Yorktown	Foraminifera
Orbulina cornwallisi	McLean 1956	PRI 22411	Pliocene, Yorktown	Foraminifera
Rotalia limbatobeccarii	McLean 1956	Syntypes PRI 22365-22369	Pliocene, Yorktown	Foraminifera
Massilina mansfieldi	Cushman and Cahill 1933	USNM 37135	Pliocene, Yorktown	Foraminifera

COLO Table 3. Fossil taxa named from specimens possibly found within COLO ("Yorktown" refers to the formation, not the location). The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column.

Taxon	Publication	Catalog Number	Provenance	Notes
Balanus finchii	Lea 1833	Unknown	Pliocene, Yorktown	Barnacle
Balanus proteus	Conrad 1834	ANSP 18813?	Pliocene, Yorktown	Barnacle
Abra ovalis	Conrad 1862b	Missing ANSP specimen	Pliocene, Yorktown	Bivalve
Amphidesma subovata	Say 1824	BMNH L-13298	Pliocene, Yorktown	Bivalve
Anatina antiqua	Conrad 1834	ANSP 19648	Pliocene, Yorktown	Bivalve
Arca centenaria	Say 1824	BMNH L-13206	Pliocene, Yorktown	Bivalve
Arca incile	Say 1824	BMNH L-13205	Pliocene, Yorktown	Bivalve
Astarte concentrica	Conrad 1834	Missing ANSP specimen	Pliocene, Yorktown	Bivalve
Astarte orbicularior	Meyer 1888	USNM 638907	Pliocene, Yorktown	Bivalve
Astarte symmetrica	Conrad 1834	Missing ANSP specimen	Pliocene, Yorktown	Bivalve
Astarte undulata	Say 1824	Missing BMNH specimen	Pliocene, Yorktown	Bivalve
Astarte vicina	Say 1824	Missing BMNH specimen	Pliocene, Yorktown	Bivalve
Cardium acutilaqueatum	Conrad 1839	Missing ANSP specimen	Pliocene, Yorktown	Bivalve
Corbula cuneata	Say 1824	Lost BMNH specimen	Pliocene, Yorktown	Bivalve
Corbula inaequale	Say 1824	Lost BMNH specimen	Pliocene, Yorktown	Bivalve
Crassinella lunulata harrisi	Gardner 1943	USNM 1630	Pliocene, Yorktown	Bivalve
Cytherea pandata	Conrad 1834	Syntypes ANSP 30573 and 30574?	Pliocene, Yorktown	Bivalve
Diplodonta yorkensis	Dall 1900	USNM 144548	Pliocene, Yorktown	Bivalve
Erycinella ovalis	Conrad 1845	ANSP 30621	Pliocene, Yorktown	Bivalve
Gemma magna virginiana	Dall 1903	Cotypes including USNM 144643	Pliocene, Yorktown	Bivalve
Isocardia fraterna	Say 1824	BMNH L-13202	Pliocene, Yorktown	Bivalve
Lithophaga pectinicola	Olsson 1916	PRI 1372	Pliocene, Yorktown	Bivalve
Lithophaga yorkensis	Olsson 1914	PRI 3491 and 3493	Pliocene, Yorktown	Bivalve
Lucina acclinis	Conrad 1832	Missing ANSP specimen	Pliocene, Yorktown	Bivalve
Lucina anodonta	Say 1824	BMNH L-13198	Pliocene, Yorktown	Bivalve
Lucina contracta	Say 1824	BMNH L-13196	Pliocene, Yorktown	Bivalve
Lucina cribraria	Say 1824	Unnumbered BMNH specimen	Pliocene, Yorktown	Bivalve
Macoma cookei	Gardner 1943	USNM 325592	Pliocene, Yorktown	Bivalve
Macoma virginiana	Conrad 1866	Missing ANSP specimen	Pliocene, Yorktown	Bivalve
Mactra clathrodon	Lea 1833	ANSP 3309	Pliocene, Yorktown	Bivalve
Mactra clathrodonta	Conrad 1833	ANSP 16242	Pliocene, Yorktown	Bivalve
Mactra confraga	Conrad 1833	ANSP 30560	Pliocene, Yorktown	Bivalve
Mactra modicella	Conrad 1833	ANSP 4311	Pliocene, Yorktown	Bivalve
Mactra virginiana	Conrad 1867a	Missing ANSP specimen	Pliocene, Yorktown	Bivalve
Modiolaria virginica	Conrad 1867b	Missing ANSP specimen	Pliocene, Yorktown	Bivalve
Montacuta sagrinata	Dall 1900	USNM 155772	Pliocene, Yorktown	Bivalve
Mya producta	Conrad 1839	Missing ANSP specimen (possibly at the Wagner Free Institute of Science)	Pliocene, Yorktown	Bivalve

COLO Table 3 (continued). Fossil taxa named from specimens possibly found within COLO ("Yorktown" refers to the formation, not the location). The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column.

Taxon	Publication	Catalog Number	Provenance	Notes
Mytillus lateralis	Say 1822	ANSP 52663	Pliocene, Yorktown	Bivalve
Natica interna	Say 1824	Unnumbered BMNH specimen	Pliocene, Yorktown	Bivalve
Nucula laevis	Say 1824	Missing BMNH specimen	Pliocene, Yorktown	Bivalve
Ostrea compressirostra	Say 1824	BMNH L-13204	Pliocene, Yorktown	Bivalve
Pandora (*Clidiophora*) *prodromos*	Gardner and Aldrich 1919	USNM 325499	Pliocene, Yorktown	Bivalve
Pandora arenosa	Conrad 1834	ANSP 30584	Pliocene, Yorktown	Bivalve
Panopaea reflexa	Say 1824	BMNH L-13200a	Pliocene, Yorktown	Bivalve
Pecten clintonius	Say 1824	BMNH L-13203	Pliocene, Yorktown	Bivalve
Pecten madisonius	Say 1824	ANSP 31787	Pliocene, Yorktown	Bivalve
Pecten septenarius	Say 1824	BMNH L-13197	Pliocene, Yorktown	Bivalve
Pecten yorkensis	Conrad 1867a	Missing ANSP specimen	Pliocene, Yorktown	Bivalve
Pectunculus subovatus	Say 1824	BMNH L-13209	Pliocene, Yorktown	Bivalve
Phacoides (*Cardiolucina*) *postalveatus*	Gardner 1943	USNM 325539	Pliocene, Yorktown	Bivalve
Pholadomya abrupta	Conrad 1832	Syntypes ANSP 20386	Pliocene, Yorktown	Bivalve
Plicatula marginata	Say 1824	BMNH L-13199	Pliocene, Yorktown	Bivalve
Semele? *virginiana*	Meyer 1888	USNM 638911	Pliocene, Yorktown	Bivalve
Sportella yorkensis	Dall 1900	USNM 144323	Pliocene, Yorktown	Bivalve
Tellina aequistriata	Say 1824	Missing BMNH specimen	Pliocene, Yorktown	Bivalve
Tellina declivis	Conrad 1834	ANSP 4306	Pliocene, Yorktown	Bivalve
Tellina gardnerae	McGavock 1944	ANSP 16012	Pliocene, Yorktown	Bivalve
Venericardia granulata	Say 1824	Unnumbered BMNH specimen	Pliocene, Yorktown	Bivalve
Venus rileyi	Conrad 1839	Syntypes ANSP 20084	Pliocene, Yorktown	Bivalve
Pecten jeffersonius	Say 1824	BMNH L-13212	Pliocene, Yorktown	Bivalve
Cytherea convexa	Say 1824	BMNH L-13210	Pliocene, Yorktown	Bivalve; preoccupied, renamed *Cytherea sayana* (Conrad 1833)
Anachis harrisii	Dall 1892	USNM 113258	Pliocene, Yorktown	Gastropod
Buccinum porcinum	Say 1824	BMNH Q-12191	Pliocene, Yorktown	Gastropod
Busycon alveatum	Conrad 1862a	ANSP 2697	Pliocene, Yorktown?	Gastropod
Busycon filosum	Conrad 1862b	ANSP 14310	Pliocene, Yorktown	Gastropod
Busycon tritonis	Conrad 1862a	ANSP 14323 and 14324	Pliocene, Yorktown	Gastropod
Caecum stevensoni	Meyer 1888	Missing AMNH specimen	Pliocene, Yorktown	Gastropod

COLO Table 3 (continued). Fossil taxa named from specimens possibly found within COLO ("Yorktown" refers to the formation, not the location). The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column.

Taxon	Publication	Catalog Number	Provenance	Notes
Caecum virginianum	Meyer 1888	Missing AMNH specimen	Pliocene, Yorktown	Gastropod
Calliostoma conradi	Gardner 1948	USNM 325468	Pliocene, Yorktown	Gastropod
Calliostoma virginicum gizehi	Gardner 1948	USNM 325467	Pliocene, Yorktown	Gastropod
Calyptraea costata	Say 1824	ANSP 15294	Pliocene, Yorktown	Gastropod
Calyptraea grandis	Say 1824	BMNH Q-12190	Pliocene, Yorktown	Gastropod
Conus marylandicus	Green 1830	Unknown	Pliocene, Yorktown	Gastropod
Delphinula arenosa	Conrad 1846	Missing ANSP specimen	Pliocene, Yorktown	Gastropod
Fissurella redimicula	Say 1824	Missing BMNH specimen	Pliocene, Yorktown	Gastropod
Fulgur incilis	Conrad 1833	ANSP 1637	Pliocene, Yorktown	Gastropod
Fulgur maximus	Conrad 1839	ANSP 17191	Pliocene, Yorktown	Gastropod
Fusus 4-costatus [*Fusus quadricostatus*]	Say 1824	BMNH GG 12661	Pliocene, Yorktown	Gastropod
Fusus pumilis	Lea 1833	ANSP 13827a	Pliocene, Yorktown	Gastropod
Mangelia virginiana	Conrad 1862b	ANSP 30737	Pliocene, Yorktown	Gastropod
Melampus (*Ensiphorus*) *longidens*	Conrad 1862a	Missing ANSP specimen	Pliocene, Yorktown	Gastropod
Natica perspectiva	Rogers and Rogers 1837	Unknown	Pliocene, Yorktown	Gastropod
Odostomia limnia	Conrad 1846	Missing ANSP specimen	Pliocene, Yorktown	Gastropod
Odostomia protexta	Conrad 1846	ANSP 15631?	Pliocene, Yorktown	Gastropod
Pyramis promilium	Meyer 1888	USNM 638905	Pliocene, Yorktown	Gastropod
Rotella nana	Lea 1833	ANSP 1569	Pliocene, Yorktown	Gastropod
Teinostoma (*Solariorbis*) *variabilis*	Olsson 1914	PRI 3512	Pliocene, Yorktown	Gastropod
Terebra (*Strioterebrum*?) *grayi*	Gardner 1948	USNM 325369	Pliocene, Yorktown	Gastropod
Tritonalia? *barbitoides*	Gardner 1948	USNM 325429	Pliocene, Yorktown	Gastropod
Turritella fluxionalis	Rogers and Rogers 1839	Unknown	Pliocene, Yorktown	Gastropod
Turritella quadri-striata	Rogers and Rogers 1837	MCZ 29170	Pliocene, Yorktown	Gastropod
Dentalium attenuatum	Say 1824	Unnumbered BMNH specimen	Pliocene, Yorktown	Scaphopod
Serpula granifera	Say 1824	BMNH GG12662	Pliocene, Yorktown	Serpulid worm tube
Prorosmarus alleni	Berry and Gregory 1906	USNM 9343	Pliocene, Yorktown	Walrus, now considered a synonym of *Ontocetus emmonsi*
Miliola marylandica	Lea 1833	ANSP 79409	Pliocene, Yorktown	Foraminifera
Spirillina orbicularis	Bagg 1898	USNM 371526	Pliocene, Yorktown	Foraminifera

Cultural Resource Contexts

Fossils from COLO have a number of connections to cultural contexts. The historic aspects of Yorktown fossils have already been discussed. The abundant shells of the York-James Peninsula have long been an economic resource, used primarily for agricultural purposes (Rogers and Rogers 1837; Clark and Miller 1906; Clark et al. 1912). The coquina of the Yorktown Formation has also been used for construction. Local Yorktown Formation coquina was used to build Grace Episcopal Church in Yorktown (Roberts 1932; Johnson et al. 1981). Coquina from Yorktown was also used for fill at Fort Monroe (see FOMR section for more information), but it deteriorated quickly and was replaced with Petersburg granite (Frye 1986). Cornwallis Cave is within the coquina as well (Roberts 1932). Limestone (unspecified provenance) with fossil fragments has been used in the keystone and buttress caps of a bridge overpass on the Colonial Overpass south of Williamsburg (Webb and Sweet 1993). Because of the long history of human habitation at Jamestown and the area, there is also the possibility of finding fossils in archeological contexts, such as fossils and fossiliferous stones used for tools or other artifacts. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts, including a discussion of Lister's *Chesapecten jeffersonius*.

Paleontological Resource Management, Preliminary Recommendations

- A dedicated paleontological inventory for COLO would be of great value. The park contains substantial quantities of fossils that are exposed to erosion, unauthorized collecting, and other issues that are of management concern (although shore protection has covered many exposures), and its fossils are of enormous historical interest, with untapped educational potential.
- Park staff should be encouraged to observe exposed sedimentary deposits for fossil material while conducting their usual duties. To promote this, they should also 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, recreation area staff should take advantage of them, if funding and time permit.
- Staff should photodocument and monitor any occurrences of paleontological resources that may be observed in situ. Fossils and their associated geologic context (surrounding rock/sediments) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. 2009).
- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist. Any fossil with 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.
- Quaternary fossils and deposits are of interest because they can be used to describe the effects of past climate and sea level changes, and to predict natural responses to future changes. Further study of these fossils and deposits in and around COLO is encouraged.

- The fate of the Banks collection, formerly on display at COLO, should be investigated. If some or all of the material still exists, it could be used in a new exhibit.
- Contact the NPS Geologic Resources Division for technical assistance with paleontological resource management issues.

References Cited

Akers, H. W., and P. E. Koeppel. 1974. Age of some Neogene formations, Atlantic Coastal Plains, United States and Mexico. Pages 80-93 *in* L. A. Smith and J. Hardenbol, editors. Symposium on calcareous nannofossils, proceedings. Gulf Coast Section of the Society of Economic Paleontology and Mineralogy, Houston, Texas.

Andrews, G. W. 1986. Miocene diatoms from Richmond, Virginia. *Journal of Paleontology* 60(2):497–538.

Anonymous. 1811. Curious discovery [elephant bones from York River, Williamsburg, Virginia]. *Philadelphia Repertory* 2:87–88. Available at http://books.google.com/books?id=Maw7AQAAMAAJ (accessed January 2014).

Anonymous. 1938. Barclay prepares specimens from Va. for British Museum in London. Daily Press, Newport News, April 10, 1938.

Bagg, R. M., Jr. 1898. The Tertiary and Pleistocene foraminifera of the middle Atlantic slope. *Bulletins of American Paleontology* 2(10). Available at http://biodiversitylibrary.org/page/30681179 (accessed January 2014).

Bailey, R. H. 1987. Stratigraphy and depositional history of the Yorktown Formation in northeastern North Carolina. *Southeastern Geology* 28(1):1–19.

Banks, G. 1932. Memorandum for monthly report [August 2, 1938]. Subject: Natural History Museum. Unpublished National Park Service report. On file at COLO.

Barber, M. B. 1978. The vertebrate faunal analysis of JC27 (James City County, Virginia): an exercise in plow zone archeology. *Quarterly Bulletin of the Archaeological Society of Virginia* 32(4):94–100.

Barbour, S. L. 1998. Prey selectivity and paleoecology of gastropod predatory borings in bivalves of the Yorktown Formation (Pliocene) of Virginia. *Abstracts with Programs - Geological Society of America* 30(4):2.

Baum, G. R., and W. H. Wheeler. 1977. Cetaceans from the St. Marys and Yorktown formations, Surry County, Virginia. *Journal of Paleontology* 51(3):492–504.

Berry, E. W., and W. K. Gregory. 1906. *Prorosmarus alleni*, a new genus and species of walrus from the upper Miocene of Yorktown, Virginia. *American Journal of Science* (series 4) 21(126):444–450. Available at http://books.google.com/books?id=9kMPAAAAIAAJ (accessed January 2014).

Bevan, A. C. 1957. Geologic ancestry of the York-James Peninsula. *Virginia Journal of Science* 8(1):19–34.

Bick, K. F., and N. K. Coch. 1969. Geology of the Williamsburg, Hog Island, and Bacons Castle quadrangles, Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Report of Investigations 18. Available at http://www.dmme.virginia.gov/commercedocs/RI_18.pdf (accessed January 2014).

Blackwelder, B. W. 1981. Late Cenozoic marine deposition in the United States Atlantic Coastal Plain related to tectonism and global climate. *Palaeogeography, Palaeoclimatology, Palaeoecology* 34:87–114.

Blow, W. C. 2003. New brachyuran crabs (Crustacea, Decapoda) from the upper Pliocene Yorktown Formation of southeastern Virginia. *Proceedings of the Biological Society of Washington* 116(1):168–189. Available at http://decapoda.nhm.org/pdfs/30802/30802.pdf (accessed January 2014).

Blow, W. C., and R. H. Bailey. 1992. *Chasmocarcinus robertsi*, a new crab species from the Miocene of Virginia, with notes on the genus *Falconoplax*: Crustacea, Decapoda, Goneplacidae. *Tulane Studies in Geology and Paleontology* 25(4):175–185.

Blow, W. C., and R. H. Bailey. 2003. A late Pliocene pea crab infestation of the slipper-shell *Crepidula fornicata* (Linnaeus, 1758) from the Yorktown Formation of southeastern Virginia. *Abstracts with Programs - Geological Society of America* 35(6):58.

Burns, J. 1991. Fossil collecting in the Mid-Atlantic states. Johns Hopkins University Press, Baltimore, Maryland.

Campbell, L. D. 1993. Pliocene molluscs from the Yorktown and Chowan River formations in Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 127. Available at http://www.dmme.virginia.gov/commercedocs/PUB_127.pdf (accessed January 2014).

Campbell, M. R. 1997. Pliocene nannofossil correlations of the Yorktown Formation. *Abstracts with Programs - Geological Society of America* 29(6):103.

Cederstrom, D. J. 1957. Geology and ground-water resources of the York-James Peninsula, Virginia. U.S. Geological Survey, Washington, DC. Water-Supply Paper 1361. Available at http://pubs.er.usgs.gov/publication/wsp1361 (accessed January 2014).

Chuang, S. H. 1964. On *Glottidia inexpectans* Olsson. *Journal of Paleontology* 38(1):153–155.

Clark, W. B., and B. L. Miller. 1906. Clay deposits of the Virginia coastal plain. *Virginia Geological Survey Bulletin* 2(1). Available at http://www.dmme.virginia.gov/commercedocs/BUL_2.pdf (accessed January 2014).

Clark, W. B., B. L. Miller, E. W. Berry, and T. L. Watson. 1912. The physiography and geology of the coastal plain province of Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 4. Available at http://www.dmme.virginia.gov/commercedocs/BUL_4.pdf (accessed January 2014).

Clarke, M. R., and J. E. Fitch. 1975. First fossil records of cephalopod statoliths. *Nature* 257:380–381.

Cocke, E. C., I. F. Lewis, and R. Patrick. 1934. A further study of Dismal Swamp peat. *American Journal of Botany* 21(7):374–395.

Collins, G. S., and K. Wünnermann. 2005. How big was the Chesapeake Bay impact? Insights from numerical modeling. *Geology* 33(12):925–928.

Colquhoun, D. J., G. H. Johnson, P. C. Peebles, P. F. Huddlestun, and T. Scott. 1991. Quaternary geology of the Atlantic Coastal Plain. Pages 629–650 *in* R. B. Morrison, editor. Quaternary nonglacial geology: conterminous U.S. The geology of North America K-2. Geological Society of America, Boulder, Colorado.

Conrad, T. A. 1832. Fossils of the medial Tertiary or Miocene Formation of the United States 1. Judah Dobson, Philadelphia, PA. Available at http://books.google.com/books?id=T7vPAAAAIAAJ (accessed January 2014).

Conrad, T. A. 1833. On some new fossil and recent shells of the United States. *American Journal of Science*, 1st series, 23(2):339–346. Available at http://biodiversitylibrary.org/page/27909441 (accessed January 2014).

Conrad, T. A. 1834. Descriptions of new Tertiary fossils from the southern states. *Journal of the Academy of Natural Sciences of Philadelphia*, 1st series, 7:130–157. Available at http://biodiversitylibrary.org/page/24676784 (accessed January 2014).

Conrad, T. A. 1839. Fossils of the medial Tertiary of the United States 1. Judah Dobson, Philadelphia, Pennsylvania. Available at http://books.google.com/books?id=asoQAAAAIAAJ (accessed January 2014).

Conrad, T. A. 1845. Fossils of the medial Tertiary or Miocene Formation of the United States 3. Judah Dobson, Philadelphia, Pennsylvania. Available at http://books.google.com/books?id=XgszAQAAIAAJ (accessed January 2014).

Conrad, T. A. 1846. Descriptions of new species of fossil and recent shells and corals. *Proceedings of the Academy of Natural Sciences* 3(1):19–27. Available at http://biodiversitylibrary.org/page/1659288 (accessed January 2014).

Conrad, T. A. 1862a. Descriptions of new, recent, and Miocene shells. *Proceedings of the Academy of Natural Sciences of Philadelphia* 14:583-586. Available at http://biodiversitylibrary.org/page/1952057 (accessed January 2014).

Conrad, T. A. 1862b. Descriptions of new genera, subgenera, and species of Tertiary and recent shells. *Proceedings of the Academy of Natural Sciences of Philadelphia* 14:284–291. Available at http://biodiversitylibrary.org/page/1951756 (accessed January 2014).

Conrad, T. A. 1866. Note on the genus *Gadus* with descriptions of some new genera and species of American fossil shells. *American Journal of Conchology* 2(1):75–78. Available at http://biodiversitylibrary.org/page/15841041 (accessed January 2014).

Conrad, T. A. 1867a. Notes on fossil shells and descriptions of new species. *American Journal of Conchology* 3(2):188–190. Available at http://biodiversitylibrary.org/page/6658790 (accessed January 2014).

Conrad, T. A. 1867b. Descriptions of new genera and species of Miocene shells, with notes on other fossil and recent species. *American Journal of Conchology* 3(4):257–270. Available at http://biodiversitylibrary.org/page/6658871 (accessed January 2014).

Corbett, M. J. 2007. Taphonomy and bioerosion of a Pliocene coral thicket from Virginia, using computer based area analysis. *Abstracts with Programs - Geological Society of America* 39(1):73.

Cronin, T. M., L. M. Bybell, R. Z. Poore, B. W. Blackwelder, J. C. Liddicoat, and J. E. Hazel. 1984. Age and correlation of emerged Pliocene and Pleistocene deposits, U.S. Atlantic Coastal Plain. *Palaeogeography, Palaeoclimatology, Palaeoecology* 47(1–2):21–51.

Cronin, T. M., H. J. Dowsett, L. B. Gosnell, and R. M. Ross. 1989. Pliocene marine micropaleontology of southeastern Virginia and northeastern North Carolina. U.S. Geological Survey, Reston, Virginia. Open-File Report 89-678. Available at http://pubs.usgs.gov/of/1989/0678/report.pdf (accessed January 2014).

Cushman, J. A. and E. D. Cahill. 1933. Miocene foraminifera of the coastal plain of the eastern United States. Pages 1–50 in Shorter contributions to general geology, 1932-33. U.S. Geological Survey, Washington, D.C. Professional Paper 175. Available at http://pubs.er.usgs.gov/publication/pp175A (accessed January 2014).

Cushman, J. A., and D. J. Cederstrom. 1945. An upper Eocene foraminiferal fauna from deep wells in York County, Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 67. Available at http://www.dmme.virginia.gov/commercedocs/BUL_67.pdf (accessed January 2014).

Dall, W. H. 1892. Contributions to the Tertiary fauna of Florida, with especial reference to the Miocene Silex-beds of Tampa and the Pliocene beds of the Caloosahatchie River. Part II. Transactions of the Wagner Free Institute of Science of Philadelphia 3(2). Available at https://archive.org/details/contributionsto00dallgoog (accessed January 2014).

Dall, W. H. 1900. Contributions to the Tertiary fauna of Florida, with especial reference to the Miocene Silex-beds of Tampa and the Pliocene beds of the Caloosahatchie River. Part V. Transactions of the Wagner Free Institute of Science of Philadelphia 3(5). Available at https://archive.org/details/contributionstot35dallrich (accessed January 2014).

Dall, W. H. 1903. Contributions to the Tertiary fauna of Florida, with especial reference to the Miocene Silex-beds of Tampa and the Pliocene beds of the Caloosahatchie River. Part VI. Transactions of the Wagner Free Institute of Science of Philadelphia 3(6). Available at https://archive.org/details/contributionstot36dallrich (accessed January 2014).

Dischinger, J. B., Jr. 1987. Late Mesozoic and Cenozoic stratigraphic and structural framework near Hopewell, Virginia. U.S. Geological Survey, Reston, Virginia. Bulletin 1567. Available at http://pubs.er.usgs.gov/publication/b1567 (accessed January 2014).

Dowsett, H. J., and L. B. Wiggs. 1992. Planktonic foraminiferal assemblage of the Yorktown Formation, Virginia, USA. *Micropaleontology* 38(1):75–86.

Eshelman, R., and F. Grady. 1986. Quaternary vertebrate localities of Virginia and their avian and mammalian fauna. Pages 43–70 *in* J. N. McDonald and S. O. Bird, editors. The Quaternary of Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 75. Available at http://www.dmme.virginia.gov/commercedocs/PUB_75.pdf (accessed January 2014).

Fierstine, H. L. 1998. *Makaira* sp. cf. *M. nigricans* Lacepede, 1802 (Teleostei, Perciformes, Istiophoridae) from the Eastover Formation, late Miocene, Virginia, and a reexamination of *Istiophorus calvertensis* Berry, 1917. *Journal of Vertebrate Paleontology* 18(1):30–42.

Fierstine, H. L. 1999. A new shortbilled marlin of the genus Makaira, from the Yorktown Formation (early Pliocene), eastern North Carolina at Lee Creek Mine, USA. *Tertiary Research* 19(3–4):71–77. Available at http://digitalcommons.calpoly.edu/bio_fac/19/ (accessed January 2014).

Fierstine, H. L. 2001. Analysis and new records of billfish (Teleostei: Perciformes: Istiophoridae) from the Yorktown Formation, early Pliocene of eastern North Carolina at Lee Creek Mine. Pages 21–69 *in* C. E. Ray and D. J. Bohaska, editors. Geology and paleontology of the Lee Creek Mine, North Carolina, III. Smithsonian Contributions to Paleobiology 90. Available at http://si-pddr.si.edu/dspace/handle/10088/2006 (accessed January 2014).

Forester, R. M. 1980. A systematic revision of the ostracode species described by Ulrich and Bassler and by Malkin from the Chesapeake Group in Maryland and Virginia. U.S. Geological Survey, Reston, Virginia. Professional Paper 1128. Available at http://pubs.er.usgs.gov/publication/pp1128 (accessed January 2014).

Frye, K. 1986. Roadside geology of Virginia. Mountain Press Publishing Company, Missoula, Montana.

Gardner, J. 1943. Mollusca from the Miocene and lower Pliocene of Virginia and North Carolina. Part 1. Pelecypoda. U.S. Geological Survey, Washington, D.C. Professional Paper 199-A. Available at http://pubs.er.usgs.gov/publication/pp199A (accessed January 2014).

Gardner, J. 1948. Mollusca from the Miocene and lower Pliocene of Virginia and North Carolina. Part 2. Scaphopoda and Gastropoda. U.S. Geological Survey, Washington, D.C. Professional Paper 199-B. http://pubs.er.usgs.gov/publication/pp199B (accessed January 2014).

Gardner, J. A., and T. H. Aldrich. 1919. Mollusca from the Upper Miocene of South Carolina with descriptions of new species. *Proceedings of the Academy of Natural Sciences of Philadelphia* 71(1):17-53. Available at http://biodiversitylibrary.org/page/1970633 (accessed January 2014)

Geisler, J. H., S. J. Godfrey, and O. Lambert. 2012. A new genus and species of late Miocene inioid (Cetacea, Odontoceti) from the Meherrin River, North Carolina, U.S.A. *Journal of Vertebrate Paleontology* 32(1):198–211.

Gibson, M. L., and J. H. Geisler. 2009. A new Pliocene dolphin (Cetacea, Pontoporiidae), from the Lee Creek Mine, North Carolina. *Journal of Vertebrate Paleontology* 29(3):966–971.

Gibson, T. G. 1983. Key foraminifera from Upper Oligocene to Lower Pleistocene strata of the central Atlantic coastal plain. Pages 355–453 *in* C. E. Ray, editor. Geology and paleontology of the Lee Creek Mine, North Carolina: I. Smithsonian Contributions to Paleobiology 53. http://si-pddr.si.edu/dspace/handle/10088/1975 (accessed January 2014).

Green, J. 1830. Monograph of the cones of North America, including three new species. *Transactions of the Albany Institute* 1:121–125. Available at http://books.google.com/books?id=DjQgAQAAIAAJ (accessed January 2014).

Groot, J. J. 1991. Palynological evidence for late Miocene, Pliocene, and Early Pleistocene climate changes in the Middle U.S. Atlantic Coastal Plain. *Quaternary Science Reviews* 10:147–166.

Hagadorn, J. W., and G. E. Boyajian. 1997. Subtle changes in mature predator-prey systems: an example from Neogene Turritella (Gastropoda). *Palaios* 12(4):372–379.

Harris, M. S., and G. H. Johnson. 1986. *Prorosmarus alleni*, a giant walrus from the Yorktown Formation (Pliocene), Williamsburg, Virginia. *Virginia Journal of Science* 37(2):106.

Hay, O. P. 1923. The Pleistocene of North America and its vertebrated animals from the states east of the Mississippi River and from the Canadian provinces east of longitude 95 degrees. Carnegie Institution of Washington, Washington, D.C. Publication 322. Available at https://archive.org/details/pleistoceneofnor00hayouoft (accessed January 2014).

Hazel, J. E. 1971. Ostracode biostratigraphy of the Yorktown Formation (upper Miocene and lower Pliocene) of Virginia and North Carolina. U.S. Geological Survey, Washington, DC. Professional Paper 704. Available at http://pubs.er.usgs.gov/publication/pp704 (accessed January 2014).

Hazel, J. E. 1977. Distribution of some biostratigraphically diagnostic ostracodes in the Pliocene and lower Pleistocene of Virginia and northern North Carolina. *Journal of Research of the U.S. Geological Survey* 5(3):373–388. Available at http://pubs.er.usgs.gov/publication/70007420 (accessed January 2014).

Hazel, J. E. 1983. Age and correlation of the Yorktown (Pliocene) and Croatan (Pliocene and Pleistocene) formations at the Lee Creek Mine. Pages 83–191 *in* C. E. Ray, editor. Geology and paleontology of the Lee Creek Mine, North Carolina: I. Smithsonian Contributions to Paleobiology 53. http://si-pddr.si.edu/dspace/handle/10088/1975 (accessed January 2014).

Herman, J. D. 1991. The effects of groundwater leaching on fossil preservation in the Yorktown Fm. *Virginia Journal of Science* 42(2):220. Available at http://www.vacadsci.org/vjsArchives/V42/42-2/42-155.pdf (accessed January 2014).

Hueber, F. M. 1983. Fossil woods and resin-like substances from the Lee Creek Mine. Pages 269–285 *in* C. E. Ray, editor. Geology and paleontology of the Lee Creek Mine, North Carolina: I. Smithsonian Contributions to Paleobiology 53. Available at http://si-pddr.si.edu/dspace/handle/10088/1975 (accessed January 2014).

Johnson, G. H. 1972. Geology of the Yorktown, Poquoson West, and Poquoson East quadrangles, Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Report of Investigations 30. Available at http://www.dmme.virginia.gov/commercedocs/RI_30.pdf (accessed January 2014).

Johnson, G. H., and C. R. Berquist, Jr. 1989. Geology and mineral resources of the Brandon and Norge quadrangles, Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 87. Available at http://www.dmme.virginia.gov/commercedocs/PUB_87.pdf (accessed January 2014).

Johnson, G. H., and C. H. Hobbs, III. 2001. The geology of Jamestown Island. Pages 9–78 *in* G. Johnson, C. Hobbs, S. Mrozowski, D. Currie, G. Kelso, D. Blanton, L. Kealhofer and A. Horning, editors. Geological development and environmental reconstruction of Jamestown Island. Colonial Williamsburg Foundation–College of William and Mary, Williamsburg, Virginia.

Johnson, G. H., and K. W. Ramsey. 1987. Geology and geomorphology of the York-James Peninsula, Virginia. College of William and Mary, Williamsburg, Virginia.

Johnson, G. H., C. R. Berquist, K. W. Ramsey, and P. C. Peebles. 1981. Guidebook to the late Cenozoic geology and economic geology of the lower York-James Peninsula, Virginia. College of William and Mary, Williamsburg, Virginia. Department of Geology Guidebook 2. 1981 edition.

Johnson, G. H., S. E. Kruse, A. W. Vaughn, J. K. Lucey, C. H. Hobbs, III, and D. S. Powars. 1998. Postimpact deformation associated with the late Eocene Chesapeake Bay impact structure in southeastern Virginia. *Geology* 26(6):507–510.

Jones, C. C. 1978. The type of *Chione cortinaria* (W. B. Rogers and H. D. Rogers) (Mollusca: Bivalvia). *Journal of Paleontology* 52(3):746–747.

Kallal, R. J., S. J. Godfrey, and D. J. Ortner. 2012. Bone reactions on a Pliocene cetacean rib indicate short-term survival of predation event. *International Journal of Osteoarchaeology* 22(3):253–260.

Kelley, P. H., S. E. Barrett, J. M. Clifton, W. B. Edwards, D. T. Hill, J. N. Jancauskas, and J. W. O'Connor. 2007. Relationship of drilling gastropod predation to escalation levels of Miocene and Pliocene mollusc faunas of the U.S. Atlantic Coastal Plain. *Abstracts with Programs - Geological Society of America* 39(2):94.

Kenworthy, J. P., and V. L. Santucci. 2003. Colonial National Historical Park. Pages 13–21 *in* J. P. Kenworthy and V. L. Santucci. Paleontological resource inventory and monitoring: Northeast Coastal and Barrier Network. TIC# D-340. National Park Service, Denver, Colorado.

Kenworthy, J. P., and V. L. Santucci. 2006. A preliminary investigation of National Park Service paleontological resources in cultural resource contexts, Part 1: general overview. Pages 70–76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf (accessed January 2014).

Kier, P. M. 1972. Upper Miocene echinoids from the Yorktown Formation of Virginia and their environmental significance. Smithsonian Contributions to Paleobiology 13. Available at http://si-pddr.si.edu/dspace/handle/10088/1944 (accessed January 2014).

Kimmel, P. G., and R. Purdy. 1984. Fossil fish of the Calvert and Eastover formations. Pages 205–209 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia coastal plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Krantz, D. E. 1990. Mollusk-isotope records of Plio-Pleistocene marine paleoclimate, U. S. Middle Atlantic Coastal Plain. *Palaios* 5(4):317–335.

Lea, I. 1833. Contributions to geology. Carey, Lea, and Blanchard. Philadelphia, Pennsylvania. Available at https://archive.org/details/contributionstog00leai (accessed January 2014).

Lincoln, B. 1783. An account of several strata of earth and shells on the banks of York River in Virginia. *Proceedings of the American Academy of Arts and Sciences* 1:372–376. Available at http://www.jstor.org/stable/25053772 (accessed January 2014).

Lister, M. 1687. Historiae conchyliorum Liber III. London, United Kingdom.

Malkin, D. S. 1953. Biostratigraphic study of Miocene Ostracoda of New Jersey, Maryland, and Virginia. *Journal of Paleontology* 27(6):761–799.

Mansfield, W. C. 1943. Stratigraphy of the Miocene of Virginia and the Miocene and Pliocene of North Carolina. Pages 1–19 *in* J. Gardner. Mollusca from the Miocene and lower Pliocene of Virginia and North Carolina. Part 1. Pelecypoda. U.S. Geological Survey, Washington, D.C. Professional Paper 199-A. Available at http://pubs.er.usgs.gov/publication/pp199A (accessed January 2014).

McClain, J. M. 2014. Un-beached whale. College of William & Mary, Williamsburg, Virginia. Available at http://www.wm.edu/research/ideation/science-and-technology/un-beached-whale123.php (accessed January 2014).

McGavock, C. B., Jr. 1944. New Pelecypoda from the Yorktown Formation of Virginia. Notulae Naturae of the Academy of Natural Sciences of Philadelphia 139. Available at http://books.google.com/books?id=2b9giIbfUHsC (accessed January 2014).

McLean, J. D., Jr. 1956. The Foraminifera of the Yorktown Formation in the York-James Peninsula of Virginia, with notes on the associated mollusks. *Bulletins of American Paleontology* 36(160):261–394. Available at http://archive.org/details/bulletinsofameri155160pale (accessed January 2014).

McLean, J. D., Jr. 1957. The Ostracoda of the Yorktown Formation in the York-James Peninsula of Virginia (with notes on the collection made by Denise Mongin from the area). *Bulletins of American Paleontology* 38(167):57–103. Available at http://biodiversitylibrary.org/page/28022595 (accessed January 2014).

McLean, J. D., Jr. 1966. Miocene and Pleistocene Foraminifera and Ostracoda of southeastern Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Report of Investigations 9. Available at http://www.dmme.virginia.gov/commercedocs/RI_9.pdf (accessed January 2014).

Meyer, O. 1888. On Miocene invertebrates from Virginia. *Proceedings of the American Philosophical Society* 25(27):135–144. Available at http://www.jstor.org/stable/983296 (accessed January 2014).

Mirecki, J. E., J. F. Wehmiller, and A. F. Skinner. 1995. Geochronology of Quaternary coastal plain deposits, southeastern Virginia, U.S.A. *Journal of Coastal Research* 11(4):1135–1144.

Mitchill, S. L. 1818. Observations on the geology of North America; illustrated by the description of various organic remains found in that part of the World. Pages 319–431 in G. Cuvier, Essay on the theory of the Earth, with mineralogical notes, and an account of Cuvier's geological discoveries, by Professor Jameson: New York, Kirk and Mercein. Available at https://archive.org/details/essayontheoryea00mitcgoog (accessed January 2014).

Mixon, R. B., B. J. Szabo, and Owens, J. P. 1982. U-series dating of mollusks and corals, and age of Pleistocene deposits, Chesapeake Bay area, Virginia and Maryland. U.S. Geological Survey Professional Paper 1067-E. Available at http://pubs.er.usgs.gov/publication/pp1067E (accessed January 2014).

Mixon, R. B., C. R. Berquist, W. L. Newell, and G. H. Johnson. 1989. Geologic map and generalized cross sections of the coastal plain and adjacent parts of the Piedmont, Virginia. U.S. Geological Survey, Reston, Virginia. Miscellaneous Investigations Series Map I-2033. Scale 1:250,000. Available at http://pubs.er.usgs.gov/publication/i2033 (accessed January 2014).

Mixon, R. B., D. S. Powars, and J. S. Schindler. 1994. Sedimentary facies of the Pliocene Yorktown Formation and related stratigraphy, structure, and geomorphology of the inner coastal plain, northeastern Virginia. Pages 127–139 *in* A. P. Schultz and E. K. Rader, editors. Studies in eastern energy and the environment; AAPG Eastern Section special volume. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 132. Available at http://www.dmme.virginia.gov/commercedocs/PUB_132.pdf (accessed January 2014).

Moore, E. J. 1962. Conrad's Cenozoic fossil marine mollusk type specimens at the Academy of Natural Sciences of Philadelphia. *Proceedings of the Academy of Natural Sciences of Philadelphia* 114(2):23–120. Available at http://books.google.com/books?id=2VbwCgqs8rkC (accessed January 2014).

National Park Service. 2001. Jamestown archeological assessment. National Park Service, Washington, D.C.

Newell, W. L., and E. K. Rader. 1985. Eastover (upper Miocene) and Yorktown (lower Pliocene) formations in Virginia: tracking a shifting depocenter. *AAPG Bulletin* 69(9):1443–1444.

O'Donnell, M. J., R. Lockwood, and G. H. Johnson. 2003. Brackish-water environments in the upper Yorktown Formation, Virginia. *Abstracts with Programs - Geological Society of America* 35(1):69.

Oaks, R. Q., Jr., and D. R. Whitehead. 1979. Geologic setting and origin of the Dismal Swamp, southeastern Virginia and northeastern North Carolina. Pages 1–24 *in* P. W. Kirk, Jr., editor. The Great Dismal Swamp. University Press of Virginia, Charlottesville, Virginia.

Olson, S. L. 1985. A brief synopsis of the fossil birds from the Pamunkey River and other Tertiary marine deposits in Virginia. Pages 217–223 *in* L. W. Ward, and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Olson, S. L., and P. C. Rasmussen. 2001. Miocene and Pliocene birds from the Lee Creek Mine, North Carolina. Pages 233–365 *in* C. E. Ray and D. J. Bohaska, editors. Geology and paleontology of the Lee Creek Mine, North Carolina, III. Smithsonian Contributions to Paleobiology 90. Available at http://si-pddr.si.edu/dspace/handle/10088/2006 (accessed January 2014).

Olsson, A. A. 1914. New and interesting Neogene fossils from the Atlantic Coastal Plain. *Bulletins of American Paleontology* 5(24). Available at http://biodiversitylibrary.org/page/32510568 (accessed January 2014).

Olsson, A. A. 1916. New Miocene fossils. *Bulletins of American Paleontology* 5(27). Available at http://biodiversitylibrary.org/page/32510720 (accessed January 2014).

Peebles, P. C., G. H. Johnson, and C. R. Berquist. 1984. The middle and late Pleistocene stratigraphy of the outer coastal plain, southeastern Virginia. *Virginia Minerals* 30(2):13–22. Available at http://www.dmme.virginia.gov/DGMR/pdf/vamin/VAMIN_VOL30_NO02.pdf (accessed January 2014).

Phillips, M. P. and Brennan, S. R. 1983. Geological displays in Virginia. Virginia Minerals 29(3):34–35. Available at http://www.dmme.virginia.gov/DGMR/pdf/vamin/VAMIN_VOL29_NO03.pdf (accessed January 2014).

Poag, C. W. 1997. The Chesapeake Bay bolide impact: a convulsive event in Atlantic Coastal Plain evolution. *Sedimentary Geology* 108(1–4):45–90.

Powars, D. S., and T. S. Bruce. 1999. The effects of the Chesapeake Bay impact crater on the geological framework and correlation of hydrogeologic units of the lower York-James Peninsula, Virginia. U.S. Geological Survey, Reston, Virginia. Professional Paper 1612. Available at http://pubs.er.usgs.gov/publication/pp1612 (accessed January 2014).

Purdy, R. W., V. P. Schnieder, S. P. Applegate, J. H. McLellan, R. L. Meyer, and B. H. Slaughter. 2001. The Neogene sharks, rays, and bony fishes from Lee Creek Mine, Aurora, North Carolina. Pages 71–202 *in* C. E. Ray and D. J. Bohaska, editors. Geology and paleontology of the Lee Creek Mine, North Carolina, III. Smithsonian Contributions to Paleobiology 90. Available at http://si-pddr.si.edu/dspace/handle/10088/2006 (accessed January 2014).

Ramsey, K. W. 1992. Coastal response to late Pliocene climate change: Middle Atlantic Coastal Plain, Virginia and Delaware. Pages 121–127 *in* C. H. Fletcher, III, and J. F. Wehmiller, editors. Quaternary coasts of the United States: marine and lacustrine systems. Society of Economic Paleontologists and Mineralogists, Tulsa, Oklahoma. Special Publication 48.

Rathbun, M. 1935. Fossil Crustacea of the Atlantic and Gulf Coastal Plain. Geological Society of America, Boulder, Colorado. Special Paper 2. Available at http://decapoda.nhm.org/pdfs/10746/10746-001.pdf (accessed January 2014).

Ray, C. E. 1983. Prologue. Pages 1–14 *in* C. E. Ray, editor. Geology and paleontology of the Lee Creek Mine, North Carolina: I. Smithsonian Contributions to Paleobiology 53. Available at http://si-pddr.si.edu/dspace/handle/10088/1975 (accessed January 2014).

Ray, C. E. 1987. Foreword. Pages 1–8 *in* C. E. Ray, editor. Geology and paleontology of the Lee Creek Mine, North Carolina: II. Smithsonian Contributions to Paleobiology 61. Available at http://si-pddr.si.edu/dspace/handle/10088/1983 (accessed January 2014).

Reinhart, T. R. 1976. Excavations at the Powhatan Creek Site. *Quarterly Bulletin of the Archaeological Society of Virginia* 31(2):37–65.

Reinhart, T. R. 1978. Plow zone archeology on College Creek (James City County, Virginia). *Quarterly Bulletin of the Archeological Society of Virginia* 32(4):81–93.

Richards, H. G. 1947. Invertebrate fossils from deep wells along the Atlantic Coastal Plain. *Journal of Paleontology* 21(1):23–37.

Richards, H. G. 1968. Catalogue of invertebrate fossil types at the Academy of Natural Sciences of Philadelphia. Academy of Natural Sciences of Philadelphia, Philadelphia, PA. Special Publication 8.

Roberts, J. K. 1932. The lower York-James peninsula. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 37. Available at http://www.dmme.virginia.gov/commercedocs/BUL_37.pdf (accessed January 2014).

Roberts, J. K. 1942. Annotated geological bibliography of Virginia. University of Virginia bibliographical series 2.

Robinson, W. M., Jr. 1933. The geological aspects of the Colonial National Monument. *Virginia Journal of Science* 1932-33:51.

Rogers, W. B., and H. D. Rogers. 1837. Contributions to the geology of the Tertiary formations of Virginia. Transactions of the *American Philosophical Society*, new series 5:319–341. Available at http://biodiversitylibrary.org/page/35958024 (accessed January 2014).

Rogers, W. B., and H. D. Rogers. 1839. Contributions to the geology of the Tertiary formations of Virginia—second series—continued: being a description of several species of Meiocene and Eocene shells, not before described. *Transactions of the American Philosophical Society*, new series 6:371–377. Available at http://biodiversitylibrary.org/page/35980192.

Ross, A. 1964. Cirripedia from the Yorktown Formation (Miocene) of Virginia. *Journal of Paleontology* 38(3):483–491.

Ruhle, J. L. 1962a. Selected Tertiary fossil localities of the Virginia Coastal Plain. *Virginia Minerals* 8(3):2–10. Available at http://www.dmme.virginia.gov/commercedocs/VAMIN_VOL08_NO03.pdf (accessed January 2014).

Ruhle, J. L. 1962b. Guidebook to the Coastal Plain of Virginia north of the James River. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Information Circular 6. Available at http://www.dmme.virginia.gov/commercedocs/IC_6.pdf (accessed January 2014).

Sabol, J. W. 1960. The microfauna of the Yorktown Formation from James River, Surry County, Virginia. *Bulletins of American Paleontology* 41(191):211–246. Available at http://biodiversitylibrary.org/page/10654907 (accessed January 2014).

Sager, E. D., G. H. Johnson, and C. H. Hobbs, III. 1994. Geologic development of Kingsmill Creek, Jamestown Island, Virginia. *Abstracts with Programs - Geological Society of America* 26(4):60.

Santucci, V. L., J. Kenworthy, and R. Kerbo. 2001. An inventory of paleontological resources associated with National Park Service caves. NPS Geologic Resources Division, Denver, Colorado. Technical Report NPS/NRGRD/GRDTR-01/02. TIC# D-2231. Available at http://nature.nps.gov/geology/paleontology/pub/cavepaleo.pdf (accessed January 2014).

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado.

Say, T. 1822. An account of some of the marine shells of the United States. *Journal of the Academy of Natural Sciences of Philadelphia*, 1st series, 2:221–248, 257–276, 302–325. Available at http://biodiversitylibrary.org/page/36831411 (accessed January 2014).

Say, T. 1824. An account of some fossil shells from Maryland. *Journal of the Academy of Natural Sciences of Philadelphia*, 1st series, 4:124–155. Available at http://biodiversitylibrary.org/page/24655238 (accessed January 2014).

Schneider, V. P., and H. L. Fierstine. 2004. Fossil tuna vertebrae punctured by istiophorid billfishes. *Journal of Vertebrate Paleontology* 24(1):253–255.

Schuchert, C. 1905. Catalogue of the type specimens of fossil invertebrates in the Department of Geology, United States National Museum. Bulletin of the United States National Museum 53(1). Available at http://books.google.com/books?id=OKsKAAAAIAAJ (accessed January 2014).

Scott, T. W., D. J. P. Swift, G. R. Whittecar, and G. A. Brook. 2010. Glacio-isostatic influences on Virginia's late Pleistocene coastal plain deposits. *Geomorphology* 116(1–2):175–188.

Sirkin, L., and J. P. Owens. 1998. Palynology of latest Neogene (middle Miocene to late Pliocene) strata in the Delmarva Peninsula of Maryland and Virginia. *Northeastern Geology and Environmental Sciences* 20(2):117–132.

Stanley, S. M. 1986. Anatomy of a regional mass extinction: Plio-Pleistocene decimation of the western Atlantic bivalve fauna. *Palaios* 1(1):17–36.

Swain, F. M. 1974. Some upper Miocene and Pliocene(?) Ostracoda of Atlantic Coastal region for use in hydrogeologic studies. U.S. Geological Survey, Washington, DC. Professional Paper 821. Available at http://pubs.er.usgs.gov/publication/pp821 (accessed January 2014).

Sweet, P. C. 1974. Mineral and fossil collecting sites in Virginia. *Virginia Minerals* 20(1):1–6. Available at http://www.dmme.virginia.gov/commercedocs/VAMIN_VOL20_NO01.pdf (accessed January 2014).

Teifke, R. H. 1973. Paleogeology of early Cretaceous through Miocene time. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 83:79–101. Available at http://www.dmme.virginia.gov/commercedocs/BUL_83.pdf (accessed January 2014).

Teifke, R. H. 1973. Stratigraphic units of the lower Cretaceous through Miocene series. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 83:1–78. Available at http://www.dmme.virginia.gov/commercedocs/BUL_83.pdf (accessed January 2014).

Thornberry-Ehrlich, T. L. 2005. Colonial National Historical Park geologic resource management issues scoping summary. National Park Service, Geologic Resources Division, Denver, Colorado. Available at http://nature.nps.gov/geology/inventory/publications/s_summaries/COLO_Scoping_Report_2005-1211.pdf (accessed January 2014).

Ulrich, E. O. and R. S. Bassler. 1904. Ostracoda. Pages 98–130 in Miocene: Maryland Geological Survey. The Johns Hopkins Press, Baltimore, Maryland. Available at https://archive.org/details/miocene01mary (text) (accessed January 2014).

Valentine, P. C. 1971. Climatic implication of a late Pleistocene ostracode assemblage from southeastern Virginia. U.S. Geological Survey, Washington, DC. Professional Paper 683-D. Available at http://pubs.er.usgs.gov/publication/pp683D (accessed January 2014).

Vélez-Juarbe, J., and N. D. Pyenson. 2012. *Bohaskaia monodontoides*, a new monodontid (Cetacea, Odontoceti, Delphinoidea) from the Pliocene of the western North Atlantic Ocean. *Journal of Vertebrate Paleontology* 32(2):476–484.

Waite, B., and C. Condit. 1969. Leaching and cementation of coquina of the Yorktown Formation (Miocene), York-James Peninsula, Virginia. *Virginia Journal of Science* 20(3):126.

Ward, L. W. 1991. The John Finch collection of Tertiary mollusks in 1824 and its significance to paleontology and geology. *Virginia Journal of Science* 42(2):221. Available at http://www.vacadsci.org/vjsArchives/V42/42-2/42-155.pdf (accessed January 2014).

Ward, L.W. 1993. The G.D. Harris 1890 manuscript on the stratigraphy of Miocene and Pliocene beds at Yorktown, Virginia. Paleontological Research Institution Special Publication 20.

Ward, L. W. 2007. Synthesis of paleontological and stratigraphic investigations at the Lee Creek Mine, Aurora, N.C. (1958-2007). Pages 15–121 *in* L. W. Ward, editor. Lee Creek Mine: Aurora, North Carolina: history, mining operations, geology, stratigraphy and paleontology: a synthesis. Virginia Museum of Natural History, Martinsville, Virginia. Guidebook 8. Available at http://www.carolinageologicalsociety.org/CGS/2000s_files/gb%202007.pdf (accessed January 2014).

Ward, L. W., and B. W. Blackwelder. 1975. *Chesapecten*, a new genus of Pectinidae (Mollusca: Bivalvia) from the Miocene and Pliocene of eastern North America. U.S. Geological Survey, Washington, DC. Professional Paper 861. Available at http://pubs.er.usgs.gov/publication/pp861 (accessed January 2014).

Ward, L. W., and B. W. Blackwelder. 1980. Stratigraphic revision of upper Miocene and lower Pliocene beds of the Chesapeake Group, middle Atlantic Coastal Plain. U.S. Geological Survey, Washington, DC. Bulletin 1482-D. Available at http://pubs.er.usgs.gov/publication/b1482D (accessed January 2014).

Ward, L. W., and D. S. Powars. 2004. Tertiary lithology and paleontology, Chesapeake Bay region. Pages 263–297 *in* S. Southworth and W. Burton, editors. Geology of the National Capital Region—field trip guidebook. U.S. Geological Survey, Reston, Virginia. Circular 1264. Available at http://pubs.usgs.gov/circ/2004/1264/pdf/trip9.pdf (accessed January 2014).

Webb, H. W. and P. C. Sweet. 1993. Interesting uses of stone in Virginia – Part II. Virginia Minerals 39(1/2). Available at http://dmme.virginia.gov/DGMR/pdf/vamin/VAMIN_VOL39_NO01_02.PDF (accessed January 2014).

Whitehead, D.R. 1972. Developmental and environmental history of the Dismal Swamp. *Ecological Monographs* 42:301–315.

Whitmore, F. C., Jr. 1984. Cetaceans from the Calvert and Eastover formations, Pamunkey River, Virginia. Pages 227–231 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia coastal plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Whitmore, F. C., Jr. 1994. Neogene climatic change and the emergence of the modern whale fauna of the North Atlantic Ocean. *Proceedings of the San Diego Society of Natural History* 29:223–227. Available at https://archive.org/details/proceedingsofsan29sand (accessed January 2014).

Wijnker, E., and S. L. Olson. 2009. A revision of the fossil genus *Miocepphus* and other Miocene Alcidae (Aves, Charadriiformes) of the western North Atlantic Ocean. *Journal of Systematic Palaeontology* 7(4):471–487.

Willard, D.A., T.M. Cronin, and S. Verardo. 2003. Late-Holocene climate and ecosystem history from Chesapeake Bay sediment cores, USA. *The Holocene* 13:201–214.

Williams, M., A. M. Haywood, E. M. Harper, A. L. A. Johnson, T. Knowles, M. J. Leng, D. J. Lunt, B. Okamura, P. D. Taylor, and J. Zalasiewicz. 2009. Pliocene climate and seasonality in North Atlantic shelf seas. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 367(1886):85–108.

Wilson, D. 1983. The Lee Creek enigma, *Mclellania aenigma*, a new taxon in fossil Cirripedia. Pages 483–498 *in* C. E. Ray, editor. Geology and paleontology of the Lee Creek Mine, North Carolina: I. Smithsonian Contributions to Paleobiology 53. Available at http://si-pddr.si.edu/dspace/handle/10088/1975 (accessed January 2014).

Additional References

Berquist, C. R. 1983. Geology and mineral resources of the Norge Quadrangle, Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Open-File Report 83-5.

Brunner, J., J. Kenworthy, and V. Santucci. 2010. Unauthorized fossil collecting from National Park Service shorelines: servicewide policy and perspectives. Pages 319–323 *in* S. Weber, editor. Rethinking protected areas in a changing world: proceedings of the 2009 George Wright Society Conference. The George Wright Society, Hancock, Michigan. Available at http://www.georgewright.org/0956brunner.pdf (accessed February 2014).

Boyd, F. M. 1979. The sedimentological and paleontological significance of *Chama congregata* from the Yorktown Formation (early Pliocene) in southeastern Virginia. *Virginia Journal of Science* 30(2):79.

Brockman, A. R., D. L. Nelms, G. E. Harlow, Jr., and J. J. Gildea. 1997. Geohydrology of the shallow aquifer system, Naval Weapons Station Yorktown, Yorktown, Virginia. U.S. Geological Survey, Reston, Virginia. Water-Resources Investigations 97-4188. Available at http://pubs.er.usgs.gov/publication/wri974188 (accessed January 2014).

Campbell, L. D. 1967. Biostratigraphy and paleoecology of Yates Cut, Williamsburg, Virginia. *Virginia Journal of Science* 18(4):184.

Campbell, L., M. Campbell, and S. Campbell. 2010. Molluscan diversity of the Yorktown Formation (Pliocene) in Virginia: an update. *Abstracts with Programs - Geological Society of America* 42(1):177.

Campbell, L., M. R. Campbell, and S. C. Campbell. 2011. Biodiversity and stratigraphy of the basal Yorktown Formation at Kings Mill, James City County, Virginia, USA. *Abstracts with Programs - Geological Society of America* 43(2):85.

Campbell, M. R. 1995. Lithology and paleontology of the Sunken Meadow Member, Yorktown Formation (Pliocene), Virginia. *Abstracts with Programs - Geological Society of America* 27(2):40.

Clark, W. B. 1890. Third annual geological expedition into southern Maryland and Virginia. *Johns Hopkins University Circulars* 9(81):69–71.

Cope, E. D. 1867. An addition to the vertebrate fauna of the Miocene period, with a synopsis of the extinct Cetacea of the United States. *Proceedings of the Academy of Natural Sciences* 19:138–157.

Darton, N. H. 1891. Mesozoic and Cenozoic formations of eastern Virginia and Maryland. *Geological Society of America Bulletin* 2:431–450.

Ellwood, B. B. 1996. Geology and America's National Park areas. Prentice Hall, Upper Saddle River, New Jersey.

Finch, I. [J.]. 1833. Travels in the United States of America and Canada. Longman, Rees, Orne, Brown, Green, and Longman, London, United Kingdom.

Finkelstein, K., and C. S. Hardaway. 1988. Late Holocene sedimentation and erosion of estuarine fringing marshes, York River, Virginia. *Journal of Coastal Research* 4(3):447–456.

Hazel, J. E. 1971. Paleoclimatology of the Yorktown Formation (upper Miocene and lower Pliocene) of Virginia and North Carolina. *Bulletin du Centre De Recherches De Pau* 5(5):361–375.

Hobbs, C. H., D. B. Blanton, R. A. Gammisch, and J. Broadwater. 1994. A marine archaeological reconnaissance using side-scan sonar, Jamestown Island, Virginia, USA. *Journal of Coastal Research* 10(2):351–359.

Johnson, G. H., and C. H. Hobbs, III. 1991. Pliocene and Pleistocene depositional environments on the York-James Peninsula, Virginia: a field guidebook. College of William and Mary, Williamsburg, Virginia.

Johnson, G. H., L. W. Ward, and P. C. Peebles. 1985. Stratigraphy of Yorktown (lower and middle Pliocene) and Chowan River (upper Pliocene) formations in southeastern Virginia. *AAPG Bulletin* 69(9):1438.

Mayor, A. 2005. Fossil legends of the first Americans. Princeton University Press, Princeton, New Jersey.

McCary, B. C. 1986. Early man in Virginia. Pages 71–78 *in* J. N. McDonald and S. O. Bird, editors. The Quaternary of Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 75. Available at http://www.dmme.virginia.gov/commercedocs/PUB_75.pdf (accessed January 2014).

Olsen, S. J. 1971. Zooarchaeology: animal bones in archaeology and their interpretation. Addison-Wesley Publishing Company, New York City, New York.

Phillips, M. P. and Brennan, S. R. 1983. Geological displays in Virginia. *Virginia Minerals* 29(3):34-35. Available at http://www.dmme.virginia.gov/DGMR/pdf/vamin/VAMIN_VOL29_NO03.pdf (accessed January 2014).

Ray, C. E., A. Wetmore, D. H. Dunkle, and P. Drez. 1968. Fossil vertebrates from the marine Pleistocene of southeastern Virginia. Smithsonian Miscellaneous Collections 153(3). Available at http://www.biodiversitylibrary.org/item/111088 (accessed January 2014).

Richards, H. G. 1936. Fauna of the Pleistocene Pamlico Formation of the southern Atlantic Coastal Plain. *Geological Society of America Bulletin* 47:1611–1656.

Rogers, W. B., and H. D. Rogers. 1839. Contributions to the geology of the Tertiary formations of Virginia—second series. *Transactions of the American Philosophical Society*, new series 6:347-370. Available at http://biodiversitylibrary.org/page/35980168 (accessed January 2014).

Ruhle, J. L. 1965. Geologic literature of the Coastal Plain of Virginia, 1783-1962. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Information Circular 9. Available at http://www.dmme.virginia.gov/commercedocs/IC_9.pdf (accessed January 2014).

Spencer, R. S., and L. D. Campbell. 1987. The fauna and paleoecology of the late Pleistocene marine sediments of southeastern Virginia. Bulletins of American Paleontology 92(327). Available at http://www.biodiversitylibrary.org/item/105198 (accessed January 2014).

Stuckenrath, R., and J. E. Mielke. 1972. Smithsonian Institution radiocarbon measurements VII. *Radiocarbon* 14(2):401–412. Available at https://journals.uair.arizona.edu/index.php/radiocarbon/article/view/322 (accessed January 2014).

Teifke, R. H. 1973. Paleogeology of early Cretaceous through Miocene time. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 83:79–101. Available at http://www.dmme.virginia.gov/commercedocs/BUL_83.pdf (accessed January 2014).

Ward, L. W. 1992. Molluscan biostratigraphy of the Miocene, Middle Atlantic Coastal Plain of North America. Virginia Museum of Natural History, Martinsville, Virginia. Memoir 2.

Winfree, R. W. 1967. The T. Gray Haddon site, King William County, Virginia (44KW4). *Quarterly Bulletin of the Archaeological Society of Virginia* 22(1):2–26.

Data Sets

Colonial National Historical Park Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications).
Originated by Santucci, Vincent; status: Active.

Colonial National Historical Park Collections
1930–present. (museum specimens; associated specimen notes; collection records; maps; etc.).
Originated by COLO staff; status: Active.

Colonial National Historical Park Digital Geologic Map
2007–present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online.

American Museum of Natural History
1880s?–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by AMNH staff; status: Active.

Academy of Natural Science of Drexel University
1820s?–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by ANSP staff; status: Active.

Boston Society of Natural History
Post-1865–1930s. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by BSNH staff; status: Inactive.

Columbia University
1953–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by Columbia University staff; status: Active.

Laboratorie de Geologie of the Institut Catholique
1950s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by Laboratorie staff; status: Active.

Louisiana State University
1953–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by LSU staff; status: Active.

Massachusetts Institute of Technology
1865?–pre-1930s. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by MIT staff; status: Inactive.

Museum of Comparative Zoology (former collections of the Boston Society of Natural History and Massachusetts Institute of Technology)
1930s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by MCZ staff; status: Active.

National Museum of Natural History (including former USGS specimens)
1929–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by USNM staff; status: Active.

Natural History Museum (London)
1820s?–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by BMNH staff; status: Active.

Paleontological Research Institution
1910s?–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by PRI staff; status: Active.

U.S. Geological Survey
1890s–present. (locality notes; collection records; maps; etc.). Originated by USGS staff; status: Active.

Virginia Division of Geology and Mineral Resources
20th century?–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by VDMR staff; status: Active.

Fire Island National Seashore

Fire Island National Seashore (FIIS) protects a 42 km (26 mile) stretch of Fire Island, one of the barrier islands flanking the south side of Long Island. The narrow island is noted for its beaches, dunes, and other coastal features (FIIS Figure 1). FIIS also includes several nearby islands, waters surrounding the island, and a parcel on the nearby southern shore of Long Island protecting the estate of William Floyd (a signatory of the Declaration of Independence). Much of the eastern part of FIIS is designated the Otis Pike Fire Island High Dune Wilderness. FIIS was authorized September 11, 1964. It boundaries changed October 9, 1965, and November 10, 1978. The wilderness area was designated December 23, 1980. FIIS encompasses 7,923.53 ha (19,579.47 acres). 2,525.70 ha (6,241.13 acres) of this total is federal, and 551.9 ha (1,363 acres) are in the wilderness area. Within the boundaries of the seashore are 17 private communities and a handful of other public lands, the largest being Smith Point County Park at the east tip of the island. The boundaries also include the waters surrounding FIIS, to a distance of up to 1,200 m (4,000 ft) offshore into the bays north of Fire Island, and up to 300 m (1,000 ft) offshore into the Atlantic Ocean south of the island.

Geologic Background

FIIS occupies the majority of Fire Island (FIIS Figure 2). The westernmost part of the island, west of the Fire Island Light area at the western end of FIIS, is within Robert Moses State Park. On the west, Fire Island is separated from Jones Beach Island by Fire Island Inlet. The east end of the island is separated from a former portion of Fire Island by Moriches Inlet, which formed in 1931. On the south is the Atlantic Ocean, and on the north a series of bays separate Fire Island from Long Island, including from east to west Moriches Bay, Narrow Bay, and Great South Bay. Many small islands are present just behind Fire Island. It is a popular seasonal recreation destination with a small permanent population scattered among 17 communities. The William Floyd Estate parcel is located in Brookhaven, on a small wide peninsula. Both the island and the William Floyd Estate sections are located in Suffolk County, New York.

Publications that touch on the geology and paleontology of FIIS include Fuller (1914), MacClintock and Richards (1936), Pluhowski and Kantrowitz (1964), Perlmutter and Todd (1965), Sirkin (1972), Sanders and Kumar (1975), Doriski and Wilde-Katz (1983), Leatherman et al. (1983), Leatherman (1985), Panageotou and Leatherman (1986), Schwab et al. (2000), Kenworthy and Santucci (2003), Benotti (2008), Schubert (2010), Thornberry-Ehrlich (2011), and NPS (2013). The NPS Geologic Resources Division held a scoping meeting for FIIS in June 2010 (Thornberry-Ehrlich 2011) and produced a digital geologic map for the seashore in 2013 (NPS 2013). The initial paleontological resource inventory and summary was prepared by Kenworthy and Santucci (2003).



FIIS Figure 1. Sunken Forest, on the north side of Fire Island in FIIS. Organic material here has been dated to the past few hundred years (Sirkin 1972) (NPS).

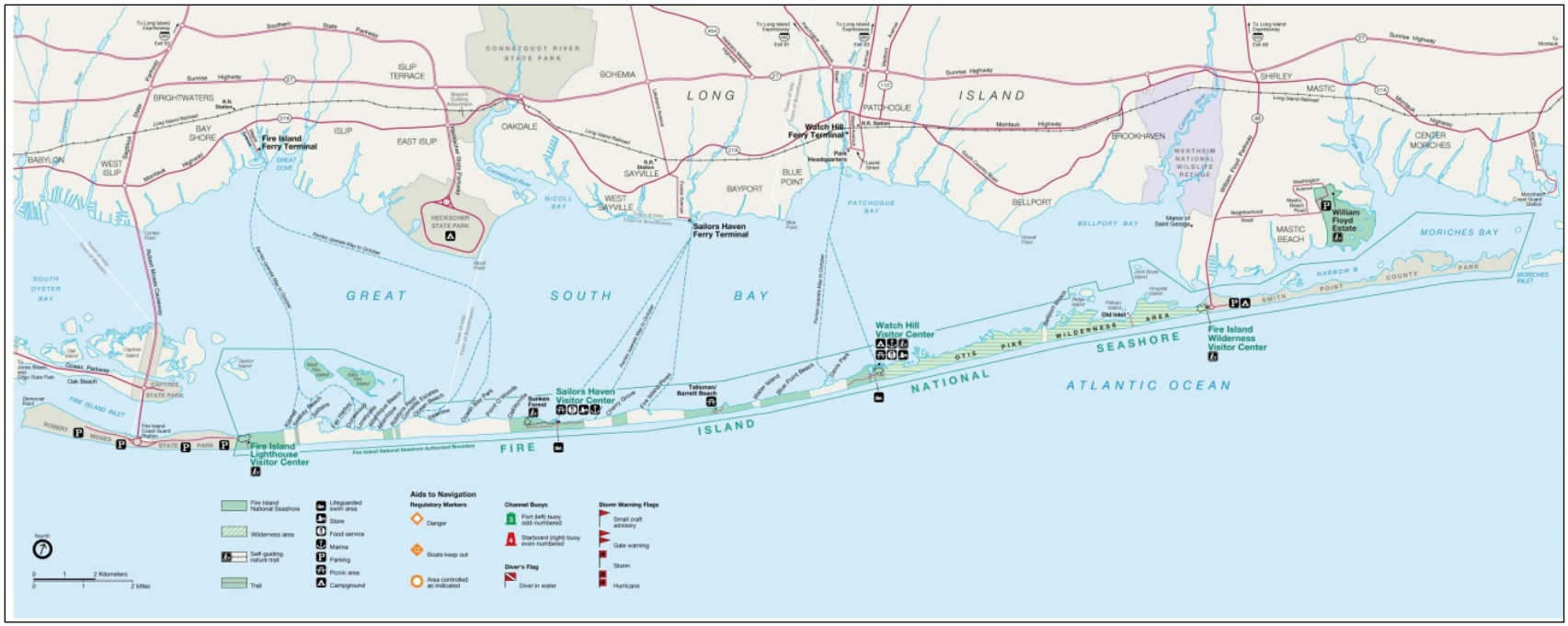
The following discussion of the geologic background is primarily derived from Stoffer (2003), except where noted. Although the surficial geology of FIIS is limited to upper Quaternary deposits (FIIS Figure 3) (see the Appendix for a geologic time chart), older Quaternary and Cretaceous deposits have been frequently accessed through wells and borings, extending the geologic record of the seashore to about 100 Ma (million years ago). The Atlantic coast of North America has generally been quiet in terms of tectonics since the breakup with Europe and Africa, which occurred during the Late Triassic and Early Jurassic (centered about 200 Ma). The subsurface of central Long Island may contain an ancient rift valley from this time, following the alignment of the Hartford Basin of Connecticut and Massachusetts, and concealed by younger sediments (Rogers et al. 1989). Another rift basin, the Newark Basin, is found west of Long Island, and includes the famous Palisades Sill, a vast igneous intrusion from 200 Ma.

A hiatus in the depositional record follows until about 100 Ma, the onset of some 50 to 60 million years of deposition from the Late Cretaceous to the Eocene that drapes the bedrock of northeastern New Jersey, New York City, and Long Island. These deposits dip to the south, so the thickness of the pile and the total time represented increase going south. Beneath central Long Island, only Cretaceous sediments are found (Perlmutter and Todd 1965). The Cretaceous sediments include a number of formations that record a transition from coastal plains to shallow marine settings, with several marine transgression-regression cycles as sea level rose and fell (Sugarman et al. 1995; Miller et al. 2003, 2004). The Long Island area is thought to have been near the strand line of the

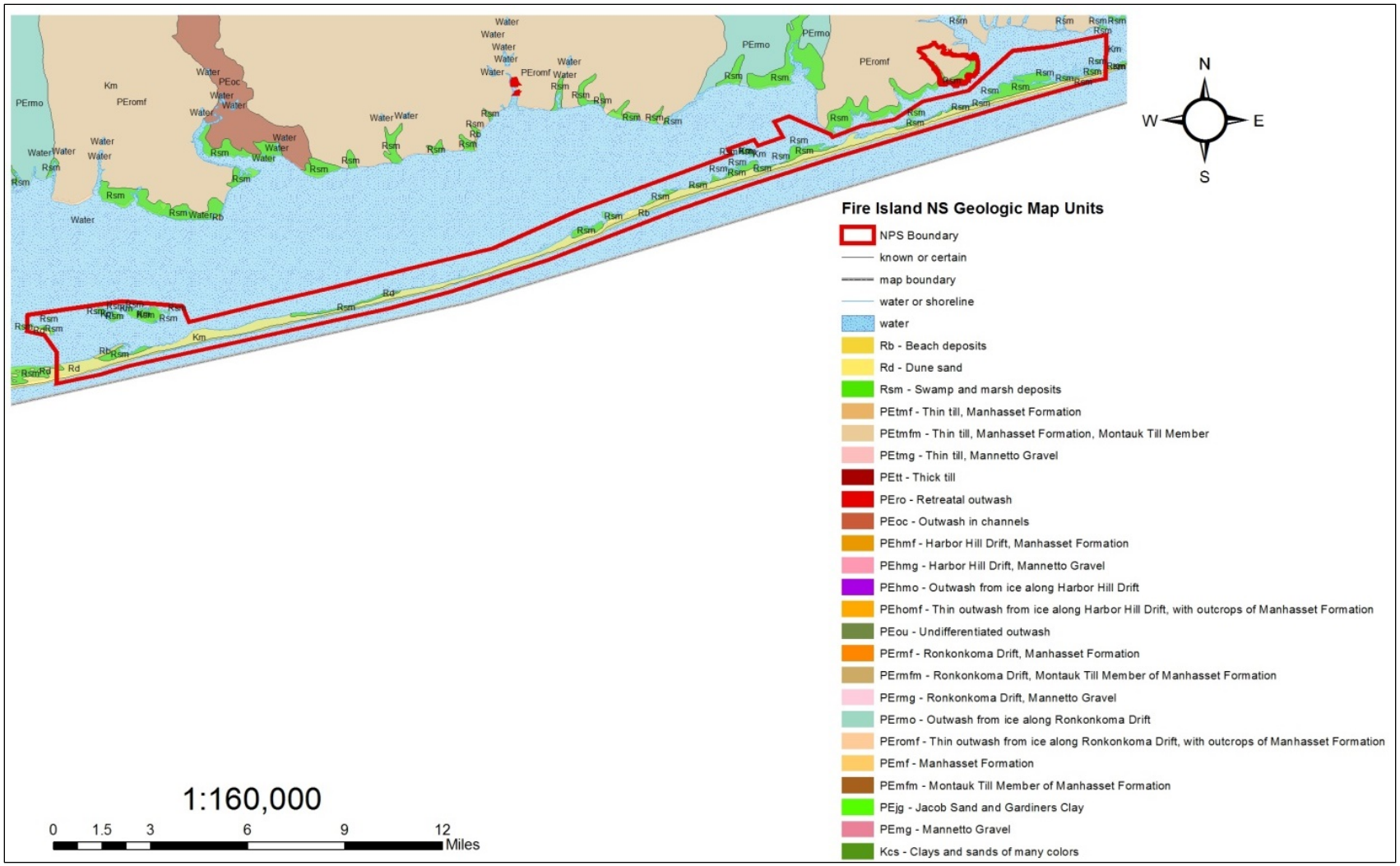
Cretaceous coastal plain, and would have been a setting of river channels, floodplains, swamps, and marshes (Pluhowski and Kantrowitz 1964).

The Quaternary geology of the FIIS area is dominated by the indirect influence of glaciers, such as glacial outwash deposits and, more broadly speaking, the effects of glaciation, post-glacial adjustment of crust depressed by ice, and glacial melting on sea level. Multiple glacial–interglacial cycles have occurred during the Quaternary, but the evidence for most of them is usually obscured by the effects of the most recent glaciation. Glaciers covered much of Long Island, but did not reach Fire Island, as shown by the locations of moraines (accumulations of glacial debris). Long Island is in large part the remains of two thick glacial terminal moraines, the older Ronkonkoma Moraine present across central Long Island, and the younger Harbor Hill Moraine of northern Long Island. They were formed during what is known as the Wisconsinan (or Wisconsin) glaciation, the most recent glacial episode. The Wisconsinan began roughly 85,000 to 75,000 years ago, reached a maximum (the Last Glacial Maximum) about 25,000 to 20,000 years ago, and ended about 11,000 years ago. Immediately before this glacial episode, the prevailing climate and sea level were similar to today; this time is known as the Sangamonian (or Sangamon) interglacial, which began about 125,000 years ago. Marine deposits from this time have been found in New Jersey and to a lesser extent southern New York.

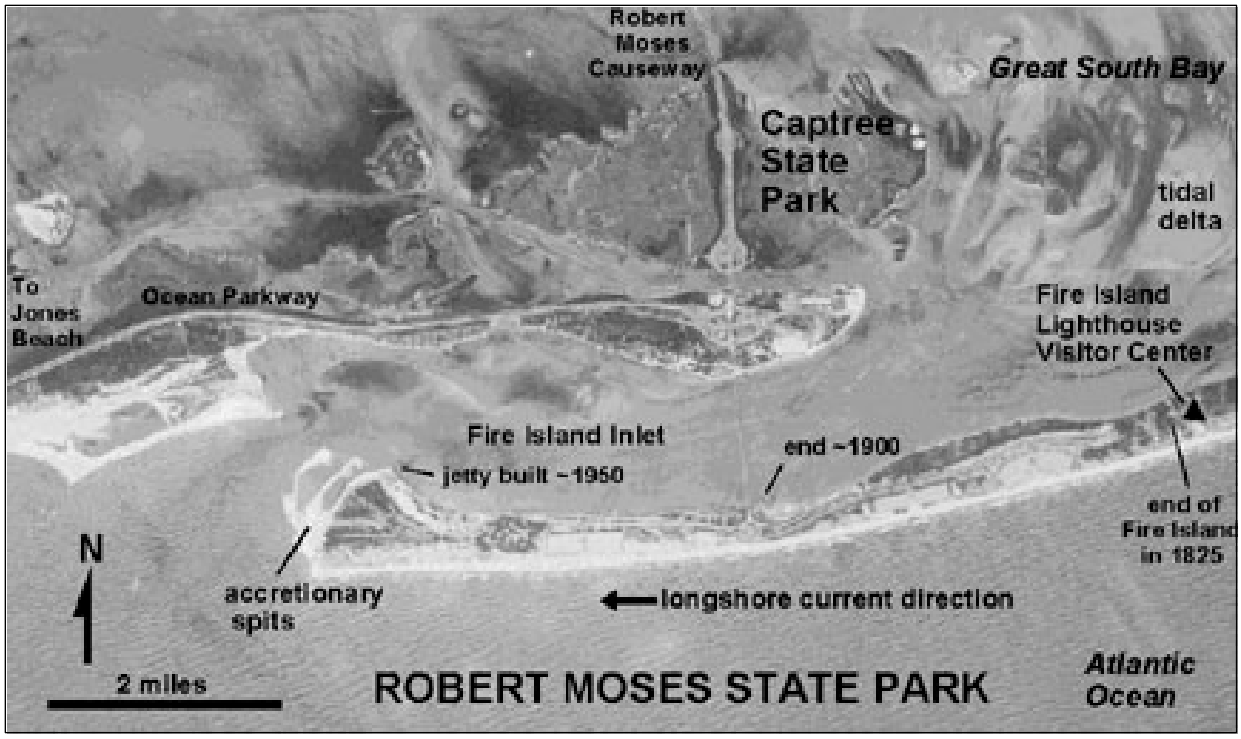
One of the effects of glaciation is to draw down global sea levels, with the effect of extending coastal plains tens of km/miles closer to ocean basins. The extended coastal plain supported a variety of plant and animal life, fossils of which are sometimes dredged from the seafloor (Whitmore et al. 1967; Gallagher et al. 1989; McDonald and Ray 1990). The area that eventually became FIIS would have been part of the coastal plain during the ice ages, until sea level rose to elevations similar to today. Relict Pleistocene channels are present offshore of Fire Island on the Atlantic side, evidence of this history (Panageotou and Leatherman 1986). Fire Island itself is geologically very young (a few thousand years old) and is quite dynamic, with rapid changes in geography; for example, the western end of the island extended 8 km (5 miles) west between 1825 and 1940 (Leatherman 1985) (FIIS Figure 4). The coastal setting leaves it vulnerable to sea level change and hurricanes. Human modification has been important as well. Humans arrived in the New York City area by around 10,000 years ago, and over the past 400 years it has become one of the most anthropogenically altered landscapes in the Western Hemisphere.



FIIS Figure 2. Geography of FIIS (NPS).



FIIS Figure 3. Schematic geological map of FIIS. Map graphic adapted from digital geologic map data available at the following URL: https://irma.nps.gov/App/Reference/Profile/2202595.



FIIS Figure 4. Fire Island has grown westward by several miles over the past 200 years (Stoffer 2003, USGS).

The development and evolution of Fire Island has inspired debate centered around the general question of whether barrier islands move continuously, in discrete "jumps" under specific conditions of sea level and sediment delivery, or both as conditions dictate. Sanders and Kumar (1975) favored a hybrid model in which the barrier system "skipped" about 5 km (3 miles) around 7,500 years ago and has been moving continuously since then. They proposed that a feature in 24 m (79 ft) of water about 7 km (4 miles) off of Fire Island represented part of the submerged pre-7,500-year-old barrier system. This model has been challenged (Leatherman et al. 1983; Leatherman 1985; Panageotou and Leatherman 1986), and other study has not found a drowned barrier island (Panageotou and Leatherman 1986; Schwab et al. 2000).

The surficial geology of FIIS is made up of a combination of beach deposits, dune sand, and swamp and marsh deposits, all from the Holocene, and Pleistocene glacial outwash (William Floyd Estate) (Fuller 1914; NPS 2013) (FIIS Figure 3). The subsurface of FIIS includes, in descending order (young to old), undivided upper Pleistocene and Holocene sediments, including the "20-ft clay" beneath the extreme western part of the seashore; a unit referred to the "Gardiners Clay" (upper Pleistocene); a section of Upper Cretaceous sediments thought to be equivalent to the Red Bank and Navesink formations of the Monmouth Group; a section of Upper Cretaceous sediments thought to be equivalent to the Mount Laurel, Wenonah, Marshalltown, Englishtown, Woodbury, and Merchantville formations of the Matawan Group; the Magothy Formation (Upper Cretaceous); the Raritan Formation (Upper Cretaceous); and crystalline bedrock (Pluhowski and Kantrowitz 1964;

Perlmutter and Todd 1965; Doriski and Wilde-Katz 1983; Schubert 2010). A deep paleochannel in the Fire Island Pines area may have some Pliocene fill as well (Doriski and Wilde-Katz 1983). The surface/nearsurface deposits of FIIS include organic matter and peat, conifer and angiosperm pollen, and shells. Samples of the subsurface have included Upper Cretaceous foraminifera and ostracodes and Quaternary shells and shell fragments (FIIS Table 1).

FIIS Table 1. Summary of FIIS stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text.

Formation	Age	Fossils Within FIIS	Depositional Environment
Surficial Quaternary sediments	Pleistocene–Holocene	Holocene organic matter, peat, angiosperm and conifer pollen, and shells	Shallow marine, beaches, marshes, glacial outwash
Subsurface Quaternary sediments	Pleistocene–Holocene	Holocene shell fragments; upper Pleistocene–Holocene shells	Shallow marine and glacial outwash
Subsurface Cretaceous sediments (including, at various locations, from youngest to oldest the Red Bank, Navesink, Mount Laurel, Wenonah, Marshalltown, Englishtown, Woodbury, Merchantville, Magothy, and Raritan formations, or undivided equivalents)	Late Cretaceous	Foraminifera and ostracodes	Coastal terrestrial to shallow marine

Sources of Paleontological Resources

The fossils of FIIS present opportunities for education, interpretation, and scientific research in the national seashore.

Subsurface (Upper Cretaceous and Quaternary)

Numerous wells and borings have been made within FIIS, although the majority are within the private community sections. These subsurface explorations have frequently encountered microfossils and shells. Because the fossiliferous sediments are buried hundreds of meters or feet below the surface, they are protected from erosion, theft, and vandalism, and only require management when brought to the surface. They are included here for completeness, and because they illustrate otherwise hidden aspects of FIIS's geologic history.

As shown in various publications (Pluhowski and Kantrowitz 1964; Perlmutter and Todd 1965; Doriski and Wilde-Katz 1983; Schubert 2010), there are several Cretaceous and Quaternary units frequently encountered in the subsurface of FIIS. Although exhaustive treatment of each unit is not relevant for this work, because of the lack of surface exposures, a short discussion is justified because they have yielded fossils within FIIS from wells and borings in the past. Detailed

descriptions of the subsurface units as they are found beneath FIIS are included in the publications cited above.

Upper Cretaceous units

The Cretaceous deposits beneath FIIS are generally composed of unconsolidated sand, silt, and clay with gravel and glauconite (a green mineral that often forms in shallow marine settings, particularly around sand grains; thus, beds with abundant glauconite are commonly called “greensand”) (Pluhowski and Kantrowitz 1964; Perlmutter and Todd 1965). The sediments are correlated, in ascending order (oldest to youngest), to parts of the Raritan and Magothy formations, the Merchantville, Woodbury, Englishtown, Marshalltown, Wenonah, and Mount Laurel formations of the Matawan Group, and the Navesink and Red Bank formations of the Monmouth Group (Perlmutter and Todd 1965; Sirkin 1986a). These formations are better known in New Jersey (see Minard [1969] for a description from northeastern New Jersey). All of the deposits above the Raritan Formation were formerly described as the Magothy(?) Formation (the question mark indicating authorial uncertainty). The Monmouth Group sediments are interpreted as mostly marine in origin, from the neritic zone, with some lignite-rich nearshore deposits in the area. The underlying Matawan Group and Magothy Formation sediments are thought to be mostly transitional coastal beds, probably from a delta and lagoon or estuary system. They lack marine fossils, but include lignite, pollen, and spores in the FIIS area (Perlmutter and Todd 1965).

These sediments represent several marine transgression-regression cycles occurring between approximately 100 and 66 million years ago, or essentially the entire Late Cretaceous (Sugarman et al. 1995; Miller et al. 2003, 2004). Fossils from these formations are diverse (note that the following lists are for the formations in general, not within FIIS, and are included as guides to what might be found; FIIS-specific examples are cited under “Subsurface fossils from FIIS” at the end of this section). Microfossils are of particular interest for FIIS because access to the formations is more or less limited to wells and borings, making microfossils the most likely type of fossils to be recovered. Larger fossils can be recovered, but they are likely to be damaged or incomplete. Types of microfossils known from these formations include coccoliths (mineralized plates of plankton) (Olsson 1975), foraminifera (single-celled organisms that secrete “shells”, typically of calcium carbonate) (Olsson 1964), diatoms (phytoplankton with cell walls made of silica) (Grier 1925a, 1925b), dinoflagellates (single-celled organisms that move using one or more whip-like flagella), spores and pollen representing mosses, lycopods (clubmosses), ferns, bennettitales (cycad-like extinct plants), conifers, and angiosperms (Kimyai 1966, 1970), scolecodonts (worm jaws) (Charletta and Boyer 1974), and ostracodes (seed shrimp) (Jennings 1936). The oldest geologic units, the Raritan and Magothy formations, are more terrestrial than the others and are especially noted for their plant fossils, representing mosses, ferns, cycads, conifers, a number of angiosperms, and undetermined plants (Newberry 1895; Hollick 1906; Weller 1907; Berry 1911; Penny 1947). These formations are also noted for amber. Fossils found in the amber include feathers and a variety of arthropods, including midges, flies, gnats, wasps, ants, bees, lacewings, beetles, leaf hoppers, scale insects, moths, roaches, mantids, barklice, caddisflies, spiders, mites, and pseudoscorpions (Grimaldi et al. 1989; Gallagher et al. 2001). Invertebrates of the Cretaceous deposits are represented by boring sponges, corals, bryozoans (moss animals), brachiopods (lamp shells), bivalves, ammonites (extinct

nautilus-like shelled animals), belemnites (extinct squid-like animals), nautiloids, gastropods, scaphopods (tusk shells), worm tubes, ostracodes, lobsters, crabs, mud shrimp, other crustaceans, echinoids (sea urchins), and burrows and borings (Weller 1907; Richards et al. 1958, 1962; Gallagher 1984). Some deposits are leached, leaving only molds and casts (Weller 1907). Vertebrates are represented by sharks, rays, and other cartilaginous fish, bony fish, turtles, mosasaurs, plesiosaurs, crocodilians, pterosaurs, carnivorous and herbivorous dinosaurs (including *Hadrosaurus foulkii*, the first Western Hemisphere dinosaur named from more than teeth), and extinct multituberculate mammals. Vertebrate trace fossils include coprolites (fossil feces) and dinosaur tracks (Weller 1907; Richards et al. 1962; Gallagher 1984).

Quaternary subsurface clay deposits

In the New York City/Long Island region, Quaternary clay beds have historically been lumped together as the Gardiners Clay, but they now appear to include multiple depositional events from different times and settings (Upson 1970; Sirkin 1986b). The original Gardiners Clay, named from Gardiners Island, appears to be a block of marine clay transported from elsewhere by glaciers, and has a cold-water fauna. Gardiners Clay deposits mapped from cliffs on the north shore of Long Island are nonmarine and possibly contain varves (annual layers), indicating origin in lakes. Clays called Gardiners Clay in the subsurface of western Long Island contain warm-climate pollen (Sirkin 1986b). This subsurface “Gardiners Clay” has yielded a variety of fossils, including foraminifera, diatoms, peat, lignite, woody fragments, pollen and spores, bryozoans, bivalves, gastropods, barnacles, and ostracodes (MacClintock and Richards 1936; Weiss 1954; Perlmutter and Geraghty 1963; Soren 1971, 1978). Foraminifera and diatoms are typical fossils in the FIIS area, showing both brackish and marine affinities (Perlmutter and Todd 1965). Deposits are up to about 15 m (50 ft) thick, and are composed of gray or green silt and clay with sand and gravel lenses (Perlmutter and Todd 1965). It is usually closer to 8 m (25 ft) thick in the area (Doriski and Wilde-Katz 1983). It is interpreted as interglacial, perhaps from the Sangamonian interglacial (roughly 125,000 to 75,000 years ago) (Soren 1971), or an interglacial as old as 225,000 years (Ricketts 1986).

Similar clays include the “20-foot clay” encountered in a small area beneath the westernmost part of FIIS (Schubert 2010), so named because of the depth it is often encountered at. The 20-foot clay includes fossil foraminifera (Soren 1978), diatoms, and marine shells (Soren 1971). It is thought to have been deposited during a sea level high of an interstadial (a warm period during a glaciation) during the Wisconsinan glaciation (Doriski and Wilde-Katz 1983). Note, though, that the concept of a Wisconsinan interstadial is controversial: marine deposits along the North American Atlantic coast frequently give radiocarbon dates that indicate sea levels similar to the present around 40,000 to 30,000 years ago, in conflict with various estimates of sea level at that time (see for example the discussion in Rampino and Sanders [1981] or Scott et al. [2010], and references therein). Rampino and Sanders (1981) interpreted the 20-foot clay and subsurface Gardiners Clay of southern Long Island as representing shallow nearshore, marine, or lagoonal sediments, perhaps from a lagoon or estuary.

Subsurface fossils from FIIS

Perlmutter and Todd (1965) and Schubert (2010) described subsurface fossils from within the boundaries of FIIS. In their description of the stratigraphy beneath the southern part of Long Island, Perlmutter and Todd (1965) reported on foraminifera and ostracodes from eleven well sites within the seashore's boundaries. It appears that all of the well sites, with the possible exception of a site associated with the Bellport Coast Guard Station, were in non-federal parts of FIIS. Eight of the eleven sites yielded Upper Cretaceous foraminifera or upper Pleistocene/Holocene shells, often both. Two sites yielded Upper Cretaceous ostracodes. All of the Upper Cretaceous fossils came from sediments assigned to the Monmouth Group, and were found between about 45 and 90 m (150 and 300 ft) down.

Schubert (2010), in a study of Fire Island groundwater, studied 35 observation wells drilled along or near four transects in FIIS. Most of the wells sampled less than 10 m (33 ft) of the subsurface, but several sampled 30 to 40 m (100 to 130 ft). The four transects were through the Kismet community, along the western boundary of Robbins Rest, through Bayberry Dunes (Watch Hill area), and just west of South Point County Park within the wilderness area. Generally, sediments above sea level were barrier island or shelf sands. A peat level was usually found at about sea level. Below that, lagoonal sediments with shell fragments typically comprised the next 5 to 10 m (16 to 33 ft) of sediment, followed by glacial outwash deposits with occasional shells until about 30 to 35 m (100 to 115 ft) below sea level, where the Gardiners Clay was encountered. A thin wedge of the 20-foot clay was inferred to be present beneath the Kismet transect within the glacial outwash, but did not persist to the east. In the back bays, some areas had seagrass beds or estuarine beds above the lagoonal deposits. It is thought that everything above the outwash is Holocene in age, although no specific ages were quoted (Schubert 2010).

A third site may be from within FIIS, but the precise location cannot be determined at this time. A test well from an unstated location on Fire Island yielded bivalves, gastropods, and echinoids in post-Gardiners Clay sediments (MacClintock and Richards 1936).

Additionally, a well site in neighboring Robert Moses State Park, designated S21091, has been discussed in several publications (Sirkin 1974, 1986a; Lonnie 1982). It reaches a depth of at least 577.3 m (1,894 ft) below the surface, and has yielded pollen at a number of levels in the Cretaceous sediments (Sirkin 1986a).

Surficial Quaternary sediments (Pleistocene–Holocene)

The Holocene sediments that make up the surficial deposits of most of FIIS are limited in the types of fossils that may be found, because they represent a geographic entity that is only a few thousand years old at most. In situ fossils may be limited to the island's peat deposits, generally found a couple of meters below the surface. Shallow cores (1 to 3 m [3 to 10 ft]) into the surficial sediments of Fire Island commonly recovered organic materials that can be dated to the past 1,500 years. For example, mud with shells from Robbins Rest has been dated to 1,100 ± 80 radiocarbon years before present (Leatherman 1985), and Sirkin (1972) dated deposits from Maple Bog in Sunken Forest to 250 ± 80 radiocarbon years before present. The Maple Bog deposits yielded pollen of conifers and angiosperms. If fossils are defined as evidence of past life in a geologic context, these finds qualify

despite their young age. Nearby but outside of FIIS, sediments near the seafloor surface on the Atlantic side of Fire Island yield peats dated to many points throughout the Holocene. Sanders and Kumar (1975) described salt marsh peat dated to 7,750 ± 125 radiocarbon years before present (8,440–7950 calibrated years before present) and 7,585 ± 125 radiocarbon years before present (8,320 –7,800 calibrated years before present), as well as burrows and bivalves. (Note that radiocarbon dates are not the same as calendar dates, and must be calibrated to approximate calendar years. Dates here were calibrated using Calib 7.0 [http://calib.qub.ac.uk/calib/] where appropriate. "Present" in "before present" is 1950.) Panageotou and Leatherman (1986) reported a series of peats from 1.3 to 2.2 km (0.81 to 1.4 miles) offshore of FIIS dated from about 3,500 years ago to about 7,700 years ago, with ages increasing with distance.

An example of a more diverse Holocene coastal assemblage has been described from Prospect Beach in West Haven, Connecticut, a little over 50 km (30 miles) north of the William Floyd Estate. Mid-Holocene fossils from this locality include remains of foraminifera, diatoms, peat, pollen, spores, conifer and angiosperm body fossils (wood, nuts, cones, and leaves), sponges, bryozoans, bivalves, gastropods, worm tubes, barnacles, crabs, lobsters, mantis shrimp, insects, and bony fish. The setting was that of shallow subtidal deposition near a mixed hardwood forest under a similar climate to today (Waage et al. 2001).

Quaternary microfossils such as pollen are a common topic of study in the vicinity of New York City, having been applied to topics such as climate change since the end of the most recent glaciation, fire histories, and responses to land-use changes. Microfossils are usually found in the deposits of lakes, swamps, and marshes, typically covering a time frame going back to around 13,000–12,000 years ago. The most commonly studied fossils are spores and pollen of various plants. Algae, mosses, clubmosses, ferns, conifers, and angiosperms are widely represented. Charcoal is utilized for studies of fire history. Pollen sites in New York and New England show a consistent succession from tundra to spruce-dominated vegetation (transition about 13,000 years ago), to pine-dominated vegetation (appearing around 11,000 to 9,000 years ago), to oak-dominated vegetation (appearing around 7,000 years ago). A selection of publications referencing paleoecological sites within about 100 km (60 miles) of FIIS include Donner (1964), Sirkin (1967, 1971), Russell (1980), Connally and Sirkin (1986), Russell et al. (1993), Maenza-Gmelch (1997), Rue and Traverse (1997), Robinson et al. (2005), and Oswald et al. (2010).

Several general categories of fossils are common in the Quaternary sediments of the Long Island/New York City area, but have not been reported from FIIS to date. In approximate order of most likely to least likely, they include fossils eroded from elsewhere and washed up on beaches; fossils of extinct Pleistocene mammals, sometimes dredged from nearshore seafloors; and fossils that have been reworked from older rocks and deposits and transported by glaciers to the New York City area.

Concretions bearing an assemblage of predominantly shallow marine fossils commonly wash up on the beaches of Gateway National Recreation Area (GATE) in the New York Bay area to the west. Common fossils include corals, bivalves, gastropods, barnacles, and bones of fish and marine mammals. Plant roots and debris, sponges, crabs, lobsters, invertebrate burrows, and a crocodilian

tooth have also been found. Most of these fossils are probably Holocene to possibly late Pleistocene in age, but some of the material is probably older (Stoffer et al. 1996, 1999, 2005; Stoffer 2003; Chamberlain et al. 2006). More information can be found in the GATE chapter of this report. The offshore geology of FIIS is not as conducive to such finds, but they are not out of the question. The Atlantic seafloor immediately offshore of Fire Island has several different types of deposits per Schwab et al. (2000). Holocene sediments dominate west of Watch Hill, but are only present as at most a veneer (<1 m [3 ft]) east of it, where Pleistocene sediments are at or near the surface. Schwab et al. also reported what they interpreted as an outcrop of Cretaceous coastal plain sediments about 5 to 10 km (3 to 5 miles) offshore of Watch Hill. Pleistocene or Cretaceous sediments at or near the seafloor would be excellent potential sources of fossils to wash up on FIIS beaches. Phil Stoffer (USGS emeritus, pers. comm., April 2014) has observed peat washed up on the beach of adjoining Robert Moses State Park, perhaps as a result of Fire Island migrating over swamp deposits. Whitmore et al. (1967) also noted a singular occurrence of a sailing ship bearing Patagonian mammal fossils destined for Harvard which apparently went down off of Fire Island sometime between 1874 and 1910.

Because FIIS is an active barrier island and has probably only existed in its approximate location for the past few thousand years (with the exception of the William Floyd Estate), it is unlikely that terrestrial vertebrate fossils from the Quaternary will be discovered there, although it is conceivable that Pleistocene fossils may wash in from offshore. Clam dredgers and others sampling surficial seafloor sediments have recovered a variety of vertebrate fossils along the Atlantic coast. Among them are remains of bony fish, giant sloths, baleen and toothed whales, walruses, seals, manatees, mastodons, mammoths, horses, tapirs, musk oxen, bison, caribou, and the extinct “stag elk” *Cervalces*. Peat and petrified wood are also sometimes taken up. The terrestrial fossils are relics of times during the Quaternary when sea level was much lower due to glaciation and the coastal plains were far more extensive (Gallagher et al. 1989). Publications discussing offshore vertebrate occurrences in the northern New Jersey–southern New York area include Whitmore et al. (1967) and Gallagher et al. (1989).

Reworked fossils are not uncommon in the glacial sediments of New York City, and have attracted interest since the late 19th century (they seem to have been a favorite topic for the Natural Science Association of Staten Island/Staten Island Institute of Arts and Sciences). Rocks from many formations exposed north of New York City have been transported there by glaciers, and some of these rocks contain fossils; see for example Gratacap (1894) or Hollick (1900, 1908). Marine shells of Quaternary age have also been found in glacial deposits (Desor 1847). Per Fuller (1914), glacial outwash and debris is present in the William Floyd Estate unit. Therefore, it is conceivable that glacially transported fossils may be found there.

Park Collections

FIIS does not have paleontological specimens in its collections at this time (C. Olijnyk, FIIS cultural resources specialist, pers. comm., April 2014). The foraminifera and ostracodes described by Perlmutter and Todd (1965) are in the collections of the National Museum of Natural History

(USNM; Washington, DC). Schubert (2010)'s publication discussing cores and fossils from FIIS was a USGS publication, so there is probably relevant information in USGS archives.

Cultural Resource Contexts

FIIS is a relatively unlikely setting to find fossils in cultural contexts. For example, the probability of finding fossils associated with archeological sites, such as fossil materials used in artifacts, is low. Fire Island is a young and transient geological feature subject to rapid changes, and there is a relative paucity of suitable fossils in the area to be incorporated, such as petrified wood. The presence of fossils in building stone is also unlikely, except perhaps in the interiors of private homes in the community sections, and there are also no notable historic records of fossils (such as "firsts" or fossils reported by settlers). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts. Further information about southeastern New York archeological sites can be found in Funk (1976) and Brennan (1977).

Paleontological Resource Management, Preliminary Recommendations

- Seashore staff should be encouraged to observe the beaches and exposed sedimentary deposits for fossil material while conducting their usual duties. To promote this, they should also 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, seashore staff should take advantage of them, if funding and time permit.

- Staff should photodocument and monitor any occurrences of paleontological resources that may be observed in situ. In most NPS units, fossils and their associated geologic context (surrounding rock/sediment) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts. However, the rapid coastal erosion at FIIS makes collection more important. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. 2009).

- Although no fossils have yet been reported from FIIS beaches, fossils often wash up elsewhere in the Long Island/New York City area. It may be of interest to educate visitors about potential fossils and to encourage them to report them to staff. There are many more visitor eyes than staff eyes, and shoreline erosion is rapid. Encouraging reporting of fossils would need to be weighed against the increased risk of unauthorized collection. Brunner et al. (2010) also discusses the issue of coastal fossil theft.

- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist. Any fossil with 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.

- Quaternary fossils and deposits are of interest because they can be used to describe the effects of past climate and sea level changes, and to predict natural responses to future changes. Further study of these fossils and deposits in and around FIIS is encouraged.
- Contact the NPS Geologic Resources Division for technical assistance with paleontological resource management issues.

References Cited

Benotti, M. J. 2008. Inventory of data sources used for watershed condition assessments of Fire Island National Seashore, Gateway National Recreation Area, and Sagamore Hill National Historic Site, New York and New Jersey. U.S. Geological Survey, Reston, Virginia. Open-File Report 2008-1298. http://pubs.er.usgs.gov/publication/ofr20081298 (accessed March 2014).

Berry, E. W. 1911. Flora of the Raritan Formation. Geological Survey of New Jersey, Trenton, New Jersey. Bulletin 3. Available at http://www.state.nj.us/dep/njgs/enviroed/oldpubs/bulletin3.pdf (accessed March 2014).

Brennan, L. A. 1977. The lower Hudson: the Archaic. *Annals of the New York Academy of Sciences* 288:411–430.

Brunner, J., J. Kenworthy, and V. Santucci. 2010. Unauthorized fossil collecting from National Park Service shorelines: servicewide policy and perspectives. Pages 319–323 *in* S. Weber, editor. Rethinking protected areas in a changing world: proceedings of the 2009 George Wright Society Conference. The George Wright Society, Hancock, Michigan. Available at http://www.georgewright.org/0956brunner.pdf (accessed February 2014).

Chamberlain, J. A., Jr., P. W. Stoffer, and P. Messina. 2006. Fossiliferous nodules from New York Gateway beaches. Page 11 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34.

Charletta, A. C., and P. S. Boyer. 1974. Scolecodonts from Cretaceous greensand of the New Jersey coastal plain. *Micropaleontology* 20(3):354–366.

Connally, G. G., and L. Sirkin. 1986. Woodfordian ice margins, recessional events, and pollen stratigraphy of the mid-Hudson Valley. Pages 50–72 *in* Cadwell, D. H., editor. The Wisconsinan Stage of the First Geological District, eastern New York. New York State Museum, Albany, New York. Bulletin 455. Available at https://www.nysm.nysed.gov/pubsforsale/detail.cfm?pubID=4936 (accessed March 2014).

Desor, E. 1847. [Fossils in drift at Brooklyn and at Westport, New York.] Proceedings of the Boston Society of Natural History 2:247. Available at http://biodiversitylibrary.org/page/9490931 (accessed March 2014).

Donner, J. J. 1964. Pleistocene geology of eastern Long Island, New York. *American Journal of Science* 262(3):355–376.

Doriski, T. P., and F. Wilde-Katz. 1983. Geology of the “20-foot” clay and Gardiners Clay in southern Nassau and southwestern Suffolk counties, Long Island, New York. U.S. Geological Survey, Reston, Virginia. Water-Resources Investigations 82-4056. Available at http://pubs.er.usgs.gov/publication/wri824056 (accessed March 2014).

Fuller, M. L. 1914. The geology of Long Island, New York, U.S. Geological Survey, Washington, DC. Professional Paper 82. Scale 1:125,000. Available at http://pubs.er.usgs.gov/publication/pp82 (accessed March 2014).

Funk, R. E. 1976. Recent contributions to Hudson Valley prehistory. New York State Museum, Albany, New York. Memoir 22. Available at http://purl.org/net/nysl/nysdocs/3078762 (accessed March 2014).

Gallagher, W. B. 1984. Paleoecology of the Delaware Valley region: Part II, Cretaceous to Quaternary. *The Mosasaur* 2:9–43.

Gallagher, W. B., D. C. Parris, B. S. Grandstaff, and C. DeTemple. 1989. Quaternary mammals from the Continental Shelf of New Jersey. *The Mosasaur* 4:101–110.

Gallagher, W. B., D. C. Parris, E. Gilmore, and R. Johnson. 2001. New Jersey’s Cretaceous amber deposits. *Northeastern Geology and Environmental Sciences* 23(4):340–345.

Gratacap, L. P. 1894. Additions to the drift fossils of Staten Island. *Proceedings of the Staten Island Institute of Arts and Sciences* 4(5):16-17.

Grier, N. M. 1925a. The fossil flora of the vicinity of Cold Spring Harbor. *American Midland Naturalist* 9(10):513–527.

Grier, N. M. 1925b. The geology of Long Island with especial reference to the Cold Spring Harbor region and its flora. *American Midland Naturalist* 9(11):531–563.

Grimaldi, D., C. W. Beck, and J. J. Boon. 1989. Occurrence, chemical characteristics, and paleontology of the fossil resins from New Jersey. American Museum Novitates 2948. Available at http://hdl.handle.net/2246/5103 (accessed March 2014).

Hollick, C. A. 1900. Geological notes [Staten Island, New York]. *Proceedings of the Staten Island Institute of Arts and Sciences* 7(13):30–32. Available at http://biodiversitylibrary.org/page/31128092 (accessed March 2014).

Hollick, C. A. 1906. The Cretaceous flora of southern New York, and New England. U.S. Geological Survey, Washington, DC. Monograph 50. Available at https://archive.org/details/cretaceousflorao01holl (accessed March 2014).

Hollick, C. A. 1908. Drift bowlders from the shore at Tottenville. Proceedings of the Staten Island Institute of Arts and Sciences 2:9. Available at http://biodiversitylibrary.org/page/30976156 (accessed March 2014).

Jennings, P. H. 1936. A microfauna from the Monmouth and basal Rancocas groups of New Jersey. Bulletins of American Paleontology 23(78). Available at http://biodiversitylibrary.org/page/30406568 (accessed March 2014).

Kenworthy, J. P., and V. L. Santucci. 2003. Fire Island National Seashore. Page 22 *in* J. P. Kenworthy and V. L. Santucci. Paleontological resource inventory and monitoring: Northeast Coastal and Barrier Network. TIC# D-340. National Park Service, Denver, Colorado.

Kenworthy, J. P., and V. L. Santucci. 2006. A preliminary investigation of National Park Service paleontological resources in cultural resource contexts, Part 1: general overview. Pages 70–76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf (accessed January 2014).

Kimyai, A. 1966. New plant microfossils from the Raritan Formation (Cretaceous) in New Jersey. *Micropaleontology* 12(4):461–476.

Kimyai, A. 1970. Plant microfossils from the Raritan Formation (Cretaceous) in Long Island. *Pollen et Spores* 12(2):181–204.

Leatherman, S. P. 1985. Geomorphic and stratigraphic analysis of Fire Island, New York. Marine *Geology* 63(1–4):173–195.

Leatherman, S. P., M. R. Rampino, and J. E. Sanders. 1983. Barrier island evolution in response to sea level rise: discussion and reply. *Journal of Sedimentary Petrology* 53(3):1026–1033.

Lonnie, T. P. 1982. Mineralogic and chemical comparison of marine, nonmarine, and transitional clay beds on south shore of Long Island, New York. *Journal of Sedimentary Petrology* 52(2):529–536.

MacClintock, D., and H. G. Richards. 1936. Correlation of Pleistocene marine and glacial deposits of New Jersey and New York. *Geological Society of America Bulletin* 47:289–338.

Maenza-Gmelch, T.E. 1997. Holocene vegetation, climate, and fire history of the Hudson Highlands, southeastern New York, USA. *The Holocene* 7:25–37.

McDonald, H. G., and C. E. Ray. 1990. The extinct sloth, *Megalonyx*, (Mammalia: Xenarthra), from the United States Mid-Atlantic continental shelf. *Proceedings of the Biological Society of Washington* 103(1):1–5. Available at http://biodiversitylibrary.org/page/34591492 (accessed March 2014).

Miller, K. G., P. J. Sugarman, J. V. Browning, M. A. Kominz, J. C. Hernandez, R. K. Olsson, J. D. Wright, M. D. Feigenson, and W. Van Sickel. 2003. Late Cretaceous chronology of large, rapid sea-level changes; glacioeustasy during the greenhouse world. *Geology* 31(7):585–588.

Miller, K. G., P. J. Sugarman, J. V. Browning, M. A. Kominz, R. K. Olsson, M. D. Feigenson, and J. C. Hernandez. 2004. Upper Cretaceous sequences and sea-level history, New Jersey coastal plain. *Geological Society of America Bulletin* 116(3–4):368–393.

Minard, J. P. 1969. Geology of the Sandy Hook Quadrangle in Monmouth County, New Jersey. U.S. Geological Survey, Washington, DC. Bulletin 1276. Available at http://pubs.er.usgs.gov/publication/b1276 (accessed March 2014).

National Park Service (NPS), Geologic Resources Inventory Program. 2013. Unpublished digital geologic map of Long Island, New York (NPS, GRD, GRI, FIIS, FIIB digital map) adapted from a U.S. Geological Survey Professional Paper map by Fuller (1914). NPS Geologic Resources Inventory Program. Lakewood, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2202595. (accessed March 2014).

Newberry, J. S. 1895. The flora of the Amboy clays. U.S. Geological Survey, Washington, DC. Monograph 26. Available at https://archive.org/details/floraofamboyclay01newb (accessed March 2014).

Olsson, R. K. 1964. Late Cretaceous planktonic foraminifera from New Jersey and Delaware. *Micropaleontology* 10(2):157–188.

Olsson, R. K. 1975. Upper Cretaceous and lower Tertiary stratigraphy: New Jersey Coastal Plain. Petroleum Exploration Society of New York, New York City, New York. Annual Field Trip 2.

Oswald, W. W., D. R. Foster, E. D. Doughty, and D. Macdonald. 2010. A record of Holocene environmental and ecological changes from Wildwood Lake, Long Island, New York. *Journal of Quaternary Science* 25(6):967–974.

Panageotou, W., and S. P. Leatherman. 1986. Holocene-Pleistocene stratigraphy of the inner shelf off Fire Island, New York: implications for barrier-island migration. *Journal of Sedimentary Petrology* 56(4):528–537.

Penny, J. S. 1947. Studies on the conifers of the Magothy flora. *American Journal of Botany* 34(5):281–296.

Perlmutter, N. M., and J. J. Geraghty. 1963. Geology and ground-water conditions in southern Nassau and southeastern Queens counties, Long Island, New York. U.S. Geological Survey, Washington, DC. Water-Supply Paper 1613-A. Available at http://pubs.er.usgs.gov/publication/wsp1613A (accessed March 2014).

Perlmutter, N. M., and R. Todd. 1965. Correlation and foraminifera of the Monmouth Group (Upper Cretaceous) Long Island, New York. U.S. Geological Survey, Washington, DC. Professional Paper 483-I. Available at http://pubs.er.usgs.gov/publication/pp483I (accessed March 2014).

Pluhowski, E. J., and I. H. Kantrowitz. 1964. Hydrology of the Babylon-Islip area, Suffolk County, Long Island, New York. U.S. Geological Survey, Washington, DC. Water-Supply Paper 1768. Scale 1:62,500. Available at http://pubs.er.usgs.gov/publication/wsp1768 (accessed March 2014).

Rampino, M. R., and J. E. Sanders. 1981. Upper Quaternary stratigraphy of southern Long Island, New York. *Northeastern Geology* 3(2):116–128.

Richards, H. G., C. W. Cooke, H. F. Garner, B. F. Howell, J. A. Jeletzky, A. K. Miller, H. W. Miller, Jr., R. C. Ramsdell, J. B. Reeside, Jr., H. B. Roberts, and J. W. Wells. 1958. The Cretaceous fossils of New Jersey, Part 1. New Jersey Geological Survey, Bureau of Geology and Topography, Trenton, New Jersey. Bulletin 61. Available at http://www.state.nj.us/dep/njgs/enviroed/oldpubs/bulletin61-I.pdf (accessed March 2014).

Richards, H. G., C. W. Cooke, H. F. Garner, B. F. Howell, J. A. Jeletzky, A. K. Miller, H. W. Miller, Jr., R. C. Ramsdell, J. B. Reeside, Jr., H. B. Roberts, and J. W. Wells. 1962. The Cretaceous fossils of New Jersey, Part 2. New Jersey Geological Survey, Bureau of Geology and Topography, Trenton, New Jersey. Bulletin 61. Available at http://www.state.nj.us/dep/njgs/enviroed/oldpubs/bulletin61-II.pdf (accessed March 2014).

Ricketts, H. C. 1986. Examination in boreholes of the subsurface Gardiners Clay (Pleistocene), in the context of the Cretaceous-Quaternary section of Great Neck, Long Island, New York. *Northeastern Geology* 8(1–2):13–22.

Robinson, G. S., L. P. Burney, and D. A. Burney. 2005. Landscape paleoecology and megafaunal extinction in southeastern New York State. *Ecological Monographs* 75(3):295–315.

Rogers, W. B., M. Aparisi, and L. Sirkin. 1989. Search for clues to Mesozoic graben on Long Island. *Marine Geology* 90(1–2):119–124.

Rue, D. J., and A. Traverse. 1997. Pollen analysis of the Hackensack, New Jersey Meadowlands tidal marsh. *Northeastern Geology and Environmental Sciences* 19(3):211–215.

Russell, E. W. B. 1980. Vegetational change in northern New Jersey from precolonization to the present: a palynological interpretation. *Bulletin of the Torrey Botanical Club* 107(3):432–446.

Russell, E. W. B., R. B. Davis, R. S. Anderson, T. E. Rhodes, and D. S. Anderson. 1993. Recent centuries of vegetational change in the glaciated north-eastern United States. *Journal of Ecology* 81:647–664.

Sanders, J. E., and N. Kumar. 1975. Evidence of shoreface retreat and in-place “drowning” during Holocene submergence of barriers, shelf off Fire Island, New York. *Geological Society of America Bulletin* 86(1):65–76.

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado.

Schubert, C. E. 2010. Analysis of the shallow groundwater flow system at Fire Island National Seashore, Suffolk County, New York. U.S. Geological Survey, Reston, Virginia. Scientific Investigations Report 2009-5259. Available at http://pubs.er.usgs.gov/publication/sir20095259 (accessed March 2014).

Schwab, W. C., E. R. Thieler, J. R. Allen, D. S. Foster, B. A. Swift, and J. F. Denny. 2000. Influence of inner-continental shelf geologic framework on the evolution and behavior of the barrier-island system between Fire Island Inlet and Shinnecock Inlet, Long Island, New York. *Journal of Coastal Research* 16(2):408–422.

Scott, T. W., D. J. P. Swift, G. R. Whittecar, and G. A. Brook. 2010. Glacio-isostatic influences on Virginia's late Pleistocene coastal plain deposits. *Geomorphology* 116(1–2):175–188.

Sirkin, L. A. 1967. Late-Pleistocene pollen stratigraphy of western Long Island and eastern Staten Island, New York. Pages 249–274 *in* E. J. Cushing and H. E. Wright, editors. Quaternary paleoecology. Yale University Press, New Haven, Connecticut. International Association for Quaternary Research, Proceedings of the 7th Congress.

Sirkin, L. A. 1971. Surficial glacial deposits and postglacial pollen stratigraphy in central Long Island, New York. *Pollen et Spores* 13(1):93–100.

Sirkin, L. A. 1972. Origin and history of Maple Bog in the Sunken Forest, Fire Island, New York. *Bulletin of the Torrey Botanical Club* 99(3):131–135.

Sirkin, L. A. 1974. Palynology and stratigraphy of Cretaceous strata in Long Island, New York, and Block Island, Rhode Island. Journal of Research of the U.S. *Geological Survey* 2(4):431–440. Available at http://pubs.er.usgs.gov/publication/70007403 (accessed March 2014).

Sirkin, L. A. 1986a. Palynology and stratigraphy of Cretaceous and Pleistocene sediments on Long Island, New York: a basis for correlation with New Jersey coastal plain sediments. U.S. Geological Survey, Washington, DC. Bulletin 1559. Available at http://pubs.er.usgs.gov/publication/b1559 (accessed March 2014).

Sirkin, L. 1986b. Pleistocene stratigraphy of Long Island, New York. Pages 6–21 *in* Cadwell, D. H., editor. The Wisconsinan Stage of the First Geological District, eastern New York. New York State Museum, Albany, New York. Bulletin 455. Available at https://www.nysm.nysed.gov/pubsforsale/detail.cfm?pubID=4936 (accessed March 2014).

Soren, J. 1971. Ground-water and geohydrologic conditions in Queens County, Long Island, New York. U.S. Geological Survey, Washington, DC. Water-Supply Paper 2001-A. Scale 1:62,500. Available at http://pubs.er.usgs.gov/publication/wsp01A (accessed March 2014).

Soren, J. 1978. Subsurface geology and paleogeography of Queens County, Long Island, New York. U.S. Geological Survey, Washington, DC. Water-Resources Investigations 77-34. Available at http://pubs.er.usgs.gov/publication/wri7734 (accessed March 2014).

Stoffer, P. 2003. Geology of the New York City region: a preliminary regional field-trip guidebook. U.S. Geological Survey, Reston, Virginia. Available at http://3dparks.wr.usgs.gov/nyc/index.html (accessed March 2014; online only).

Stoffer, P. W., P. Messina, and J. A. Chamberlain, Jr. 1996. Fossils from beaches in Gateway National Recreation Area: implications for the geologic history of the New York Bight. *Abstracts with Programs - Geological Society of America* 28(7):A–143.

Stoffer, P. W., P. Messina, and J. A. Chamberlain, Jr. 1999. Fossiliferous concretions from New York Bight beaches: implications for late Pleistocene and Holocene coastal environments around Sandy Hook and western Long Island. Pages 119–143 *in* J. H. Puffer, editor. New Jersey beaches and coastal processes from geologic and environmental perspectives. Geological Association of New Jersey, Newark, NJ. Annual Field Conference 16.

Stoffer, P. W., J. A. Chamberlain, Jr., R. Scal, and P. Messina. 2005. Late Quaternary and early Holocene fossils from New York City beaches: implications for stability in coastal environments in western Long Island and New Jersey. *Abstracts with Programs - Geological Society of America* 37(7):366.

Sugarman, P. J., K. G. Miller, D. Bukry, and M. D. Feigenson. 1995. Uppermost Campanian-Maestrichtian strontium isotopic, biostratigraphic, and sequence stratigraphic framework of the New Jersey coastal plain. *Geological Society of America Bulletin* 107(1):19–37.

Thornberry-Ehrlich, T. L. 2011. Geologic resource inventory scoping summary, Fire Island National Seashore. National Park Service, Geologic Resources Division, Denver, Colorado. Available at http://nature.nps.gov/geology/inventory/publications/s_summaries/FIIS_Scoping_Summary_2011-1013.pdf (accessed March 2014).

Upson, J. E. 1970. The Gardiners Clay of eastern Long Island, New York: a reexamination. Pages B157–B160 in Geological Survey research 1970, Chapter B. U.S. Geological Survey, Washington, DC. Professional Paper 700-B. Available at http://pubs.er.usgs.gov/publication/pp700B (accessed March 2014).

Waage, K. M., C. MacClintock, and L. J. Hickey. 2001. Post-glacial fossils from Long Island Sound off West Haven, Connecticut. Postilla 225. Available at http://www.biodiversitylibrary.org/part/83201#/summary (accessed March 2014).

Weiss, L. 1954. Foraminifera and origin of the Gardiners Clay (Pleistocene), eastern Long Island, New York. U.S. Geological Survey, Washington, DC. Professional Paper 254-G. Available at http://pubs.er.usgs.gov/publication/pp254G (accessed March 2014).

Weller, S. 1907. A report on the Cretaceous paleontology of New Jersey. Geological Survey of New Jersey, Trenton, New Jersey. Paleontology Series 4. Available at https://archive.org/details/reportonpaleontopt104newjiala (accessed March 2014).

Whitmore, F. C., Jr., K. O. Emery, H. B. S. Cooke, and D. J. P. Swift. 1967. Elephant teeth from the Atlantic Continental Shelf. *Science* 156(3781):1477–1481.

Additional References

Baker, J. E. B. 1995. Simple methods for extracting microfossils of the Navesink Formation (Cretaceous, N.J.). Pages 302–309 *in* J. E. B. Baker, editor. Contributions to the paleontology of New Jersey: proceedings of a symposium, field trips and teacher workshop on the topic. Geological Association of New Jersey, Newark, NJ. Annual Field Conference 12.

Belknap, D. F. 1984. Amino acid racemization in "mid-Wisconsin" C-14 dated formations on the Atlantic Coastal Plain. *Abstracts with Programs - Geological Society of America* 16(1):2-3.

Blumberg, B. 2009. Sea-level rise, climate change, and salt-marsh development processes at Fire Island. *Park Science* 26(2):16-17. Available at http://www.nature.nps.gov/parkscience/index.cfm?ArticleID=319&ArticleTypeID=28 (accessed March 2014).

Coch, N. K., and D. Weiss. 1989. Environmental geology and geological development of the lower Hudson Estuary and New York Harbor. Pages 15–25 *in* C. A. Baskerville, editor. Environmental, engineering, and urban geology in the United States. Volume 1, New York and Washington, D.C.: geology and engineering geology of the New York metropolitan area. Field trips for the 28th International Geological Congress. American Geophysical Union, Washington, DC. Field Trip T361.

Diperna, C. J. 2008. A paleoecological assessment of urbanized coastal lagoons: Moriches Bay and Great South Bay, Long Island, New York. Thesis. University of Rhode Island, Kingston, Rhode Island.

Ellwood, B. B. 1996. Geology and America's National Park areas. Prentice Hall, Upper Saddle River, New Jersey.

Foster, D. S., B. A. Swift, and W. C. Schwab. 1999. Stratigraphic framework maps of the nearshore area of southern Long Island from Fire Island to Montauk Point, New York. U.S. Geological Survey, Reston, Virginia. Open-File Report 99-559. Available at http://pubs.er.usgs.gov/publication/ofr99559 (accessed March 2014).

Gustavson, T. C. 1976. Paleotemperature analysis of the marine Pleistocene of Long Island, New York, and Nantucket Island, Massachusetts. *Geological Society of America Bulletin* 87(1):1–8.

Hartnagel, C. A., and S. C. Bishop. 1921. The mastodons, mammoths and other Pleistocene mammals of New York State. New York State Museum, Albany, NY. Bulletins 241 and 242.

Hay, O. P. 1923. The Pleistocene of North America and its vertebrated animals from the states east of the Mississippi River and from the Canadian provinces east of longitude 95 degrees. Carnegie Institution of Washington, Washington, D.C. Publication 322. Available at https://archive.org/details/pleistoceneofnor00hayouoft (accessed January 2014).

Jepsen, G. L. 1960. A New Jersey mastodon. New Jersey State Museum, Trenton, New Jersey. Bulletin 6.

Johnson, C. E. 1982. Historic and geomorphic evidence of barrier dynamics and the origin of the Sunken Forest, south shore of Long Island, New York. Thesis. University of Massachusetts at Amherst, Amherst, Massachusetts.

Kuehne, D. F. 1999. Upper Cretaceous macroinvertebrate faunas of the Northern Atlantic Coastal Plain. *The Mosasaur* 6:29–79.

Lucas, S. G. 1993. A Pleistocene horse from Connecticut. *The Mosasaur* 5:43–46.

Mayor, A. 2005. Fossil legends of the first Americans. Princeton University Press, Princeton, New Jersey.

Olsen, S. J. 1971. Zooarchaeology: animal bones in archaeology and their interpretation. Addison-Wesley Publishing Company, New York City, New York.

Sirkin, L. 1996. Field trip 1: Deglaciation of central Long Island. Pages 159–165 *in* Geology of Long Island and metropolitan New York. SUNY at Stony Brook, Long Island Geologists, Stony Brook, New York. Available at http://dspace.sunyconnect.suny.edu/handle/1951/48042?show=full (accessed March 2014).

Sirkin, L., and R. Stuckenrath. 1980. The Portwashingtonian warm interval in the northern Atlantic Coastal Plain. *Geological Society of America Bulletin* 91(6):332–336.

Veatch, A. C. 1906. Outlines of the geology of Long Island. Pages 15–52 *in* Veatch, A. C., C. S. Slichter, I. Bowman, W. O. Crosby, and R. E. Horton. Underground water resources of Long Island, New York. U.S. Geological Survey, Washington, DC. Professional Paper 44. Available at http://pubs.er.usgs.gov/publication/pp44 (accessed March 2014).

Weiss, L. 1951. Origin of the (Pleistocene) Gardiners Clay in eastern Long Island, New York. Thesis. New York University, New York City, New York.

Data Sets

Fire Island National Seashore Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Fire Island National Seashore Digital Geologic Map
2013–present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active.
https://irma.nps.gov/App/Reference/Profile/2202595.

National Museum of Natural History
1960s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by USNM staff; status: Active.

U.S. Geological Survey
2000s–present. (locality notes; collection records; maps; etc.). Originated by USGS staff; status: Active.

Gateway National Recreation Area

Gateway National Recreation Area (GATE) protects a variety of natural and cultural resources in the New York Harbor area of New Jersey and New York. There are three parcels, the Jamaica Bay, Sandy Hook, and Staten Island units. The Jamaica Bay Unit is centered on the Jamaica Bay Wildlife Refuge, with a number of parcels on the surrounding shores, such as Breezy Point Tip and Fort Tilden on the Rockaway Peninsula and the historic Floyd Bennett Field airport. The Sandy Hook Unit includes the Sandy Hook spit (GATE Figure 1) and Fort Hancock. The Staten Island Unit includes Great Kills Park, Miller Field, and Fort Wadsworth, as well as Hoffman and Swinburne islands, which are closed to the public. GATE was established October 27, 1972. It encompasses 10,767.32 ha (26,606.63 acres), of which 8,273.56 ha (20,444.40 acres) are federal.



GATE Figure 1. Fossils often wash up on the beaches of GATE, such as this beach on Sandy Point (NPS).

New York City has a number of small (<24 ha [60 acres], mostly 0.4 ha [1 acre] or less) NPS units that are not included in the I&M program, but are geographically within the NCBN. These units include African Burial Ground National Monument (AFBG), Castle Clinton National Monument (CACL), Federal Hall National Memorial (FEHA), General Grant National Memorial (GEGR), Governors Island National Monument (GOIS), Hamilton Grange National Memorial (HAGR), Saint

Paul's Church National Historic Site (SAPA), Statute of Liberty National Monument (STLI), and Theodore Roosevelt Birthplace National Historic Site (THRB), as well as the affiliated Lower East Side Tenement National Historic Site. It is unlikely that fossils will be found at these units. The most likely type of paleontological resource would be fossiliferous building stones. Fossils may also be present at depth below them, but would only be encountered through drilling. CACL, GOIS, and STLI could conceivably receive fossils washed in from elsewhere, although their locations deep in the Upper Bay make this unlikely. They could also have fossils transported by glaciers, or fossils associated with archeological sites. STLI's Liberty Island was once known as one of New York's "Oyster Islands" and has shell middens from the past thousand years. The information in this report for GATE can be used in a general way for the non-I&M units.

Geologic Background

GATE's units are distributed around New York Harbor, within one of the largest urban agglomerations in the world (GATE Figure 2). The Jamaica Bay Unit includes parts of southeastern Kings County and southern Queens County, New York, on the southwestern corner of Long Island. The Sandy Hook Unit is located on the northeastern extremity of Monmouth County, New Jersey. The Staten Island Unit is located on the northeast margin of Staten Island, in Richmond County, New York. Publications that describe the geology and paleontology of GATE units include Woolman (1897), Veatch (1906), Kümmel and Poland (1910), Shupack (1934), MacClintock and Richards (1936), Lohman (1939), Perlmutter and Arnow (1953), Minard (1969), Soren (1971, 1978, 1988), Petters (1976), Halsey et al. (1979), Stoffer et al. (1996, 1999, 2005), Stanford (2000), Peteet and Liberman (2001), Kenworthy and Santucci (2003), Stoffer (2003), Pendleton et al. (2005), Chamberlain et al. (2006), Hunt et al. (2006), Benotti (2008), and Thornberry-Ehrlich (2011). The NPS Geologic Resources Division held a scoping meeting for GATE in June 2010 (Thornberry-Ehrlich 2011), and the initial paleontological resource inventory and summary was prepared by Kenworthy and Santucci (2003). Phil Stoffer and Paula Messina have produced a website, "Geology and Geography of New York Bight Beaches" (http://www.geo.hunter.cuny.edu/bight/index.html), which includes a great deal of valuable information, including a page on fossils found on GATE beaches (http://www.geo.hunter.cuny.edu/bight/fossil.html).

The following discussion of the geologic background is primarily derived from Stoffer (2003), except where noted. Although the surficial geology of the three GATE units is limited to upper Quaternary deposits (GATE Figure 3) (see the Appendix for a geologic time chart), older Quaternary and Cretaceous deposits have been frequently accessed through wells and borings and are widely exposed in the vicinity, extending the geologic record of the recreation area to about 100 Ma (million years ago). The Atlantic coast of North America has generally been quiet in terms of tectonics since the breakup with Europe and Africa, which occurred during the Late Triassic and Early Jurassic (centered about 200 Ma). The subsurface of central Long Island may contain an ancient rift valley from this time, following the alignment of the Hartford Basin of Connecticut and Massachusetts, and concealed by younger sediments (Rogers et al. 1989). Another rift basin, the Newark Basin, is present west of GATE, and includes the famous Palisades Sill, a vast igneous intrusion from 200 Ma.

A hiatus in the depositional record follows until about 100 Ma, the onset of some 50 to 60 million years of deposition from the Late Cretaceous to the Eocene that drapes the bedrock of northeastern New Jersey and New York City. These deposits dip to the south, so the thickness of the pile and the total time represented increase going south. The Cretaceous sediments include a number of formations that record a transition from coastal plains to shallow marine settings, with several marine transgression-regression cycles as sea level rose and fell (Sugarman et al. 1995; Miller et al. 2003, 2004). The Sandy Hook area is noted for preserving the thickest and most complete section of Upper Cretaceous sediments in the New Jersey coastal plain (Minard 1969). A similar pattern of deposition persisted in New Jersey well into the Cenozoic, but in GATE itself and New York City, the geologic record is interrupted after the Cretaceous deposition and does not resume until sometime in the past few million years. White quartz pebbles in ironstone conglomerates on Sandy Hook may represent material from the Neogene-age Beacon Hill Gravel, a thin unit found occasionally at high elevations in Monmouth County (P. Stoffer, USGS emeritus, pers. comm., April 2014).

The Quaternary geology of the GATE area is dominated by the influence of glaciers, both direct (such as sediments moved by glaciers) and indirect (such as deposition by glacial meltwater lakes and, more broadly speaking, the effects of glaciation, post-glacial adjustment of crust depressed by ice, and glacial melting on sea level). Multiple glacial–interglacial cycles have occurred during the Quaternary, but the evidence for most of them is usually obscured by the effects of the most recent glaciation. Glaciers reached as far south as Staten Island and covered much of Long Island. It does not appear that they reached the Jamaica Bay and Sandy Hook units, but the Staten Island Unit is roughly at the terminus. Long Island is in large part the remains of two thick glacial terminal moraines (accumulations of glacial debris), the older Ronkonkoma Moraine present across central Long Island, and the younger Harbor Hill Moraine of northern Long Island. They were formed during what is known as the Wisconsinan (or Wisconsin) glaciation, the most recent glacial episode. The Wisconsinan began roughly 85,000 to 75,000 years ago, reached a maximum (the Last Glacial Maximum) about 25,000 to 20,000 years ago, and ended about 11,000 years ago. Immediately before this glacial episode, the prevailing climate and sea level were similar to today; this time is known as the Sangamonian (or Sangamon) interglacial, which began about 125,000 years ago. Marine deposits from this time have been found in New Jersey and to a lesser extent southern New York. Lakes formed after glaciers melted, behind the moraines of unconsolidated debris, and sometimes broke out of these barriers in catastrophic fashion.

One of the effects of glaciation is to draw down global sea levels, with the effect of extending coastal plains tens of km/miles closer to ocean basins. For example, during the Last Glacial Maximum, the Raritan and Sandy Hook bays were not submerged, and were drained by rivers. They became estuarine following the end of glaciation. Flooding of the bays has been dated variously to 11,500 years ago and about 6,000 years ago (Klein and McHugh 2009), although the chronology is complicated by the effects of postglacial rebound (see below). The extended coastal plain supported a variety of plant and animal life, fossils of which are sometimes dredged from the seafloor (Whitmore et al. 1967; Gallagher et al. 1989; McDonald and Ray 1990). The Hudson River formerly drained through Jamaica Bay (Soren 1978), and appears to have flowed east of Sandy Hook on its way to the Atlantic Ocean during the recent time of low sea level (McDonald and Ray 1990).

The presence of glaciers had other significant effects on the GATE area. The sheer mass of glacial ice sheets depresses land surface beneath them, while also causing the land just beyond the ice to bulge up. When glacial sheets depart, the deglaciated land is initially depressed, sometimes significantly below sea level, and marine waters can flow into the depressed area. The depressed land soon begins to rebound and the bulge follows the departing ice. Over a period of thousands of years the formerly glaciated land returns to a more neutral elevation. This process happened in the GATE area. Glacial retreat allowed marine waters to enter depressed parts of the New York Bight around 11,500 years before present, depositing marine marl and clay. By about 7,000 years before present, the rate of rebound had surpassed the rate of sea level rise, and marine deposition was converted to estuarine deposition.

GATE's three units are all coastal, and feature geologically young (a few thousand years old) and dynamic environments. Sandy Hook, for example, lengthened about 300 m (1,000 ft) in a quarter of a century (Minard 1969). Their coastal setting leaves them vulnerable to sea level change and hurricanes. Human modification has been important as well. Humans arrived in the New York City area by around 10,000 years ago, and over the past 400 years it has become one of the most anthropogenically altered landscapes in the Western Hemisphere.

The surficial and subsurface geology of each of the three GATE units has been studied. Generally each unit has Holocene deposits over Pleistocene deposits over coastal and marine Upper Cretaceous deposits (a schematic geologic map from the Geologic Resources Division is usually included, but the files have not yet been prepared for GATE). Fossils have been reported from each GATE unit, and can be broken down into subsurface fossils (Cretaceous lignite, Pleistocene and Holocene microfossils and fragments of larger fossils) and fossils that have washed up on beaches (mostly Holocene or Pleistocene marine invertebrates, but also plant and vertebrate fossils) (GATE Table 1).

The Jamaica Bay Unit is covered by a thin veneer of Holocene shore and salt marsh sediment over Upper Pleistocene deposits (Soren 1978). These Upper Pleistocene deposits include glacial till, lake, and glacial outwash sediment, with a thickness of approximately 45 m (150 ft). Beneath them are Pleistocene clays attributed to the Gardiner Clay, fluvial Pleistocene gravel of the Jameco Gravel, undivided sediments of the Matawan Group and Magothy Formation (Upper Cretaceous), the Raritan Formation (Upper Cretaceous), and finally bedrock between 300 to 350 m (980 to 1,100 ft) below sea level (Soren 1971, 1978).

The Sandy Hook Unit is covered by beach and nearshore marine sand of Holocene age, with silt and clay in the neighboring Sandy Hook Bay (Stanford 2000). Tidal marsh deposits are also present. The Holocene sediments generally thin going south, from about 60 m (200 ft) to 12 m (40 ft) across the Sandy Hook Unit. Within these sediments are scattered lenses of foraminiferal clay of Pleistocene–Holocene age, and below it are several south-dipping Upper Cretaceous formations that have been encountered in wells and borings. In ascending order (oldest to youngest; coincidentally north to south as well at this location), they include the Magothy Formation, Merchantville Formation, Woodbury Clay, Englishtown Formation, Marshalltown Formation, Wenonah Formation, Mount Laurel Sand, Navesink Formation, and Sandy Hook Member of the Red Bank Sand (Minard 1969).

At greater depths, the Raritan Formation (Upper Cretaceous) has also been encountered beneath Sandy Hook (Kümmel and Poland 1910).

The Staten Island Unit is covered by Quaternary deposits to a depth of about 15 to 30 m (50 to 100 ft). Below these deposits is the Raritan Formation (Upper Cretaceous), to a depth of about 30 to 120 m (100 to 400 ft), increasing from north to south. Below this are Paleozoic and Precambrian metamorphic bedrock units (Soren 1988).



GATE Figure 2. Geography of GATE (NPS; modified to make park water stand out).

GATE Table 1. Summary of GATE stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text.

Formation	Age	Fossils Within GATE	Depositional Environment
Surficial Quaternary sediments	Pleistocene–Holocene	Holocene foraminifera, pollen, gastropods, and fish scales and teeth in surficial deposits of Jamaica Bay; Reworked fossils washed up on beaches, thought to be mostly late Pleistocene and Holocene in origin, but Late Cretaceous and possibly Eocene fossils have also been found; include diatomaceous earth, plant roots and debris, pine cones, sponges, corals, bivalves, gastropods, barnacles, crabs, lobsters, invertebrate burrows, teeth and vertebrae of fish and marine mammals such as walruses, and a crocodilian tooth	Shallow marine, beaches, marshes
Subsurface Quaternary sediments	Pleistocene–Holocene	Holocene: shell fragments Latest Pleistocene–earliest Holocene clay: foraminifera, rootlets, reed fragments Pleistocene: diatoms Unspecified: foraminifera, diatoms, sponge spicules, bivalves, and unspecified mollusk shell fragments	Shallow marine
Subsurface Cretaceous sediments (including, at various locations, from youngest to oldest the Red Bank, Navesink, Mount Laurel, Wenonah, Marshalltown, Englishtown, Woodbury, Merchantville, Magothy, and Raritan formations, or undivided equivalents)	Late Cretaceous	Lignite, possibly microfossils	Coastal terrestrial to shallow marine

Sources of Paleontological Resources

The fossils of GATE present opportunities for education, interpretation, and scientific research in the recreation area. Both the Sandy Hook and Staten Island units are near notable fossil localities. Sandy Hook is just northeast of a general region of productive Upper Cretaceous and Paleogene outcrops, including the Cretaceous deposits of nearby Atlantic Highlands. Staten Island has long been noted for somewhat older Cretaceous plant fossils and amber.

Subsurface (Upper Cretaceous and Quaternary)

Numerous wells and borings have been made within GATE units, particularly the Sandy Hook Unit. These subsurface explorations have frequently encountered fossils, such as microfossils, lignite, and shells. Because the fossiliferous sediments are buried hundreds of meters or feet below the surface, they are protected from erosion, theft, and vandalism, and only require management when brought to the surface. They are included here for completeness, and because they illustrate otherwise hidden aspects of GATE's geologic history.

As shown in various publications (Minard 1969; Soren 1971, 1978, 1988), there are several Cretaceous and Quaternary units frequently encountered in the subsurface of GATE. Although exhaustive treatment of each unit is not relevant for this work, because of the lack of surface exposures, a short discussion is justified both because they have yielded fossils within GATE from wells and borings in the past, and because eroding outcrops nearby shed fossils that may wash up on GATE beaches. Detailed descriptions of the subsurface units as they are found beneath various GATE units are included in the publications cited above.

Upper Cretaceous units

The Cretaceous deposits beneath GATE are generally composed of unconsolidated sand, silt, and clay, often with glauconite (a green mineral that often forms in shallow marine settings, particularly around sand grains; thus, beds with abundant glauconite are commonly called “greensand”). The different formations have different proportions of these types of sediment (Minard 1969). These sediments represent several marine transgression-regression cycles occurring between approximately 100 and 66 million years ago, or essentially the entire Late Cretaceous (Sugarman et al. 1995; Miller et al. 2003, 2004). Fossils from these formations are diverse (note that the following lists are for the formations in general, not within GATE, and are included as guides to what might be found; GATE-specific examples are cited under “Subsurface fossils from GATE” at the end of this section). Microfossils are of particular interest for GATE because the formations are typically sampled via wells and borings, making microfossils the most likely type of fossils to be recovered. Types of microfossils known from these formations in general include coccoliths (mineralized plates of plankton) (Olsson 1975), foraminifera (single-celled organisms that secrete “shells”, typically of calcium carbonate) (Olsson 1964), diatoms (phytoplankton with cell walls made of silica) (Grier 1925a, 1925b), dinoflagellates (single-celled organisms that move using one or more whip-like flagella), spores and pollen representing mosses, lycopods (clubmosses), ferns, bennettitales (cycad-like extinct plants), conifers, and angiosperms (Kimyai 1966, 1970), scolecodonts (worm jaws) (Charletta and Boyer 1974), and ostracodes (seed shrimp) (Jennings 1936). The oldest geologic units, the Raritan and Magothy formations, are more terrestrial than the others and are especially noted for their plant fossils, representing mosses, ferns, cycads, conifers, a number of angiosperms, and undetermined plants (Newberry 1895; Hollick 1906a; Weller 1907; Berry 1911; Penny 1947). These formations are also noted for amber. Fossils found in the amber include feathers and a variety of arthropods, including midges, flies, gnats, wasps, ants, bees, lacewings, beetles, leaf hoppers, scale insects, moths, roaches, mantids, barklice, caddisflies, spiders, mites, and pseudoscorpions (Grimaldi et al. 1989; Gallagher et al. 2001). Invertebrates of the Cretaceous deposits are represented by boring sponges, corals, bryozoans (moss animals), brachiopods (lamp shells), bivalves, ammonites (extinct nautilus-like shelled animals), belemnites (extinct squid-like animals), nautiloids, gastropods, scaphopods (tusk shells), worm tubes, ostracodes, lobsters, crabs, mud shrimp, other crustaceans, echinoids (sea urchins), and burrows and borings (Weller 1907; Richards et al. 1958, 1962; Gallagher 1984). Some deposits are leached, leaving only molds and casts (Weller 1907). Vertebrates are represented by sharks, rays, and other cartilaginous fish, bony fish, turtles, mosasaurs, plesiosaurs, crocodilians, pterosaurs, carnivorous and herbivorous dinosaurs (including *Hadrosaurus foulkii*, the first Western Hemisphere dinosaur named from more than teeth), and extinct multituberculate

mammals. Vertebrate trace fossils include coprolites (fossil feces) and dinosaur tracks (Weller 1907; Richards et al. 1962; Gallagher 1984).

Reports of Cretaceous plant fossils from Staten Island go back at least as far as the 1880s. The island's plant fossils include material that is in place and material that has been eroded and redeposited. Noted localities on the island include Arrochar, Charleston (Kreischerville in pre-World War I reports), Green Ridge, Prince's Bay, Richmond Valley, and Tottenville. Fossils include lignite, amber, wood, leaf impressions, fragmentary leaves, fruit, and stems representing conifers and angiosperms (Hollick 1892a, 1892b, 1898, 1905, 1906a; Hollick and Jeffrey 1909). Markings on some pieces of lignite have been interpreted as insect borings (Hollick 1906b), and the Charleston wood has been suggested as evidence of a forest fire (Hollick 1906c). The fossils came from beds within what are now identified as the Raritan and Magothy formations (Hollick 1906a). Brachiopods and bivalves have also been found (Hollick 1892a).

Quaternary subsurface clay deposits

The most fossiliferous subsurface Quaternary deposits in the GATE area are lenses and beds of clay. In the New York City/Long Island region, Quaternary clay beds have historically been lumped together as the Gardiners Clay, but they now appear to include multiple depositional events from different times and settings (Upson 1970; Sirkin 1986). The original Gardiners Clay, named from Gardiners Island, appears to be a block of marine clay transported from elsewhere by glaciers, and has a cold-water fauna. Gardiners Clay deposits mapped from cliffs on the north shore of Long Island are nonmarine and possibly contain varves (annual layers), indicating origin in lakes. Clays called Gardiners Clay in the subsurface of western Long Island contain warm-climate pollen (Sirkin 1986). This subsurface "Gardiners Clay" has yielded a variety of fossils, including foraminifera, diatoms, peat, lignite, woody fragments, pollen and spores, bryozoans, bivalves, gastropods, barnacles, and ostracodes (MacClintock and Richards 1936; Weiss 1954; Perlmutter and Geraghty 1963; Soren 1971, 1978). Deposits are up to 43 to 46 m (140 to 150 ft) thick beneath the New York units of GATE, and are composed of gray-green clay and silt, with lenses of sand and gravel (Perlmutter and Geraghty 1963; Soren 1971). It is interpreted as interglacial, perhaps from the Sangamonian interglacial (roughly 125,000 to 75,000 years ago) (Soren 1971), or an interglacial as old as 225,000 years (Ricketts 1986).

The subsurface Gardiners Clay has been suggested as the source of most of the fossils that wash up on GATE beaches (see under "Surficial Quaternary sediments" below) (Kenworthy and Santucci 2003), although this seems too old; one or more of the similar but younger clay beds of the area could also be the source. MacClintock and Richards (1936) attributed the subsurface Pleistocene fossils from Sandy Hook borings and wells to the Cape May Formation. The difference may be academic, given that the Cape May Formation has sometimes been considered to be equivalent to the Gardiners Clay (Upson 1970), and dates to the Sangamonian (Stanford 2000). The Cape May Formation, better known from southern New Jersey, is a marine unit deposited under approximately 6 to 9 m (20 to 30 ft) of warm water (MacClintock and Richards 1936), in beach and estuarine settings (Stanford 2000). It produces fossils of foraminifera, diatoms, bryozoans, bivalves,

gastropods, barnacles, echinoids, and sponge borings (MacClintock and Richards 1936; Gallagher 1984).

Stoffer (2003; pers. comm., April 2014) described a younger marine unit in the New York Bight as the “Gardiners Clay”. This unit was deposited during the latest Pleistocene and early Holocene, and is interpreted as having formed in the depressed Bight in the brief period between deglaciation and postglacial rebound. It is a source of the fossils that wash up on GATE beaches (see under “Surficial Quaternary sediments” below). Based on age, it may be the same as Minard (1969)’s “foraminiferal clay” beneath the Sandy Hook Unit (see under “Subsurface fossils from GATE” below).

Similar clays include the “foraminiferal clay” (Minard 1969) and the “20-foot clay” beneath the Jamaica Bay Unit (Soren 1971, 1978), so named because of the depth it is usually encountered at. The 20-foot clay includes fossil foraminifera (Soren 1978), diatoms, and marine shells (Soren 1971). It is thought to have been deposited during a sea level high of an interstadial (a warm period during a glaciation) during the Wisconsinan glaciation (Doriski and Wilde-Katz 1983). Note, though, that the concept of a Wisconsinan interstadial is controversial: marine deposits along the North American Atlantic coast frequently give radiocarbon dates that indicate sea levels similar to the present around 40,000 to 30,000 years ago, in conflict with various estimates of sea level at that time (see for example the discussion in Rampino and Sanders [1981] or Scott et al. [2010], and references therein). Other fossils reported from local subsurface clay deposits include foraminifera, bivalve fragments, gastropods, and fish teeth from Pleistocene clay (Shupack 1934), and wood, bivalves, gastropods, and crabs from postglacial clay (MacClintock and Richards 1936).

Subsurface fossils from GATE

Most reports of subsurface fossils from GATE are from the Sandy Hook Unit, where a number of borings and wells have yielded fossils. Examples include the following, in separate paragraphs for readability:

At Fort Hancock, a well described by Woolman (1897) reached 60 m (200 ft). The entire thickness was attributed to the Quaternary, but more recent subsurface reports (Kümmel and Poland 1910; Minard 1969) suggest that it is likely at least some of the lower sediments are Cretaceous. Woolman reported clam shells at 23 m (73 ft), diatoms and sponge spicules in greenish fine clayey sand at 38 m (125 ft), and foraminifera, diatoms, and fragments of mollusk shells in greenish clay from 41 to 44 m (135 to 145 ft);

Kümmel and Poland (1910) discussed three wells from the Sandy Hook Unit, two at Fort Hancock and one near Spermaceti Cove. Fossils were not reported from the Fort Hancock wells, but three lignite-bearing units were reported from the Spermaceti Cove well. This well was described as showing recent sand (0 to 18 m down [0 to 60 ft]), the Marshalltown Formation (18 to 40 m [60 to 131 ft]), the Englishtown Formation (40 to 88 m [131 to 288 ft]), the Woodbury and Merchantville formations undivided (88 to 118 m [288 to 387 ft]), and the Magothy Formation (118 to at least 130 m [387 to at least 427 ft]). Lignite was present in the Marshalltown Formation (sand from 21 to 36 m [68 to 118 ft]), the Englishtown Formation (sand from 40 to 85 m [131 to 280 ft]), and the Magothy Formation;

Lohman (1939) reported Pleistocene diatoms from two levels in a well at Sandy Hook, at 38 and 41 m (125 and 135 ft) below the surface. The 38 m diatoms were marine, and the 41 m diatoms had more brackish affinities;

Minard (1969) found fossils in several boreholes taken along the length of Sandy Hook. They were present in two types of deposits: beach sand and buried beds of foraminifera-rich clay. The beach sand contained numerous shell fragments, and is assumed to be primarily Holocene in age. The foraminiferal clays (at least two levels) are composed of medium to dark gray clayey fine sand and fine sandy clay. As the name suggests, foraminifera are common in these deposits, but a boring in GATE also recovered rootlets and reed fragments from a clay layer present between 29 and 44 m (95 and 143 ft) below the surface, with a date of 9,840 ± 300 radiocarbon years before present (11,720–10,010 calibrated years before present) at the top of the deposit. (Note that radiocarbon dates are not the same as calendar dates, and must be calibrated to approximate calendar years. Dates here were calibrated using Calib 7.0 [http://calib.qub.ac.uk/calib/] where appropriate. “Present” in “before present” is 1950.) These clays were probably deposited in settings similar to the modern bays on the south short of Long Island, in a few meters of water. Bivalves and ostracodes have also been reported from the clays, and may be found within GATE if additional borings are made;

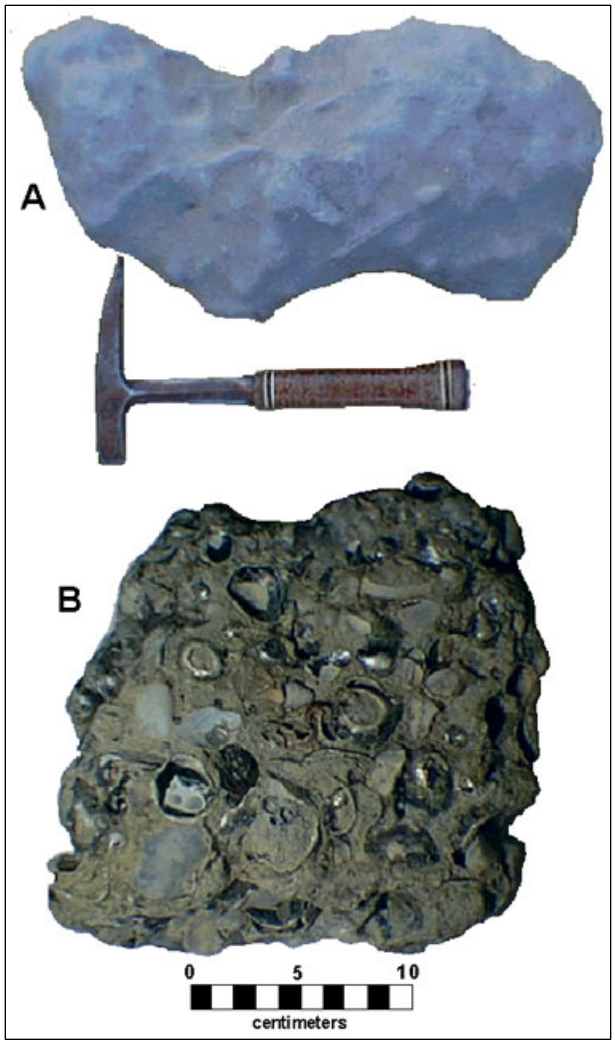
Finally, Petters (1976) discussed a well at Fort Hancock that reached 267 m (857 ft), and correlated part of the deposits to the Magothy and Raritan formations. From at least approximately 76 m (250 ft) to approximately 200 m (650 ft), the sediments are thought to represent the Magothy Formation. Lignite was present near the top of this section. The text suggests that microfossils were used for correlative purposes, but none are specifically noted.

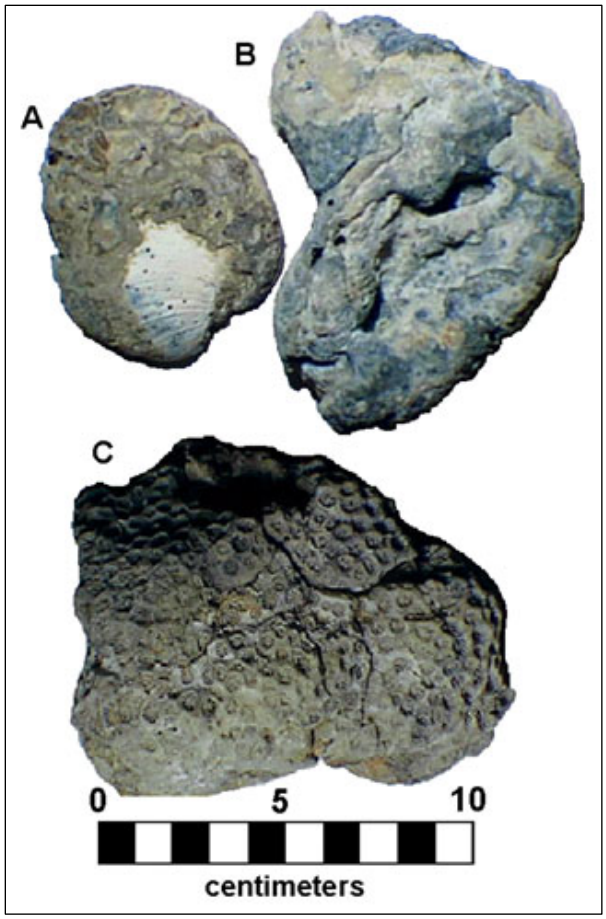
Subsurface fossils have also been reported from the other GATE units. Woolman (1897) reported on a well located on Barren Island, in the Jamaica Bay Unit. It penetrated to basement rock at 225 m (740 ft), passing through Holocene sediments (land surface to 21 m [70 ft]), Pleistocene sediments (21 to 67 m [70 to 220 ft]), “Matawan” sediments (67 to 210 m [220 to 690 ft]), and “Raritan” sediments (210 to 225 m [690 to 740 ft]) (the Cretaceous units are in quotes because of the various correlations applied to them). Lignite was found throughout much of the “Matawan” sediments (Woolman 1897). Veatch (1906) included a well that reached over 210 m (690 ft) below Barren Island, but it is not clear if this is the same well, because two were depicted on the island. From the Staten Island Unit, Perlmutter and Arnow (1953) found traces of lignite in Raritan Formation clay between 75 and 76 m (246 and 250 ft) below the surface at a well on the border of Great Kills Park.

Surficial Quaternary Sediments (Pleistocene–Holocene)

Fossils found at the surface in GATE are reworked (eroded from one location and transported elsewhere), typically found in concretions washed up on the recreation area’s beaches (GATE Figures 3–9). Such fossils are often delivered by storms. Hurricane (“Superstorm”) Sandy (October 2012), for example, washed fossils onto GATE beaches (VLS, pers. obs.; GATE Figure 9). Common beach fossils include corals, bivalves (especially oysters and scallops), gastropods, barnacles, and teeth and vertebrae of fish and marine mammals. More exotic specimens include a crocodilian tooth found at Fort Tilden (most likely from a Cretaceous unit, not a Quaternary unit), coal-like material with casts of clams and other invertebrates, and concretions containing crabs (Stoffer et al. 1996).

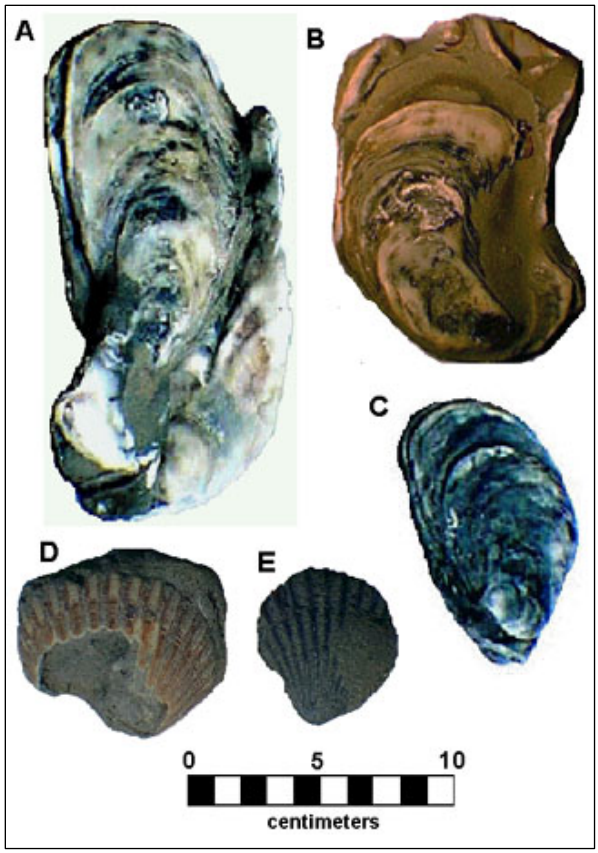
Plant roots and plant debris, sponges, lobsters, and burrows have also been reported (Stoffer et al. 2005; Chamberlain et al. 2006). Most of the fossiliferous concretions are probably Holocene to possibly late Pleistocene in age, from estuarine and beach deposits, but some are probably from Cretaceous deposits, like greenish glauconitic nodules found at Sandy Hook (Chamberlain et al. 2006). Others may be Cenozoic; Stoffer (pers. comm., April 2014) suggested the Eocene Shark River Formation as a source of glauconitic sandstone and diatomaceous earth boulders on Sandy Hook. Stoffer (2003) suggested that many of the fossils come from concretions eroded from submerged barrier islands of latest Pleistocene to early Holocene age. An oyster from one New York concretion has been dated to 7,610 ± 150 radiocarbon years before present (8,730–7,770 calibrated years before present) (Stoffer et al. 2005). The types of concretions and fossils that wash up differ from beach area to beach area. Rockaway Spit finds are dominated by sandy nodules containing brackish and estuarine oysters, scallops, gastropods, and crabs, with some black mud containing plant debris (Stoffer et al. 2005; Chamberlain et al. 2006). “A number” of cedar stumps have washed up on Rockaway Spit, featuring a combination of fresh-looking red wood and minerals filling cracks. They wash up after the largest storms (P. Stoffer, pers. comm., April 2014). Nearly complete juvenile estuarine crabs have been found in Rockaway Spit nodules, but crabs are rare at Sandy Hook. The concretions found at Sandy Hook have a wider range of lithologies, including not only sand but also conglomeratic concretions and greenish, glauconitic sandy concretions. Sandy Hook finds are dominated by corals, various bivalves (clams, jingle shells, scallops, and slipper shells), gastropods, and lobsters, with some encrusting sponges and corals, and the common presence of cedar roots in matrix. The fossils have more of a littoral or open bay influence. Nodules, such as the greenish nodules, can also contain burrows. Vertebrates include walruses and terrestrial forms. The types of fossils are similar to organisms living in the bay today, with a few exceptions, such as the absence of fossil surf clams (Stoffer et al. 2005; Chamberlain et al. 2006). Stauffer (pers. comm., April 2014) suggested that the Shrewsbury Rocks south of Sandy Hook may be one source area. Corals are reportedly present there.

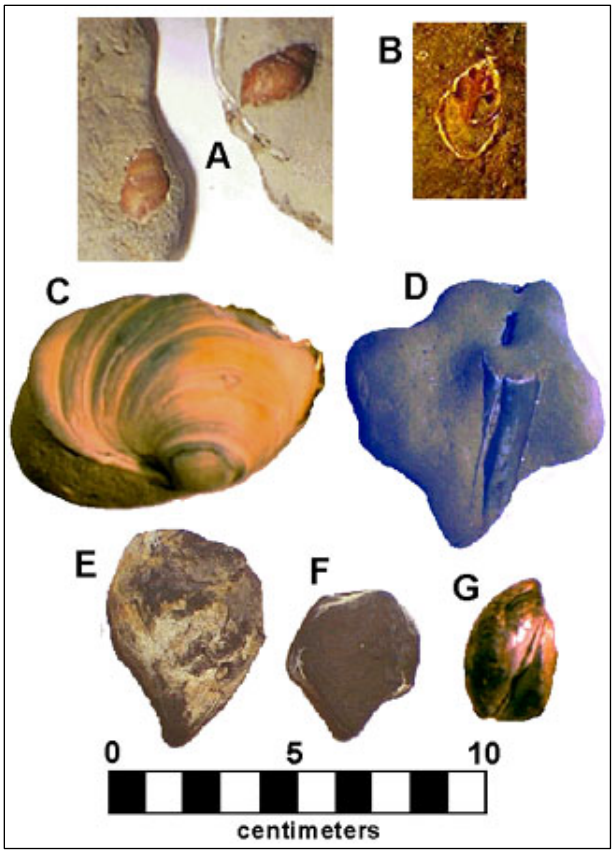




GATE Figure 3 (left). Fossiliferous concretions: “A. concretion displaying massive bioturbation structures (hammer handle is 1 foot for scale); B. Concretion containing fossils of jingle shells, spruce pine cones, bone, and oyster shell . These specimens washed up on the beach at Sandy Hook during a winter storm” (Stoffer 2003; USGS). The presence of spruce pine, today found in the southeastern United States, is noteworthy.

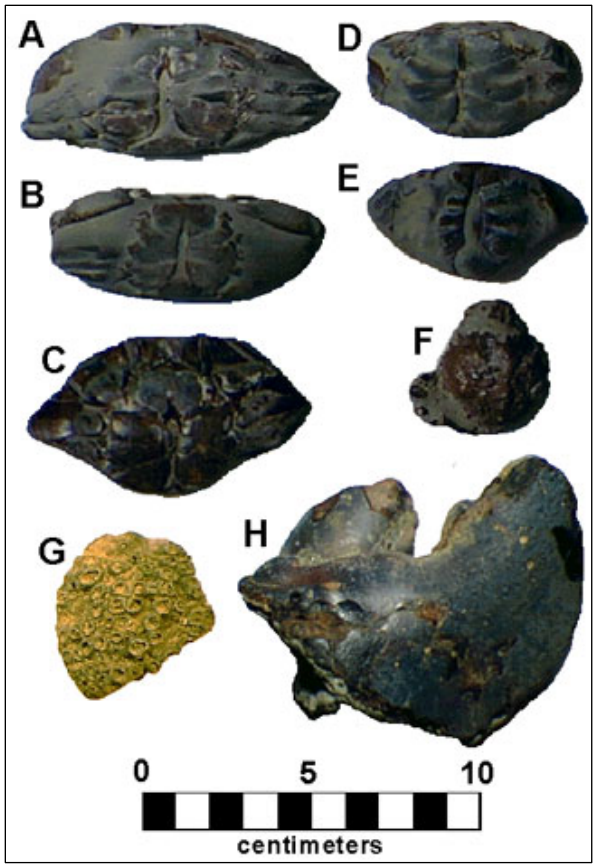
GATE Figure 4 (right). “Calcareous sponges: A. sponge encrusting a quahog shell; B. sponge encrusting an oyster shell; C. Stony Coral encrusting a concretion. These specimens were derived from Pleistocene-Holocene marine sediments, but both all species occur in the modern New York Bight. All specimens were found on Breezy Point, NY.” (Stoffer 2003; USGS).

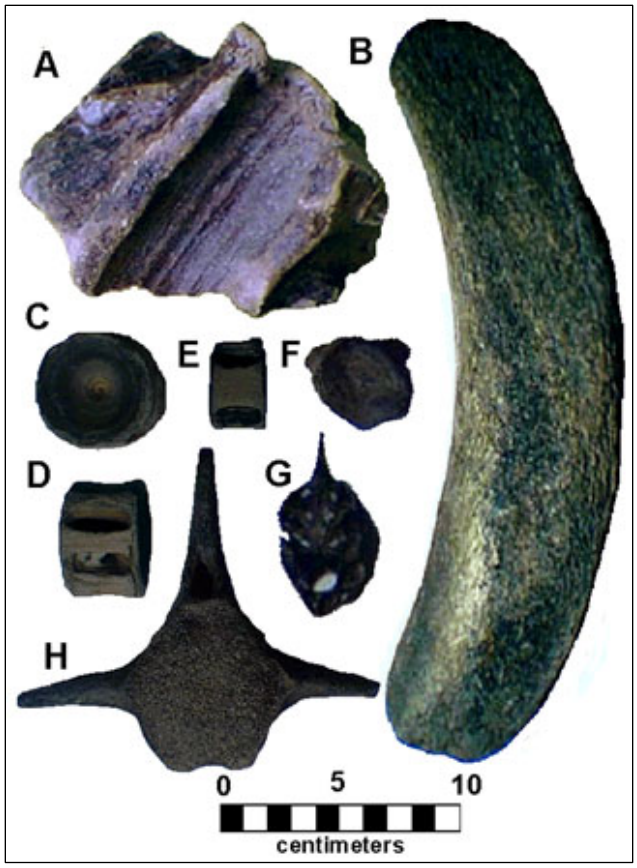




GATE Figure 5 (left). "Bivalves: A-C: Oysters preserved in growth position preserved in sideritic sandstone matrix; found on Breezy Point, NY. A radiocarbon analysis of a sample of oyster shell in concretion matrix yielded an Early Holocene date of 7,610 (+/-150) years before present. The matrix of oyster shell-bearing concretions contain an abundance of gastropods (mud dog whelk). Both species thrive in estuary environments. D-E: Bay scallops in concretion matrix; Sandy Hook, NJ" (Stoffer 2003; USGS).

GATE Figure 6 (right). "Bivalves: A-B. gastropods (mud dog whelk); Breezy Point, NY. C. surf clam; Breezy Point, NY. D. razor clam; Sandy Hook, NJ. E-G. Internal molds of bivalve in lithified bay mud; Breezy Point, NY" (Stoffer 2003; USGS).





GATE Figure 7 (left). “Arthropods: A-C. Blue claw crabs (Breezy Point, NY). D-E. green crabs (Breezy Point, NY). F. spider crab (Sandy Hook, NJ). G. barnacles attached to shell (Sandy Hook, NJ); H. American lobster claw (Sandy Hook, NJ)” (Stoffer 2003; USGS).

GATE Figure 8 (right). Vertebrate fossils from Rockaway Beach, NY. “A. American walrus skull (left ventral view - note tusk socket); B. whale vertebrae. C-F. fish or shark vertebrae. G-H. unidentified vertebrae” (Stoffer 2003; USGS).

Shupack (1934) reported that Pleistocene and Holocene foraminifera were present in the shallow surficial sediments of Jamaica Bay and Sandy Hook, but it does not appear that the Pleistocene forms were found at the stations detailed in the text, which were all reportedly Holocene (more stations were collected than discussed in the text, where representative examples were chosen). Stations within GATE included Station 2, on the west side of Cross Bay Boulevard less than 1 km (0.5 miles) below Howard Beach, and Station 5, a site inside the Horseshoe at Sandy Hook. Quaternary foraminifera known from the New York Harbor area are limited to a handful of species in the flat coiled genera *Elphidium* and *Rotalia*. Jamaica Bay creeks also yielded gastropods and fish teeth (Shupack 1934).



GATE Figure 9. A *Crassostrea* (bivalve) fossil washed up on the beach at Great Kills in GATE by Hurricane Sandy (VLS).

Peteet and Liberman (2001) presented preliminary findings from shallow cores taken in a number of locations in Jamaica Bay, including Big Egg Marsh, JoCo Marsh, Little Egg Marsh, Silver Hole Marsh, Stony Creek Marsh, and Yellow Bar Hassock. Their investigations focused on the thin (<2 m [7 ft]) Holocene marsh sediments and the sand immediately beneath. The JoCo and Yellow Bar cores were analyzed for pollen and macrofossils. The JoCo core produced foraminifera, conifer and angiosperm pollen, and killifish scales representing a setting of sandy shallow pools that existed about 2,000 years ago, before the marshes and corresponding peat layer. The uppermost 30 cm (12 in) included *Salicornia* ("sea bean") seeds. Variations in salinity and climate and the effects of human influence can be observed via the types of microfossils.

Quaternary microfossils such as pollen are a common topic of study in the GATE area, having been applied to topics such as climate change since the end of the most recent glaciation, fire histories, and responses to land-use changes. Microfossils are usually found in the deposits of lakes, swamps, and marshes, typically covering a time frame going back to around 13,000–12,000 years ago. The most commonly studied fossils are spores and pollen of various plants. Algae, mosses, clubmosses, ferns, conifers, and angiosperms are widely represented. Charcoal is utilized for studies of fire history. An example of a site near GATE is a bog site on Fingerboard Road, eastern Staten Island, described by Sirkin (1967). Although the deposits have not been directly dated, by comparison to other sites the record here must extend into the latest Pleistocene. Rhizopods (amoebae), algae, fern and moss spores, and conifer and angiosperm pollen were found here. Pollen sites in New York and New England show a consistent succession from tundra to spruce-dominated vegetation (transition about 13,000 years ago), to pine-dominated vegetation (appearing around 11,000 to 9,000 years ago), to oak-dominated vegetation (appearing around 7,000 years ago). A selection of publications referencing paleoecological sites in the vicinity of GATE include Donner (1964), Sirkin (1967,

1971), Watts (1979), Russell (1980), Connally and Sirkin (1986), Russell et al. (1993), Maenza-Gmelch (1997), Rue and Traverse (1997), Robinson et al. (2005), and Oswald et al. (2010).

Two general categories of fossils are common in the Quaternary sediments of the GATE area, but have not been reported from GATE to date. They include fossils that have been reworked from older rocks and deposits and transported by glaciers to the New York City area, and fossils of extinct Pleistocene mammals, commonly found in bogs and sometimes dredged from nearshore seafloors.

Reworked fossils are not uncommon in the glacial sediments of New York City, and have attracted interest since the late 19th century (they seem to have been a favorite topic for the Natural Science Association of Staten Island/Staten Island Institute of Arts and Sciences). Rocks from many formations exposed north of New York City have been transported there by glaciers. For example, a bluff at Prince's Bay on Staten Island yielded stones with burrows (Potsdam Sandstone) and brachiopods and crinoids (Helderberg Group) (Britton 1881). Hollick (1908) described fossils from five geologic periods and at least ten formations that had been part of a glacial deposit in Tottenville. The specimens included Ordovician brachiopods, stromatoporoid sponges, and worm tracks; Silurian brachiopods and crustacean tracks; Devonian brachiopods and nautiloids; Triassic trace fossils; and Cretaceous leaves, root traces, and bivalves. Other reworked fossils found on Staten Island include bryozoans, gastropods, trilobites (Gratacap 1894), and Triassic-age horsetail and conifer specimens (Hollick 1900). Marine shells of Quaternary age have also been found in glacial deposits (Desor 1847). It would not be at all surprising if similar glacially transported fossils are found in the Staten Island Unit of GATE.

The fossils of extinct Pleistocene mammals are found throughout New Jersey and New York, with numerous examples within about 100 km (60 miles) of GATE (Hartnagel and Bishop 1921; Hay 1923; Jepsen 1960). Typical examples from the immediate vicinity of GATE include teeth and bone fragments of a mastodon found in what is now Baisley Pond Park, north of the Jamaica Bay Unit (Brevoort 1859), and a mastodon tooth found in a swamp at the Moravian Cemetery of New Dorp on Staten Island (Hollick 1901). Carl Mehling (American Museum of Natural History senior scientific assistant) reported that possible mastodon remains had been found in 1880 on Coney Island, and that mastodon remains had been found in west-central Brooklyn (pers. comm., April 2014). Not infrequently, Quaternary vertebrate fossils are dredged from seafloor sediments, typically by clam dredgers sampling the surficial deposits. Among them are remains of bony fish, giant sloths, baleen and toothed whales, walruses, seals, manatees, mastodons, mammoths, horses, tapirs, musk oxen, bison, caribou, and the extinct "stag elk" *Cervalces*. Peat and petrified wood are also sometimes taken up. The terrestrial fossils are relics of times during the Quaternary when sea level was much lower due to glaciation and the coastal plains were far more extensive (Gallagher et al. 1989). Publications discussing offshore occurrences near GATE include Whitmore et al. (1967), Gallagher et al. (1989), and McDonald and Ray (1990).

Park Collections

There are a few collections that include GATE fossils or are relevant to GATE paleontology. The recreation area itself has collections of beach fossils, but this collection was reported as inactive by Kenworthy and Santucci (2003). The foraminifera in Shupack (1934)'s study were reposited at the

American Museum of Natural History, although they may be modern forms only. The material that Phil Stoffer collected was donated to the American Museum of Natural History as well (C. Mehling, pers. comm., April 2014; P. Stoffer, pers. comm., April 2014). Finally, many of the various cores and borings were performed under the auspices of the New Jersey Geological Survey and the USGS, or at least reported in their publications, so these institutions should at least have documentation of the work, if not necessarily actual specimens.

Cultural Resource Contexts

Fossils are known from cultural contexts in the New York City area, although they have not been documented from GATE yet. There is the possibility that fossils will be found in archeological contexts, such as artifacts of fossils or fossiliferous materials (such as tools made of petrified wood or shark teeth), or as faunal remains in ancient sites. For example, shell middens are known from Staten Island (Britton 1881). Dredging off of Sandy Hook accidentally produced more than 200 stone artifacts from a site that has been submerged by sea level rise (Merwin 2006); conceivably, similar artifacts could wash up on GATE beaches, some of which could be fossils or made of fossiliferous material. It is possible that some of the oyster shells that wash up on the beaches are derived from submerged shell middens (P. Stoffer, pers. comm., April 2014). Further information about Hudson Valley archeological sites can be found in Funk (1976) and Brennan (1977). Fossils are also known in building stone in New York City. New York flagstones of the 19th century commonly included rocks of the Devonian-age Hamilton Group quarried at Kingston, New York. These rocks often had fossils, including leaves, crinoids (sea lilies), fragments of fish, and trace fossils ("fucoids") (Stevens 1874). As an interesting sidelight, "sea coal" (perhaps either lignite from local Cretaceous formations or coal reworked from Appalachian coal fields) was collected from New York City-area beaches as long ago as 1677. Coaly material is still found on beaches, but at least some of it is simply reworked dumped cellar ash from factories or coal lost from ships (Stoffer 2003). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- Recreation area staff should be encouraged to observe the beaches and exposed sedimentary deposits for fossil material while conducting their usual duties. To promote this, they should also 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, recreation area staff should take advantage of them, if funding and time permit.

- Staff should photodocument and monitor any occurrences of paleontological resources that may be observed in situ. Fossils and their associated geologic context (surrounding rock/sediment) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. 2009).

- Various outside geoscientists have expressed concerns about the fate of fossils that wash up on GATE beaches. One possible avenue to prevent loss is to encourage visitors to report and/or bring finds to staff. The fossils have lost most of their geologic context due to transport. Issues to consider include the possibility that unauthorized collection would be inadvertently encouraged, the potential for confusing visitors about NPS policies, and the logistics of curating the fossils. Brunner et al. (2010) discuss some of the issues related to coastal fossil theft.
- GATE could develop an arrangement with the American Museum of Natural History to do periodic or post-storm event monitoring for beach fossils.
- GATE should maintain a small collection of fossils. These could be used for educational purposes and as references specimens for the staff.
- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist. Any fossil with 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.
- Quaternary fossils and deposits are of interest because they can be used to describe the effects of past climate and sea level changes, and to predict natural responses to future changes. Further study of these fossils and deposits in and around GATE is encouraged.
- Contact the NPS Geologic Resources Division for technical assistance with paleontological resource management issues.

References Cited

Benotti, M. J. 2008. Inventory of data sources used for watershed condition assessments of Fire Island National Seashore, Gateway National Recreation Area, and Sagamore Hill National Historic Site, New York and New Jersey. U.S. Geological Survey, Reston, Virginia. Open-File Report 2008-1298. http://pubs.er.usgs.gov/publication/ofr20081298 (accessed March 2014).

Berry, E. W. 1911. Flora of the Raritan Formation. Geological Survey of New Jersey, Trenton, New Jersey. Bulletin 3. Available at http://www.state.nj.us/dep/njgs/enviroed/oldpubs/bulletin3.pdf (accessed March 2014).

Brennan, L. A. 1977. The lower Hudson: the Archaic. *Annals of the New York Academy of Sciences* 288:411–430.

Brevoort, J. C. 1859. Remains of the American Mastodon found on Long Island, near New York. *Proceedings of the American Association for the Advancement of Science* 12:232–234. Available at http://books.google.com/books?id=mLLIlX9qu2AC&pg=PA232 (accessed March 2014).

Britton, N. L. 1881. On the geology of Richmond County, New York. *Annals of the New York Academy of Sciences* 2:161–182. Available at http://biodiversitylibrary.org/page/35264703 (accessed March 2014).

Brunner, J., J. Kenworthy, and V. Santucci. 2010. Unauthorized fossil collecting from National Park Service shorelines: servicewide policy and perspectives. Pages 319–323 *in* S. Weber, editor. Rethinking protected areas in a changing world: proceedings of the 2009 George Wright Society Conference. The George Wright Society, Hancock, Michigan. Available at http://www.georgewright.org/0956brunner.pdf (accessed February 2014).

Chamberlain, J. A., Jr., P. W. Stoffer, and P. Messina. 2006. Fossiliferous nodules from New York Gateway beaches. Page 11 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34.

Charletta, A. C., and P. S. Boyer. 1974. Scolecodonts from Cretaceous greensand of the New Jersey coastal plain. *Micropaleontology* 20(3):354–366.

Connally, G. G., and L. Sirkin. 1986. Woodfordian ice margins, recessional events, and pollen stratigraphy of the mid-Hudson Valley. Pages 50–72 *in* Cadwell, D. H., editor. The Wisconsinan Stage of the First Geological District, eastern New York. New York State Museum, Albany, New York. Bulletin 455. Available at https://www.nysm.nysed.gov/pubsforsale/detail.cfm?pubID=4936 (accessed March 2014).

Desor, E. 1847. [Fossils in drift at Brooklyn and at Westport, New York.] Proceedings of the Boston Society of Natural History 2:247. Available at http://biodiversitylibrary.org/page/9490931 (accessed March 2014).

Donner, J. J. 1964. Pleistocene geology of eastern Long Island, New York. *American Journal of Science* 262(3):355–376.

Doriski, T. P., and F. Wilde-Katz. 1983. Geology of the "20-foot" clay and Gardiners Clay in southern Nassau and southwestern Suffolk counties, Long Island, New York. U.S. Geological Survey, Reston, Virginia. Water-Resources Investigations 82-4056. Available at http://pubs.er.usgs.gov/publication/wri824056 (accessed March 2014).

Funk, R. E. 1976. Recent contributions to Hudson Valley prehistory. New York State Museum, Albany, New York. Memoir 22. Available at http://purl.org/net/nysl/nysdocs/3078762 (accessed March 2014).

Gallagher, W. B. 1984. Paleoecology of the Delaware Valley region: Part II, Cretaceous to Quaternary. *The Mosasaur* 2:9–43.

Gallagher, W. B., D. C. Parris, B. S. Grandstaff, and C. DeTemple. 1989. Quaternary mammals from the Continental Shelf of New Jersey. *The Mosasaur* 4:101–110.

Gallagher, W. B., D. C. Parris, E. Gilmore, and R. Johnson. 2001. New Jersey's Cretaceous amber deposits. *Northeastern Geology and Environmental Sciences* 23(4):340–345.

Gratacap, L. P. 1894. Additions to the drift fossils of Staten Island. *Proceedings of the Staten Island Institute of Arts and Sciences* 4(5):16-17.

Grier, N. M. 1925a. The fossil flora of the vicinity of Cold Spring Harbor. *American Midland Naturalist* 9(10):513–527.

Grier, N. M. 1925b. The geology of Long Island with especial reference to the Cold Spring Harbor region and its flora. *American Midland Naturalist* 9(11):531–563.

Grimaldi, D., C. W. Beck, and J. J. Boon. 1989. Occurrence, chemical characteristics, and paleontology of the fossil resins from New Jersey. American Museum Novitates 2948. Available at http://hdl.handle.net/2246/5103 (accessed March 2014).

Halsey, S. D., S. C. Farrell, and S. W. Johnson. 1979. Further investigations of the geomorphic history of the mid-Wisconsinan(?) coastal system of New Jersey. *Abstracts with Programs - Geological Society of America* 11(1):15–16.

Hartnagel, C. A., and S. C. Bishop. 1921. The mastodons, mammoths and other Pleistocene mammals of New York State. New York State Museum, Albany, NY. Bulletins 241 and 242.

Hay, O. P. 1923. The Pleistocene of North America and its vertebrated animals from the states east of the Mississippi River and from the Canadian provinces east of longitude 95 degrees. Carnegie Institution of Washington, Washington, D.C. Publication 322. Available at https://archive.org/details/pleistoceneofnor00hayouoft (accessed January 2014).

Hollick, C. A. 1892a. The palaeontology of the Cretaceous formation on Staten Island. *Transactions of the New York Academy of Sciences* 11:96–104. Available at http://biodiversitylibrary.org/page/12566235 (accessed March 2014).

Hollick, C. A. 1892b. Additions to the paleobotany of the Cretaceous formation on Staten Island. *Transactions of the New York Academy of Sciences* 12:28–39. Available at http://biodiversitylibrary.org/page/4560741 (accessed March 2014).

Hollick, C. A. 1898. Additions to the paleobotany of the Cretaceous formation on Staten Island. No. II. *Annals of the New York Academy of Sciences* 11:415–430. Available at http://biodiversitylibrary.org/page/35293255 (accessed March 2014).

Hollick, C. A. 1900. Geological notes [Staten Island, New York]. *Proceedings of the Staten Island Institute of Arts and Sciences* 7(13):30–32. Available at http://biodiversitylibrary.org/page/31128092 (accessed March 2014).

Hollick, C. A. 1901. Discovery of a mastodon's tooth and the remains of a boreal vegetation in a swamp on Staten Island, New York. *Annals of the New York Academy of Sciences* 14:67–68. Available at http://www.biodiversitylibrary.org/item/109569#page/101/mode/1up (accessed March 2014).

Hollick, C. A. 1905. A recent discovery of amber on Staten Island. *Journal of the New York Botanical Garden* 6:45–48. Available at http://biodiversitylibrary.org/page/31154223 (accessed March 2014).

Hollick, C. A. 1906a. The Cretaceous flora of southern New York, and New England. U.S. Geological Survey, Washington, DC. Monograph 50. Available at https://archive.org/details/cretaceousflorao01holl (accessed March 2014).

Hollick, C. A. 1906b. Insect borings in Cretaceous lignite from Kreischerville. *Proceedings of the Staten Island Institute of Arts and Sciences* 1:23–24. Available at http://biodiversitylibrary.org/page/31136820 (accessed March 2014).

Hollick, C. A. 1906c. A fossil forest fire. *Proceedings of the Staten Island Institute of Arts and Sciences* 1:21–23. Available at http://biodiversitylibrary.org/page/31136818 (accessed March 2014).

Hollick, C. A. 1908. Drift bowlders from the shore at Tottenville. Proceedings of the Staten Island Institute of Arts and Sciences 2:9. Available at http://biodiversitylibrary.org/page/30976156 (accessed March 2014).

Hollick, C. A., and E. C. Jeffrey. 1909. Studies of Cretaceous coniferous remains from Kreischerville, New York. Bulletin of the New York Botanical Garden Memoir 3. Available at http://www.biodiversitylibrary.org/bibliography/44790#/summary (accessed March 2014).

Hunt, R. K., J. P. Kenworthy, and V. L. Santucci. 2006. A preliminary inventory of fossil fish from National Park Service units. Pages 63–69 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://www.nature.nps.gov/GEOLOGY/paleontology/pub/fossil_conference_7/8%20Hunt%202.pdf (accessed February 2014).

Jennings, P. H. 1936. A microfauna from the Monmouth and basal Rancocas groups of New Jersey. Bulletins of American Paleontology 23(78). Available at http://biodiversitylibrary.org/page/30406568 (accessed March 2014).

Jepsen, G. L. 1960. A New Jersey mastodon. New Jersey State Museum, Trenton, New Jersey. Bulletin 6.

Kenworthy, J. P., and V. L. Santucci. 2003. Gateway National Recreation Area. Pages 23–24 *in* J. P. Kenworthy and V. L. Santucci. Paleontological resource inventory and monitoring: Northeast Coastal and Barrier Network. TIC# D-340. National Park Service, Denver, Colorado.

Kenworthy, J. P., and V. L. Santucci. 2006. A preliminary investigation of National Park Service paleontological resources in cultural resource contexts, Part 1: general overview. Pages 70–76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors.

America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf (accessed January 2014).

Kimyai, A. 1966. New plant microfossils from the Raritan Formation (Cretaceous) in New Jersey. *Micropaleontology* 12(4):461–476.

Kimyai, A. 1970. Plant microfossils from the Raritan Formation (Cretaceous) in Long Island. Pollen et Spores 12(2):181–204.

Klein, E. A., and C. McHugh. 2009. Late Pleistocene to Holocene sedimentation of a coastal system: Raritan and Sandy Hook Bays, New Jersey. *Abstracts with Programs - Geological Society of America* 41(3):40.

Kümmel, H. B., and H. M. Poland. 1910. Records of wells in New Jersey, 1905-1909. Pages 69–100 *in* Annual report of the State Geologist for the year 1909. Geological Survey of New Jersey, Trenton, New Jersey. Available at http://www.state.nj.us/dep/njgs/enviroed/oldpubs/SG-Annual-Report-1909.pdf (accessed March 2014).

Lohman, K. E. 1939. Pleistocene diatoms from Long Island, New York. U.S. Geological Survey, Washington, DC. Professional Paper 189-H. Available at http://pubs.er.usgs.gov/publication/pp189H (accessed March 2014).

MacClintock, D., and H. G. Richards. 1936. Correlation of Pleistocene marine and glacial deposits of New Jersey and New York. *Geological Society of America Bulletin* 47:289–338.

Maenza-Gmelch, T.E. 1997. Holocene vegetation, climate, and fire history of the Hudson Highlands, southeastern New York, USA. *The Holocene* 7:25–37.

McDonald, H. G., and C. E. Ray. 1990. The extinct sloth, *Megalonyx*, (Mammalia: Xenarthra), from the United States Mid-Atlantic continental shelf. Proceedings of the Biological Society of Washington 103(1):1–5. Available at http://biodiversitylibrary.org/page/34591492 (accessed March 2014).

Merwin, D. E. 2006. Submerged prehistoric archaeological deposits in the New York Bight. *Abstracts with Programs - Geological Society of America* 38(7):149.

Miller, K. G., P. J. Sugarman, J. V. Browning, M. A. Kominz, J. C. Hernandez, R. K. Olsson, J. D. Wright, M. D. Feigenson, and W. Van Sickel. 2003. Late Cretaceous chronology of large, rapid sea-level changes; glacioeustasy during the greenhouse world. *Geology* 31(7):585–588.

Miller, K. G., P. J. Sugarman, J. V. Browning, M. A. Kominz, R. K. Olsson, M. D. Feigenson, and J. C. Hernandez. 2004. Upper Cretaceous sequences and sea-level history, New Jersey coastal plain. *Geological Society of America Bulletin* 116(3–4):368–393.

Minard, J. P. 1969. Geology of the Sandy Hook Quadrangle in Monmouth County, New Jersey. U.S. Geological Survey, Washington, DC. Bulletin 1276. Available at http://pubs.er.usgs.gov/publication/b1276 (accessed March 2014).

Newberry, J. S. 1895. The flora of the Amboy clays. U.S. Geological Survey, Washington, DC. Monograph 26. Available at https://archive.org/details/floraofamboyclay01newb (accessed March 2014).

Olsson, R. K. 1964. Late Cretaceous planktonic foraminifera from New Jersey and Delaware. *Micropaleontology* 10(2):157–188.

Olsson, R. K. 1975. Upper Cretaceous and lower Tertiary stratigraphy: New Jersey Coastal Plain. Petroleum Exploration Society of New York, New York City, New York. Annual Field Trip 2.

Oswald, W. W., D. R. Foster, E. D. Doughty, and D. Macdonald. 2010. A record of Holocene environmental and ecological changes from Wildwood Lake, Long Island, New York. *Journal of Quaternary Science* 25(6):967–974.

Pendleton, E. A., E. R. Thieler, and S. J. Williams. 2005. Coastal vulnerability assessment of Gateway National Recreation Area (GATE) to sea-level rise. U.S. Geological Survey, Reston, Virginia. Open-File Report 2004-1257. Available at http://pubs.er.usgs.gov/publication/ofr20041257 (accessed March 2014).

Penny, J. S. 1947. Studies on the conifers of the Magothy flora. *American Journal of Botany* 34(5):281–296.

Perlmutter, N. M., and T. Arnow. 1953. Ground water in Bronx, New York, and Richmond counties with summary data on Kings and Queens counties, New York City, New York. State of New York Department of Conservation, Division of Water Power and Control, Water Power and Control Commission, Albany, New York. Bulletin GW-32. Available at https://archive.org/details/usgswaterresourcesnewyork-bull_gw_32 (accessed March 2014).

Perlmutter, N. M., and J. J. Geraghty. 1963. Geology and ground-water conditions in southern Nassau and southeastern Queens counties, Long Island, New York. U.S. Geological Survey, Washington, DC. Water-Supply Paper 1613-A. Available at http://pubs.er.usgs.gov/publication/wsp1613A (accessed March 2014).

Peteet, D. M., and L. Liberman. 2001. Millennial climate and land use history from Jamaica Bay marshes, New York. *Abstracts with Programs - Geological Society of America* 33(6):453.

Petters, S. W. 1976. Upper Cretaceous subsurface stratigraphy of Atlantic coastal plain of New Jersey. *AAPG Bulletin* 60(1):87–107.

Rampino, M. R., and J. E. Sanders. 1981. Upper Quaternary stratigraphy of southern Long Island, New York. *Northeastern Geology* 3(2):116–128.

Richards, H. G., C. W. Cooke, H. F. Garner, B. F. Howell, J. A. Jeletzky, A. K. Miller, H. W. Miller, Jr., R. C. Ramsdell, J. B. Reeside, Jr., H. B. Roberts, and J. W. Wells. 1958. The Cretaceous fossils of New Jersey, Part 1. New Jersey Geological Survey, Bureau of Geology and Topography, Trenton, New Jersey. Bulletin 61. Available at http://www.state.nj.us/dep/njgs/enviroed/oldpubs/bulletin61-I.pdf (accessed March 2014).

Richards, H. G., C. W. Cooke, H. F. Garner, B. F. Howell, J. A. Jeletzky, A. K. Miller, H. W. Miller, Jr., R. C. Ramsdell, J. B. Reeside, Jr., H. B. Roberts, and J. W. Wells. 1962. The Cretaceous fossils of New Jersey, Part 2. New Jersey Geological Survey, Bureau of Geology and Topography, Trenton, New Jersey. Bulletin 61. Available at http://www.state.nj.us/dep/njgs/enviroed/oldpubs/bulletin61-II.pdf (accessed March 2014).

Ricketts, H. C. 1986. Examination in boreholes of the subsurface Gardiners Clay (Pleistocene), in the context of the Cretaceous-Quaternary section of Great Neck, Long Island, New York. *Northeastern Geology* 8(1–2):13–22.

Robinson, G. S., L. P. Burney, and D. A. Burney. 2005. Landscape paleoecology and megafaunal extinction in southeastern New York State. *Ecological Monographs* 75(3):295–315.

Rogers, W. B., M. Aparisi, and L. Sirkin. 1989. Search for clues to Mesozoic graben on Long Island. *Marine Geology* 90(1–2):119–124.

Rue, D. J., and A. Traverse. 1997. Pollen analysis of the Hackensack, New Jersey Meadowlands tidal marsh. *Northeastern Geology and Environmental Sciences* 19(3):211–215.

Russell, E. W. B. 1980. Vegetational change in northern New Jersey from precolonization to the present: a palynological interpretation. *Bulletin of the Torrey Botanical Club* 107(3):432–446.

Russell, E. W. B., R. B. Davis, R. S. Anderson, T. E. Rhodes, and D. S. Anderson. 1993. Recent centuries of vegetational change in the glaciated north-eastern United States. *Journal of Ecology* 81:647–664.

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado.

Scott, T. W., D. J. P. Swift, G. R. Whittecar, and G. A. Brook. 2010. Glacio-isostatic influences on Virginia's late Pleistocene coastal plain deposits. *Geomorphology* 116(1–2):175–188.

Shupack, B. 1934. Some Foraminifera from western Long Island and New York Harbor. American Museum Novitates 737. Available at http://hdl.handle.net/2246/4596 (accessed March 2014).

Sirkin, L. A. 1967. Late-Pleistocene pollen stratigraphy of western Long Island and eastern Staten Island, New York. Pages 249–274 *in* E. J. Cushing and H. E. Wright, editors. Quaternary paleoecology. Yale University Press, New Haven, Connecticut. International Association for Quaternary Research, Proceedings of the 7th Congress.

Sirkin, L. A. 1971. Surficial glacial deposits and postglacial pollen stratigraphy in central Long Island, New York. *Pollen et Spores* 13(1):93–100.

Sirkin, L. 1986. Pleistocene stratigraphy of Long Island, New York. Pages 6–21 *in* Cadwell, D. H., editor. The Wisconsinan Stage of the First Geological District, eastern New York. New York State Museum, Albany, New York. Bulletin 455. Available at https://www.nysm.nysed.gov/pubsforsale/detail.cfm?pubID=4936 (accessed March 2014).

Soren, J. 1971. Ground-water and geohydrologic conditions in Queens County, Long Island, New York. U.S. Geological Survey, Washington, DC. Water-Supply Paper 2001-A. Scale 1:62,500. Available at http://pubs.er.usgs.gov/publication/wsp01A (accessed March 2014).

Soren, J. 1978. Subsurface geology and paleogeography of Queens County, Long Island, New York. U.S. Geological Survey, Washington, DC. Water-Resources Investigations 77-34. Available at http://pubs.er.usgs.gov/publication/wri7734 (accessed March 2014).

Soren, J. 1988. Geologic and geohydrologic reconnaissance of Staten Island, New York. U.S. Geological Survey, Reston, Virginia. Water-Resources Investigations Report 87-4048, scale 1:41,700. Available at http://pubs.er.usgs.gov/publication/wri874048 (accessed March 2014).

Stanford, S. D. 2000. Surficial geology of the Sandy Hook Quadrangle, Monmouth County, New Jersey. New Jersey Geological Survey, Trenton, New Jersey. Open File Map 39. Scale 1:24,000. Available at http://www.state.nj.us/dep/njgs/pricelst/ofmap/ofm39.pdf (accessed March 2014).

Stevens, R. P. 1874. On the fossils found in the “flag-stones” used in the cities of New York and Brooklyn. Lyceum of Natural History of New York. Proceedings 2:5–7. Available at https://archive.org/details/proceedingsoflyc00lyce (accessed March 2014).

Stoffer, P. 2003. Geology of the New York City region: a preliminary regional field-trip guidebook. U.S. Geological Survey, Reston, Virginia. Available at http://3dparks.wr.usgs.gov/nyc/index.html (accessed March 2014; online only).

Stoffer, P. W., P. Messina, and J. A. Chamberlain, Jr. 1996. Fossils from beaches in Gateway National Recreation Area: implications for the geologic history of the New York Bight. *Abstracts with Programs - Geological Society of America* 28(7):A–143.

Stoffer, P. W., P. Messina, and J. A. Chamberlain, Jr. 1999. Fossiliferous concretions from New York Bight beaches: implications for late Pleistocene and Holocene coastal environments around Sandy Hook and western Long Island. Pages 119–143 *in* J. H. Puffer, editor. New Jersey beaches and coastal processes from geologic and environmental perspectives. Geological Association of New Jersey, Newark, NJ. Annual Field Conference 16.

Stoffer, P. W., J. A. Chamberlain, Jr., R. Scal, and P. Messina. 2005. Late Quaternary and early Holocene fossils from New York City beaches: implications for stability in coastal environments in western Long Island and New Jersey. *Abstracts with Programs - Geological Society of America* 37(7):366.

Sugarman, P. J., K. G. Miller, D. Bukry, and M. D. Feigenson. 1995. Uppermost Campanian-Maestrichtian strontium isotopic, biostratigraphic, and sequence stratigraphic framework of the New Jersey coastal plain. *Geological Society of America Bulletin* 107(1):19–37.

Thornberry-Ehrlich, T. L. 2011. Geologic resource inventory scoping summary, Gateway National Recreation Area. National Park Service, Geologic Resources Division, Denver, Colorado. Available at http://nature.nps.gov/geology/inventory/publications/s_summaries/GATE_Scoping_Summary_2011-0928.pdf (accessed March 2014).

Upson, J. E. 1970. The Gardiners Clay of eastern Long Island, New York: a reexamination. Pages B157–B160 in Geological Survey research 1970, Chapter B. U.S. Geological Survey, Washington, DC. Professional Paper 700-B. Available at http://pubs.er.usgs.gov/publication/pp700B (accessed March 2014).

Veatch, A. C. 1906. Outlines of the geology of Long Island. Pages 15–52 *in* Veatch, A. C., C. S. Slichter, I. Bowman, W. O. Crosby, and R. E. Horton. Underground water resources of Long Island, New York. U.S. Geological Survey, Washington, DC. Professional Paper 44. Available at http://pubs.er.usgs.gov/publication/pp44 (accessed March 2014).

Watts, W.A. 1979. Late Quaternary vegetation of central Appalachia and the New Jersey coastal plain. *Ecological Monographs* 49:427–469.

Weiss, L. 1954. Foraminifera and origin of the Gardiners Clay (Pleistocene), eastern Long Island, New York. U.S. Geological Survey, Washington, DC. Professional Paper 254-G. Available at http://pubs.er.usgs.gov/publication/pp254G (accessed March 2014).

Weller, S. 1907. A report on the Cretaceous paleontology of New Jersey. Geological Survey of New Jersey, Trenton, New Jersey. Paleontology Series 4. Available at https://archive.org/details/reportonpaleontopt104newjiala (accessed March 2014).

Whitmore, F. C., Jr., K. O. Emery, H. B. S. Cooke, and D. J. P. Swift. 1967. Elephant teeth from the Atlantic Continental Shelf. *Science* 156(3781):1477–1481.

Woolman, L. 1897. Report on artesian wells. Pages 96–254 *in* Annual report of the State Geologist for the year 1896. Geological Survey of New Jersey, Trenton, New Jersey. Available at https://archive.org/details/annualreport22survgoog (accessed March 2014).

Additional References

Baker, J. E. B. 1995. Simple methods for extracting microfossils of the Navesink Formation (Cretaceous, N.J.). Pages 302–309 *in* J. E. B. Baker, editor. Contributions to the paleontology of New Jersey: proceedings of a symposium, field trips and teacher workshop on the topic. Geological Association of New Jersey, Newark, NJ. Annual Field Conference 12.

Behm, H. J. 1976. Geology and micropaleontology of freshwater ponds, Staten Island, New York. Pages 40-56 *in* A. J. Hendricks and H. J. Behm. The Cretaceous ponds: a unique area on Staten Island, New York. Staten Island Institute of Arts and Sciences, Staten Island, New York.

Belknap, D. F. 1984. Amino acid racemization in "mid-Wisconsin" C-14 dated formations on the Atlantic Coastal Plain. *Abstracts with Programs - Geological Society of America* 16(1):2-3.

Clark, W. B. 1893. A preliminary report on the Cretaceous and Tertiary formations of New Jersey. Annual Report of the State Geologist of New Jersey for 1892:167–245. Available at https://archive.org/details/annualreportsta138unkngoog (accessed March 2014)

Coch, N. K., and D. Weiss. 1989. Environmental geology and geological development of the lower Hudson Estuary and New York Harbor. Pages 15–25 *in* C. A. Baskerville, editor. Environmental, engineering, and urban geology in the United States. Volume 1, New York and Washington, D.C.: geology and engineering geology of the New York metropolitan area. Field trips for the 28th International Geological Congress. American Geophysical Union, Washington, DC. Field Trip T361.

Edwards, A. M. 1896. On the occurrence of Noecene marine Diatomaceae near New York. *American Naturalist* 30:212–216. Available at http://books.google.com/books?id=bS1OAAAAYAAJ&pg=PA212 (accessed March 2014).

Ellwood, B. B. 1996. Geology and America's National Park areas. Prentice Hall, Upper Saddle River, New Jersey.

Fuller, M. L. 1914. The geology of Long Island, New York, U.S. Geological Survey, Professional Paper 82. Scale 1:125000. Available at http://pubs.er.usgs.gov/publication/pp82 (accessed March 2014).

Gustavson, T. C. 1976. Paleotemperature analysis of the marine Pleistocene of Long Island, New York, and Nantucket Island, Massachusetts. *Geological Society of America Bulletin* 87(1):1–8.

Kuehne, D. F. 1999. Upper Cretaceous macroinvertebrate faunas of the Northern Atlantic Coastal Plain. *The Mosasaur* 6:29–79.

Lucas, S. G. 1993. A Pleistocene horse from Connecticut. *The Mosasaur* 5:43–46.

Mayor, A. 2005. Fossil legends of the first Americans. Princeton University Press, Princeton, New Jersey.

Merrill, F. J. H., N. H. Darton, A. Hollick, R. D. Salisbury, R. E. Dodge, B. Willis, and H. A. Pressey. 1902. New York City folio, Paterson, Harlem, Staten Island and Brooklyn quadrangles, New York-New Jersey; Staten Island 15' Quadrangle. U.S. Geological Survey. Geologic Atlas of the United States Folio GF-83. Scale 1:62,500. Available at http://pubs.er.usgs.gov/publication/gf83.

Newman, W. S. 1977. Late Quaternary paleoenvironmental reconstruction: some contradictions from northwestern Long Island, New York. *Annals of the New York Academy of Sciences* 288:545–570.

Olsen, S. J. 1971. Zooarchaeology: animal bones in archaeology and their interpretation. Addison-Wesley Publishing Company, New York City, New York.

Olsson, R. K. 1987. Cretaceous stratigraphy of the Atlantic Coastal Plain, Atlantic Highlands of New Jersey. Pages 87–90 *in* D. C. Roy, editor. Northeastern section of the Geological Society of America. Geological Society of America, Boulder, Colorado. Centennial Field Guide 5.

Perlmutter, N. M. and R. Todd. 1965. Correlation and foraminifera of the Monmouth Group (Upper Cretaceous), Long Island, New York. U.S. Geological Survey, Washington, DC. Professional Paper 483-I. Available at http://pubs.er.usgs.gov/publication/pp483I (accessed March 2014).

Petters, S. W. 1977. *Bolivinoides* evolution and Upper Cretaceous biostratigraphy of the Atlantic Coastal Plain of New Jersey. *Journal of Paleontology* 51(5):1023–1036.

Prather, J. K. 1905. The Atlantic Highlands section of the New Jersey Cretacic. *American Geologist* 36:162–178. Available at http://books.google.com/books?id=gPgNAQAAIAAJ (accessed March 2014).

Ramsdell, R. C. 1978. Field resources handbook: marine fossil collecting sites within reach of the Sandy Hook Field Station, New Jersey Marine Science Consortium. New Jersey Marine Sciences Consortium Special Publication 2.

Sanford, J. H. 1938. Report on the geology and hydrology of Kings and Queens counties, Long Island. State of New York Department of Conservation, Division of Water Power and Control, Water Power and Control Commission, Albany, New York. Bulletin GW-7. Available at https://ia601000.us.archive.org/18/items/usgswaterresourcesnewyork-bull_gw_7/bull_gw7.pdf (accessed March 2014).

Sirkin, L. A. 1965. Late Pleistocene palynology and chronology of western Island and eastern Staten Island, New York. Dissertation. New York University, New York City, New York.

Sirkin, L., and R. Stuckenrath. 1980. The Portwashingtonian warm interval in the northern Atlantic Coastal Plain. *Geological Society of America Bulletin* 91(6):332–336.

Waage, K. M., C. MacClintock, and L. J. Hickey. 2001. Post-glacial fossils from Long Island Sound off West Haven, Connecticut. Postilla 225. Available at http://www.biodiversitylibrary.org/part/83201#/summary (accessed March 2014).

Weiss, L. 1951. Origin of the (Pleistocene) Gardiners Clay in eastern Long Island, New York. Thesis. New York University, New York City, New York.

Whitfield, R. P. 1885. Brachiopoda and Lamellibranchiata of the Raritan clays and greensand marls of New Jersey. U.S. Geological Survey, Washington, DC. Monograph 9. Available at https://archive.org/details/brachiopodalamel00whit (accessed March 2014).

Whitfield, R. P. 1892. Gastropoda and Cephalopoda of the Raritan clays and greensand marls of New Jersey. U.S. Geological Survey, Washington, DC. Monograph 18. Available at https://archive.org/details/gasteropodacepha00whit (accessed March 2014).

Woodworth, J. B. 1901. Pleistocene geology of portions of Nassau County and Borough of Queens. *Bulletin of the New York State Museum* 48:618–670. Available at http://biodiversitylibrary.org/page/34879415 (accessed March 2014).

Data Sets

Gateway National Recreation Area Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Gateway National Recreation Area Collections
1990s. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by Phil Stoffer; status: Inactive.

Gateway National Recreation Area Digital Geologic Map
2000s–present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active.

American Museum of Natural History
1930s?–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by AMNH staff; status: Active.

New Jersey Geological Survey
1890s?–present. (locality notes; collection records; maps; etc.). Originated by NJGS staff; status: Active.

U.S. Geological Survey
1930s?–present. (locality notes; collection records; maps; etc.). Originated by USGS staff; status: Active.

George Washington Birthplace National Monument

George Washington Birthplace National Monument (GEWA) in eastern Virginia preserves a variety of cultural resources related to the birthplace of the first president of the United States, including the foundation of the house where he was born February 22, 1732, remains of outbuildings, the family burial ground, and a commemorative plantation built in the 1930s to represent a typical upper-class house from the period of his birth. GEWA was established January 23, 1930, and its boundaries changed March 30, 1931, April 11, 1972, November 10, 1978, May 3, 1993, and December 17, 2002. It presently encompasses 267.79 ha (661.73 acres), 222.67 ha (550.23 acres) of which are federal.

Geologic Background

GEWA is located in northern Westmoreland County, Virginia, bordered by Bridges Creek on the northwest, the Potomac River on the north (GEWA Figure 1), and Popes Creek on the southeast (there is also a Popes Creek in Maryland, about 23 km [14 miles] north of GEWA along the Potomac). The Washington estate was also known as Wakefield, and this name sometimes appears in geological publications (Weems 1980; Ward and Powars 1989; Olson 2009). This area is in the western part of Virginia's Northern Neck, between the Potomac and Rappahannock rivers. The nearest large city is Fredericksburg, about 48 km (30 miles) to the northwest. The geology and paleontology of GEWA have been described in Cederstrom (1957), Teifke (1973), Ward and Powars (1989), Kenworthy and Santucci (2003, 2006), Thornberry-Ehrlich (2005, 2009), Hunt et al. (2006), Newell et al. (2006), NPS (2006), Brunner et al. (2010), and Virginia Institute of Marine Science (2013). The NPS Geologic Resources Division coordinated a Geologic Resource Inventory workshop for GEWA in July 2005 (Thornberry-Ehrlich 2005) and produced a digital geologic map for the monument in 2006 (NPS 2006) and a geologic resource evaluation report in 2009 (Thornberry-Ehrlich 2009). The initial paleontological resource inventory and summary was prepared by Kenworthy and Santucci (2003).



GEWA Figure 1. The Calvert Formation along the Potomac River at GEWA; fossils such as shark teeth sometimes erode out of these exposures (VLS).

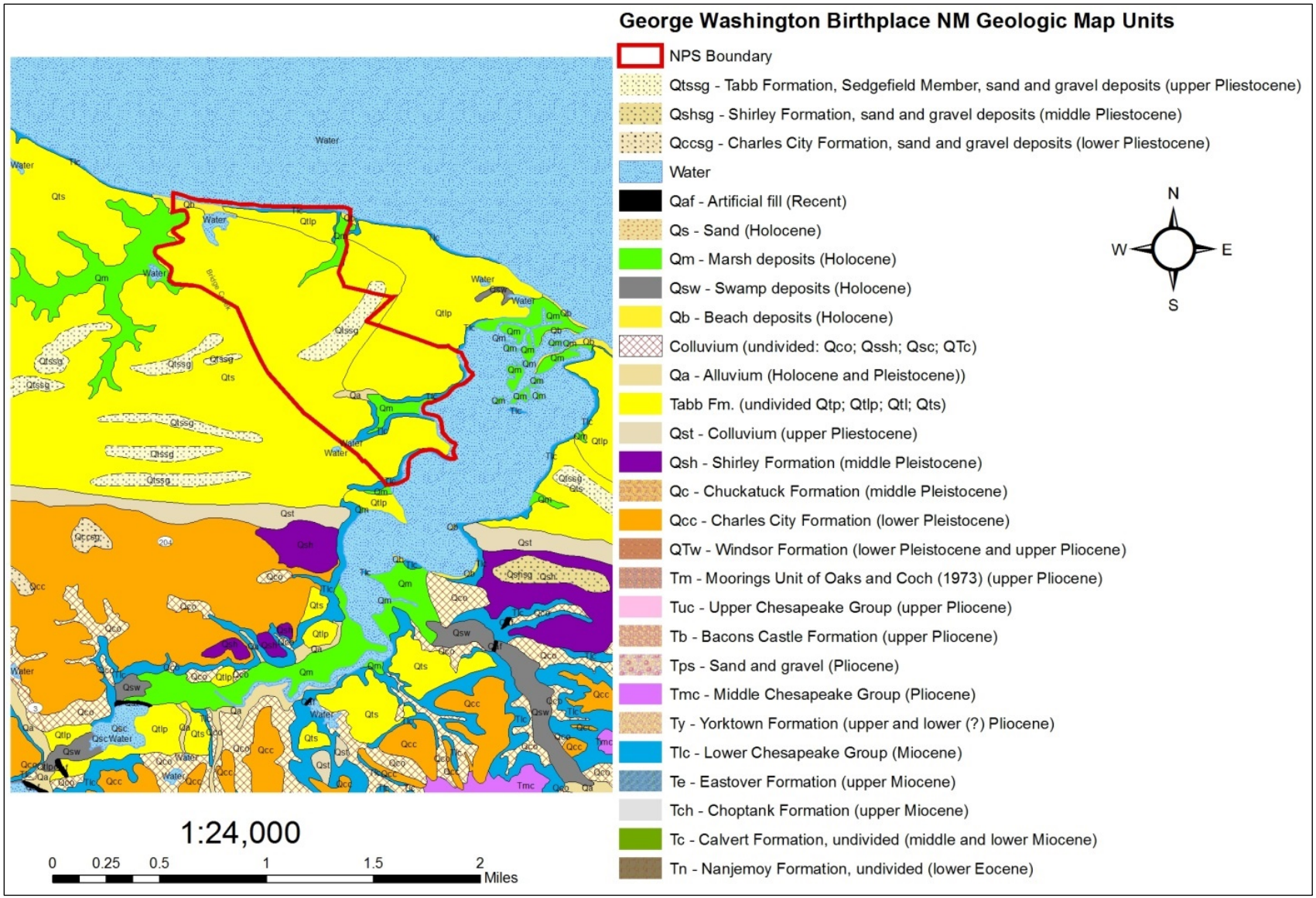
Eastern Virginia has been tectonically quiet since North America rifted from Africa and Europe in the early Mesozoic (see the Appendix for a geologic time scale). There has been one major disruption of the rocks and sediments since then: around 35 Ma (million years ago), a meteor impacted the future Chesapeake Bay (Poag 1997; Johnson et al. 1998; Powars and Bruce 1999). The resulting crater was up to 90 km (56 miles) across and 1.3 km (0.8 miles) deep, with an area of 6,400 km^2

(2,500 miles^2) (Poag 1997) (but see Collins and Wünnermann [2005], which interprets the original structure as less than half that size). The outer rim of the structure is south of GEWA, so the greatest effects of the impact were somewhat remote from the area of the monument.

Surficial geologic units at GEWA belong to two general periods of deposition: the Miocene and the past hundred thousand years. The older deposits belong to the Calvert Formation, well known from the western Chesapeake Bay coast of Maryland (the Calvert Cliffs). This formation reflects the numerous fluctuations of a shallow sea stretched across the northern Chesapeake Bay and surrounding lowlands. Shallow and deeper deposition alternated (Gibson 1982, 1983; Ward and Powars 1989). The climate was warmer than present (Gottfried et al. 1994), but the growth and shrinking of polar ice appears to have been important enough to affect sea level. Quasi-cyclic deposition of this formation and those above it on the Calvert Cliffs suggest the influence of glaciation on sea level in response to cyclic changes of the Earth's orbital parameters (Milankovitch cycles (Browning et al. 2006; Vogt and Parrish 2011). Stable isotopes in the bones of cetaceans (whale, dolphins, and porpoises) suggest substantial ice volume variations during the Miocene, although this is controversial (Barrick et al. 1992), and isotopes in fish and shark teeth and bones show opposite patterns (Barrick et al. 1993).

Following the Calvert Formation, no deposition is preserved in GEWA until roughly the past hundred thousand years, when the lower Tabb Formation was deposited. This unit formed in shallower coastal settings than the Calvert Formation, ranging from fluvial to estuarine to nearshore marine (Johnson and Berquist 1989; Scott et al. 2010). The most recent deposition in the monument dates from the past few thousand years, after sea level rose following the most recent glacial maximum. Humans had arrived in eastern Virginia sometime before this period of deposition; projectile points of the Clovis culture (about 12,000 to 10,000 years old) have been found in Westmoreland and adjacent counties (McCary 1986).

Geological formations exposed in GEWA include, in ascending order, the following: the Calvert Formation (Lower–Middle Miocene) of the Chesapeake Group; the Tabb Formation (upper Pleistocene); and unnamed Holocene sediments (Newell et al. 2006; NPS 2006) (GEWA Figure 2). The Calvert Formation is fossiliferous within GEWA (primarily shark teeth that have eroded from nearby exposures and then washed up on the monument's beaches, but also diatoms [algae that form cell walls out of silica), and the Holocene sediments are accepted as likely fossiliferous because of the prevalence of organic material (GEWA Table 1). Fossils have also been found in a well core taken from the monument, and are present in cultural contexts.



GEWA Figure 2. Schematic geological map of GEWA. Map graphic adapted from digital geologic map data available at the following URL: https://irma.nps.gov/App/Reference/Profile?Code=1041689.

GEWA Table 1. Summary of GEWA stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text.

Formation	Age	Fossils Within GEWA	Depositional Environment
Unnamed Quaternary sediments	Holocene	Middle-late Holocene shell middens with bivalves, possibly to as old as 5,000 years ago; probably organic material in marsh deposits, to as old as 6,000 years ago.	Alluvium, beach, and marsh settings
Tabb Formation	late Pleistocene	None to date	Fluvial, estuarine, and marginal and restricted marine
Calvert Formation	Early–Middle Miocene	Diatoms, shark teeth, vertebrae; fossils often wash up on the GEWA beaches, including diverse shark teeth (which are also sometimes found associated with middle and late Holocene shell middens, and may have been used as scrapers)	Shallow marine
Subsurface (includes Nanjemoy, Aquia, and "Mattaponi" formations)	Various; includes Early Eocene, Paleocene, and Cretaceous units	Foraminifera	Various; predominantly shallow marine

Sources of Paleontological Resources

The fossils of GEWA present opportunities for education, interpretation, and scientific research in the monument.

Shore erosion is a major resource management issue at GEWA, with perhaps 0.3 to 0.9 m (1 to 3 ft) of beach lost along the Potomac River each year. Aside from the obvious issue of fossils being washed into or eroded out of GEWA boundaries, this has unusual consequences for GEWA jurisdiction: the Virginia–Maryland state line has been defined as mean low tide on the Virginia side of the Potomac, and GEWA's boundaries were defined as such in 1930. Decades of erosion mean that the 1930 boundary is now offshore (Kenworthy and Santucci 2003).

Subsurface (Various Ages)

In areas like coastal Virginia, where there are fossiliferous marine formations in the subsurface, it is not uncommon for well projects to bring fossils to the surface in cores and cuttings. Because the fossiliferous sediments are buried hundreds of meters or feet below the surface, they are protected from erosion, theft, and vandalism, and only require management when brought to the surface. They are included here for completeness.

Cederstrom (1957) described a deep well from "Washington's Birthplace". The geologic units encountered included 6 m (20 ft) of the Columbia Group [=Tabb Formation], 18 m (60 ft) of the Chesapeake Group [=Calvert Formation], 44 m (144 ft) of the Nanjemoy Formation, 8.5 m (28 ft) of the Aquia Formation, and 44 m (144 ft) of the Mattaponi Formation. The Mattaponi Formation name

was later abandoned; in the original description, based on cores from GEWA and Colonial Beach, it turned out to be a misinterpretation of Paleocene and Cretaceous formations based on the mistaken belief that the Aquia Formation was Eocene in age (Ward 1985a). In the Chesapeake Bay crater area to the south, the name was used for disrupted Cretaceous–Eocene sediments (Poag 1997; Powars and Bruce 1999). Cederstrom (1957) reported foraminifera ("amoebae with shells") from the Nanjemoy, Aquia, and Mattaponi formations in the GEWA core.

Chesapeake Group: Calvert Formation (Lower–Middle Miocene)

The Calvert Formation is an extensively fossiliferous shallow marine formation. It is generally divided, in ascending order, into the Fairhaven, Plum Point, and Calvert Beach members. It is present within GEWA at low elevations along the Potomac River and Popes Creek. In this area (the Colonial Beach 7.5 minute quadrangle) it is mostly composed of fine to very fine quartz-rich sand, with lesser amounts of clay and silt. It is typically on the order of 43 m (140 ft) thick. Bedding is thick to non-apparent (massive), and the formation presents several sequences on the order of 2 to 12 m (7 to 39 ft) thick composed of a basal layer of very fine to coarse sand, a middle section of clay and silt, and an upper section of thick-bedded very fine sand. The deposits are generally olive-gray, grayish-olive, or greenish-gray, weathering to various shades of white, light-gray, pinkish-gray, and pale yellowish-orange. A variety of fossils have been found in the formation in the quadrangle. In the lower, coarser parts of sequences, wood, invertebrate shell fragments, fish bones, scales, and teeth, and marine mammal bones have been found. The middle fine-grained portions include microfossils, such as diatoms, silicoflagellates (another type of algae that form body structures out of silica), and dinoflagellate cysts (single-celled organisms that move using one or more whip-like flagella). Natural molds of mollusks can be locally abundant in the formation in general. The topography and geomorphology of GEWA (Newell et al. 2006) suggest that only the lower part of the formation is present in the monument. Ward and Powars (1989) described the Calvert Formation of the shoreline bluffs of GEWA as 1.5 m (5.0 ft) of olive-brown very fine silty diatomaceous sand with abundant vertebrate fossils, over 1.2 m (4.0 ft) of fine silty burrowed and diatomaceous sand, which they attributed to the lower Plum Point Member.

The Calvert Formation was described by Shattuck (1904), who also divided the formation into two members. The lower member, composed of sand overlain by a thicker section of diatomaceous deposits, was named the Fairhaven Diatomaceous Earth, generally known today more simply as the Fairhaven Member. The clay, sand, and sandy clay above was named the Plum Point Marl Member, also known as the Plum Point Member. Shattuck divided the Miocene sediment of the Chesapeake Group into a number of zones. The Fairhaven Member included his Zones 1 through 3, and the Plum Point Member included Zones 4 through 15. Zone 16 at the base of the overlying Choptank Formation, named the Calvert Beach Member by Gernant (1970), was later moved into the Calvert Formation under that name, becoming the upper member of the Calvert Formation (Ward 1985b). This member now includes Zones 14 to 16 (Ward 1985b). Based on the topography of GEWA, this part of the formation is probably not present in the monument. Gibson (1982, 1983) introduced new terminology (the Dunkirk beds and the Popes Creek Sand Member) for Zones 1 and 2, but these names have not generally been accepted. The most recent assessment of the formation, Ward and Andrews (2008), formally designated the zones as beds within the formation. The three widely

recognized members (Fairhaven, Plum Point, and Calvert Beach members) have unconformable contacts and were deposited in overlapping but distinct basins (Mixon et al. 2000). The upper and lower contacts of the formation are also disconformable (Ward 1989).

The Calvert Formation is a shallow marine unit. Muddy inner to middle shelf deposits alternate with heavily fossiliferous shoreface and inner shelf sands (Godfrey and Smith 2010). Diatomaceous sediments represent deposition in deeper basins (Ward and Powars 1989). The formation is punctuated with disconformities (Kidwell and Jablonski 1983), and is interpreted as having been deposited under multiple marine pulses over time. Ward and Powars (1989) interpreted the Fairhaven Member as including two marine pulses (Bed 1 and Bed 2 into lower 3), and the Plum Point and Calvert Beach members as four more pulses (Beds 4 to 9, 10 to 11, 12 to 13, and 14 to 16) (their description is somewhat contradictory, describing the formation in terms of three pulses at another point). Deposition appears to have been somewhat cyclic, with sequences on the order of 1.27 million years in duration, probably due to glacial effects on sea level in response to the cycles of the Earth's orbital parameters (Browning et al. 2006; Vogt and Parrish 2011). The geography of the formation traces a "dogleg" going west across Delaware and then turning south through eastern Virginia east of the Fall Line, although eventually the sea overtopped the high in the Delmarva area and spread more widely (Ward and Powars 1989).

The Fairhaven Member (including the Popes Creek Sand) was first deposited in middle-shelf settings beneath an open ocean, at depths of up to perhaps 80 m (260 ft). Sea level then decreased to less than 30 m (100 ft), and deposition occurred in sublittoral, shallow marine, and restricted marginal settings (Gibson 1982, 1983). Microfossils suggest that there was marine upwelling (Palmer 1986a). The overlying Plum Point Member was deposited in a variety of shallow marine settings under a fluctuating sea level. During middle Plum Point time (beds 5 to 9), a delta system formed in the southern New Jersey area and influenced deposition. In the GEWA area, the lower Plum Point Member is interpreted as having been deposited in a protected embayment setting roughly north of the Potomac River, and in an inner shelf setting south of it (Gibson 1982, 1983). Depth increased after this, reaching 40 to 50 m (130 to 160 ft) in beds 11 and 12 (Godfrey and Smith 2010). The prevailing climate during deposition of the formation is thought to have been warmer than the present, with subtropical to warm tropical estuarine and shallow marine waters (Gottfried et al. 1994), and a warm temperate coastal flora, like that found today on the coasts of South Carolina and Georgia, or along the Gulf from Florida to Texas (Berry 1916). Extensive shell beds are present in several zones, and plausibly represent cyclic deposition tied to the Earth's orbital parameters (i.e. Milankovitch cycles) (Vogt and Eshelman 1987). The presence of fossils of terrestrial turtles and mammals shows the existence of land nearby (Kellogg 1966). Petrified wood and land mammal fossils represent terrestrial remains that were washed out to sea (Vogt and Eshelman 1987).

The age of the formation is generally considered to be Early to Middle Miocene, but absolute dating has proven difficult. A sampling of different authors provides almost as many estimates as authors. Part of the difficulty is the numerous internal disconformities. It may encompass deposition from about 22 or 21 Ma to about 14 or 13 Ma, with substantial internal hiatuses (Gottfried et al. 1994; Dooley and Fraser 2005; Wijnker and Olson 2009). The terrestrial mammals documented from this

formation range in age from the Late Arikareean or Early Hemingfordian North American Land Mammal Ages (between approximately 23.8 and 17.5 Ma) to the Late Barstovian (14.8 to 12.5 Ma) (Wright and Eshelman 1987).

The Calvert Formation is fossiliferous within GEWA. Shark teeth are the most visible and notable fossils found in the monument. Teeth of *Hemipristis serra* (extinct requiem sharks), *Oxyrhina desorii* (extinct mackerel sharks), *Otodus obliquus* (extinct mackerel sharks), sand sharks, mako sharks, silky sharks, and white sharks have been found on the shores and beaches of GEWA (Kenworthy and Santucci 2003; Hunt et al. 2006) (GEWA Figure 3). Hand-sized teeth of the extinct giant white shark *Carcharodon* may have been found on the shores as well (Kenworthy and Santucci 2006). Other types of fossils have also been found (GEWA Figure 4). Storms are an effective agent of fossil delivery; a fossil collector posting in The Fossil Forum (post #2 in http://www.thefossilforum.com/index.php?/topic/30808-virginia-teeth-sites/) noted that a hurricane in the summer of 2011 (probably a reference to Hurricane Irene) had caused abundant and unusual fossils to appear on the beach at GEWA. The beach fossils can be washed in from elsewhere or eroded from the monument's riverside exposures. Brunner et al. (2010) reported that an unspecified mammal skull had been found at GEWA, but in the absence of further information this could be a reference to one of the many vertebrate specimens found in the vicinity. Diatomaceous sediments are also present in GEWA (Ward and Powars 1989).



GEWA Figure 3 (left). Teeth of the sharks *Hemipristis serra* (left) and *Isurus hastalis* (right) from the Calvert Formation of GEWA (photo by Rijk Moräwe, reproduced from Hunt et al. 2006).

GEWA Figure 4 (right). A loose vertebra found on a GEWA shore (VLS).

Field notes and records document a number of vertebrate specimens from the Calvert Formation near GEWA. Most of the specimens are associated with the National Museum of Natural History, with David Bohaska being responsible for many of the records. These include teeth of the sharks *Carcharodon*, *Galeocerdo*, and *Hemipristis*, fragments of sea turtle shells, and many cetacean specimens. Notable specimens include: a partial skeleton of the dugong *Metaxytherium*, found about

235 m (770 ft) upriver from Range Station 17, near the Bridges Creek landing, with a porpoise jaw found upriver; a partial cetothere whale skeleton including a mandible, ribs, and vertebrae, found about 460 m (1,500 ft) upriver from the GEWA beach parking lot; a beaked porpoise skull found on a beach about 820 m (2,700 ft) upriver of the GEWA beaching parking lot and a second skull with some vertebrae and ribs a short distance downstream; a jaw fragment of the sperm whale *Orycterocetus crocodilinus*, found 1.6 km (1 mile) west of GEWA; dolphin specimens and another sperm whale skull fragment, found at Church Point, a few km/miles northwest of GEWA; a baleen whale found near GEWA in the collections of the American Museum of Natural History; skull material of the "beardog" *Amphicyon*, found probably just outside of GEWA at "Wakefield"; a peccary lower jaw, found near Church Point; and a partial tibia (shin bone) from a peccary, found above the beach at "Wakefield" (Kenworthy and Santucci 2003).

Most of the above specimens have not been published outside of Kenworthy and Santucci (2003). However, a number of other specimens from the immediate vicinity have been published and are presented below, in increasing distance from GEWA and in separate paragraphs for readability:

A skull of the sea turtle *Syllomus aegyptiacus* was found in bluffs on the Morris property about 1 km (0.6 miles) west of the mouth of Bridges Creek, which would be approximately the same distance from GEWA. The discovery horizon is thought to be equivalent to bed 12 (Weems 1980);

The holotype (name-bearing specimen) of the shearwater *Calonectris kurodai* (USNM 237220) was collected from Bed 14 on June 30, 1973 by James Westgate and Pam Heater upriver from GEWA on the Latane side of the Latane–Morris property line, about 115 m (375 ft) east of Clay Creek (Olson 2009);

The Horsehead Cliffs in Westmoreland State Park, a little more than 3.1 km (1.9 miles) downstream from GEWA, has yielded fossils of foraminifera, diatoms, silicoflagellates, mollusks (Trochim and Dooley 2010), bony fish (Weems 1985), cetaceans (Gottfried et al. 1994), and peccaries (Wright and Eshelman 1987), aside from the ubiquitous shark teeth;

Just downstream, the Stratford Cliffs, about 5.6 km (3.5 miles) below GEWA, have produced a number of vertebrate fossils besides shark teeth, including bony fish (Weems 1985), turtles (Weems 1974), ducks (Alvarez and Olson 1978), the holotype (name-bearing specimen) of the tern *Feducciavis loftoni* (Olson 2011), cetaceans (Gottfried et al. 1994; Olson 2011), and peccaries (Wright and Eshelman 1987);

The Oak Grove core, obtained about 6 km (4 miles) west of GEWA, is an important nearby microfossil site, with Calvert Formation radiolarians (another group of "amoebae with shells") (Palmer 1986a, 1986b), diatoms, and dinoflagellates (Andrews et al. 1977; Gibson et al. 1980);

Finally, there is a vertebrate site in the Carmel Church area, about 30 km (20 miles) southeast of GEWA. The site was discovered fairly recently, and work is ongoing, but sharks, bony fish, turtles, crocodilians, birds, seals, sirenians (dugongs and manatees), cetaceans, horses, and peccaries have been found in the upper Calvert Formation (Dooley et al. 2004; Dooley and Fraser 2005).

The Calvert Formation is exceedingly fossiliferous in general, with diverse types of fossils from marine, freshwater, and terrestrial settings. The best-known deposits are found at the Calvert Cliffs of Maryland. These cliffs, made up of the Calvert Formation and overlying Choptank and St. Mary's formations, present the best Middle Miocene record in the northeastern United States (Vogt and Eshelman 1987). Microfossils are represented by calcareous nannofossils (McLaughlin et al. 2008), foraminifera, radiolarians, diatoms (Shattuck 1904), silicoflagellates (Tynan 1957), other siliceous "algae" (Tynan 1960), dinoflagellates (Gibson et al. 1980), fern spores, and pollen of conifers and angiosperms (Groot 1998; McLaughlin et al. 2008). Reworked Eocene foraminifera are sometimes found at the base of the formation (Gibson 1983). In terms of pollen, oak, hickory, and pine pollen are most common, with some subtropical and tropical exotic forms, and relatively few reworked Cretaceous and Paleocene grains (Groot 1992). Plants are represented by the pollen and spores mentioned above, and by body fossils of ferns, cypresses, pines, and about two dozen species of dicot angiosperms, dominated by legumes and oaks (Berry 1916). Invertebrates are represented by sponges (Tynan 1957), corals, hydrozoans (relatives of jellyfish and corals), bryozoans (moss animals), brachiopods (lamp shells), chitons, bivalves, cephalopods (squids, octopuses, and relatives), gastropods, scaphopods (tusk shells), annelid worm tubes, barnacles, ostracodes (seed shrimp), crabs (Shattuck 1904) and echinoids (sea urchins) (Schoonover 1941). Shells are sometimes leached away, being represented by molds and casts (Shattuck 1904). Trace fossils are represented by bioturbation (disruption of sediments by burrowers) (McCartan et al. 1996), burrows (Glaser 1984), snail borings (Thomas 1976; Kelley 1982, 1992), shark teeth marks on bones (Kellogg 1966), invertebrate pellets (Miller et al. 1998), and vertebrate coprolites (fossil feces) (Godfrey and Smith 2010).

Vertebrates are represented by sharks, rays (Shattuck 1904), bony fish (Kimmel and Purdy 1985), salamanders (Weems and George 2013), reptiles (Shattuck 1904), birds (Olson 1985a; Rasmussen 1998), marine mammals (Shattuck 1904; Whitmore 1985; Gottfried et al. 1994), and terrestrial mammals (Tedford and Hunter 1984; Emry and Eshelman 1998). Bony fish include sturgeons, sea catfish, tilefish, sailfish, wakeo, and ocean sunfish (Kimmel and Purdy 1985). Reptiles include turtles (Weems 1974), tortoises, glass lizards, snakes, and crocodilians (Holman 1998). Birds reported from the formation include phasianids (ground fowl), jaegers, auks, shorebirds, ducks, pseudodontorns (large extinct seabirds with tooth-like nodes in their beaks), gannets, albatrosses, shearwaters, loons (Olson 1985a), tropicbirds (Olson 1985b), and doves (Wetmore 1938). Marine mammals include seals (Ray 1976, 1985), sirenians (Kellogg 1966; Domning 1985), and diverse mysticetes (baleen whales) and odontocetes (toothed whales) (Whitmore 1985; Gottfried et al. 1994), with peak diversity in Beds 12 and 14 (Gottfried et al. 1994). The Calvert Cliffs have sometimes been proposed as a calving ground for whales (Vogt and Eshelman 1987), but this is questionable (Gottfried et al. 1994). Terrestrial mammals include shrews, hedgehogs, rodents, bats (Emry and Eshelman 1998), dogs, amphicyonids ("beardogs") (Tedford and Hunter 1984), bears, procyonids (raccoons and relatives) (Eshelman and 1998), the elephant relative *Gomphotherium* (Tedford and Hunter 1984), chalicotheres (extinct ungulates with long clawed arms) (Emry and Eshelman 1998), tapirs, rhinoceroses, horses (Tedford and Hunter 1984), anthracotheres (extinct hippo-like ungulates) (Emry and Eshelman 1998), peccaries, dromomerycids (small extinct ungulates) (Tedford and Hunter 1984), deer-like moschids, oreodonts (Emry and Eshelman 1998), and camels (Tedford and Hunter 1984). The best terrestrial vertebrate site is the Pollack Farm site near Cheswold, Delaware, over 160

km (100 miles) northeast of GEWA. This site has yielded remains of turtles, tortoises, glass lizards, snakes, crocodilians (Holman 1998), shrews, hedgehogs, rodents, bats, dogs, amphicyonids, bears, procyonids, chalicotheres, horses, rhinoceroses, anthracotheres, peccaries, moschids, and oreodonts (Emry and Eshelman 1998).

Unnamed Quaternary Deposits (Holocene)

The youngest deposits at GEWA include marsh and alluvial deposits in Dancing Marsh, and beach deposits near Bridges Creek Landing. Marsh fill is up to 5 m (15 ft) thick and includes organic debris, silt, clay, and sand, dating from roughly the past 6,000 years. Fluvial alluvium dates back about as far, and includes sand, pebbles and larger grains, clay, and organic debris. Beach deposits are about 1 to 3 m (3 to 10 ft) thick, with sand and larger grains (Newell et al. 2006). Because of the abundance of organic remains in the marsh fill, as well as the ancient shell middens (see the Cultural Resource Contexts section), these deposits are regarded as fossiliferous within GEWA. Additionally, Ward and Powars (1989) reported that the upper 1.5 m (3.0 ft) of their section at GEWA was composed of "soil with *Crassostrea* as artifacts". It is unclear what "artifacts" means; it could be a reference to the oyster shell middens in the monument.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic unit within GEWA. However, it is known to preserve fossils elsewhere, and future field investigations within the monument may locate fossils in it.

Tabb Formation (Upper Pleistocene)

The Tabb Formation is a coastal formation deposited during the Pleistocene. It includes three members, from oldest to youngest the Sedgefield, Lynnhaven, and Poquoson members. In the old marine terrace terminology, they correspond to the Pamlico Terrace (7.6 to 9.1 m [25 to 30 ft]), the Princess Anne Terrace (5.5 m [18 ft]), and the Silver Bluff Terrace (3.6 m [12 ft]) (Colquhoun et al. 1991). The Tabb Formation forms banks 5 to 8 m (15 to 25 ft) tall along the Potomac in GEWA, much lower than the neighboring bluffs below Popes Creek that expose thick sections of the Chesapeake Group and reach heights of more than 24 m (80 ft) (Virginia Institute of Marine Science 2013). It is mapped by Newell et al. (2006) in GEWA as including the Sedgefield and younger Lynnhaven members. In the Colonial Beach quadrangle, both members are composed primarily of gray sand, become finer going up (from pebbly fine to coarse sand to sandy silt), and are on the order of 1 to 5 m (3 to 15 ft) thick. They are considered to be primarily estuarine. The Sedgefield Member is found at higher elevations than the Lynnhaven Member. Both are draped over the Calvert Formation (Newell et al. 2006). The GRD map (NPS 2006) depicts the Poquoson Member as present at GEWA, but the source map (Newell et al. 2006) does not. The confusion may stem from Newell et al. (2006) using Qtlp to label the Lynnhaven Member, which implies the Poquoson Member as well. However, their text omits the Poquoson Member.

Deposition occurred in a variety of fluvial, estuarine, bay, barrier, and nearshore marine settings (Johnson and Berquist 1989). The marine fossils of the Sedgefield Member suggest shallow nearshore settings from the intertidal zone to about 15 m (50 ft) of water (Scott et al. 2010). These late Pleistocene deposits may also indicate substantial uplift, perhaps due to crustal adjustments in

response to glaciation to the north: they are found at maximum elevations of 3 to 12 m (10 to 40 ft), but they formed when sea levels were about 40 m (130 ft) lower than present (Scott et al. 2010). The Sedgefield Member is thought to date at least in part to Aminozone IIa, approximately 130,000 to 80,000 years ago (Mirecki et al. 1995; Scott et al. 2010). It has yielded a coral series with an average age of 71,000 ± 7,000 years old (Mixon et al. 1982; Mixon et al. 1989), and other corals, bivalves, and vertebrae have been dated to between about 120,000 to 60,000 years old (Scott et al. 2010). The Poquoson Member has wood that is older than radiocarbon dating. It and the underlying Lynnhaven Member are thought to have been deposited during Marine Isotope Stage 3, about 50,000 to 33,000 years ago. The Lynnhaven Member is thought to date to the early part of the stage, and the Poquoson Member is thought to date to the middle, representing two sea-level oscillations (Scott et al. 2010).

The Tabb Formation does not appear to be fossiliferous within GEWA. Thornberry-Ehrlich (2005) made reference to mastodon teeth in deposits at GEWA, but in the absence of other references to mastodon teeth from the monument, this may be a general statement. Teeth and other remains of large extinct mammals such as mastodons and mammoths are not unknown from Virginia and Maryland (Hay 1923; Eshelman and Grady 1986), but have not been reported from the immediate vicinity of GEWA. There appear to be two published Pleistocene vertebrate sites within about 100 km (60 miles) of the monument: Stratford Hall, about 7.5 km (4.7 miles) southeast of GEWA (horse); and Fairview Beach (a.k.a. Belvedere), about 30 km (20 miles) northwest of GEWA (dog, bear, peccary, and bison) (Eshelman and Grady 1986).

Plant fossils are more likely at GEWA, and have been found quite near the monument. Berry (1938) reported on a Pleistocene plant fossil site from about 550 m (1,800 ft) below the mouth of Popes Creek in Westmoreland County. The fossils included sticks, branches, seeds, burs, and other remains of water plants, sedges, vines, and oaks, as well as bivalves. The fossil site was attributed to the Princess Anne terrace, which indicates the Lynnhaven Member. Berry (1906, 1909) discussed similar fossil sites in the late Pleistocene deposits along the eastern rivers of Virginia, including at Port Royal, about 23 km (14 miles) west of GEWA, and Tappahannock, about 29 km (18 miles) south of GEWA, and Hollick (1906) described the Pleistocene plants of nearby Maryland. Cypress fossils, not recovered from the site below Popes Creek, are also common at these Pleistocene sites.

Elsewhere, each member of the Tabb Formation is fossiliferous, with the Sedgefield Member being the most productive. The Sedgefield fossil assemblage is dominated by the bivalves *Crassostrea* and *Mercenaria* (Johnson et al. 1981). Foraminifera (Johnson et al. 1981), peat, stumps (in channel fill; Mixon et al. [1989]), wood (Colquhoun et al. 1991), sponges (Johnson et al. 1981), corals (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), and vertebrae (Scott et al. 2010) have also been found. Fossils from this member are sometimes leached (Peebles et al. 1984). The Lynnhaven Member has plant material in channel fill (Mixon et al. 1989) and some burrows (Johnson and Berquist 1989). Peat and wood have been reported from the Poquoson Member (Scott et al. 2010).

Park Collections

Kenworthy and Santucci (2003) reported that GEWA was planning to add a museum building to their facilities, with some space to be given to natural resources. Aside from formal or informal GEWA collections of shark teeth (GEWA Figure 5), there does not appear to be any collections of GEWA fossils, although it is possible that there is some relevant USGS documentation related to Cederstrom (1957)'s core studies, and there are no doubt many informal personal collections of teeth taken from the monument's beaches.



GEWA Figure 5. Shark teeth in GEWA collections (VLS).

Cultural Resource Contexts

There are noteworthy connections between cultural and paleontological resources at GEWA. Fossil shark teeth have been found in shell middens in GEWA, and may have been used as scraping tools. The middens are of Archaic to Late Woodland age (5,000 to 400 years ago) (Kenworthy and Santucci 2003, 2006). Visaggi and Godfrey (2010) reported that Algonquian people formerly collected fossil shark teeth from Chesapeake Bay, and that teeth were sometimes used as scrapers and projectile points. Fossils used by people as tools and for other purposes are not unknown in NPS units, although most other examples are west of the Mississippi River and generally the material is petrified wood. There is the potential to find various faunal remains at archeological sites. An example from the vicinity is the T. Gray Haddon site, about 50 km (30 miles) south of GEWA in the vicinity of Aylett, with fish, reptile, opossum, rodent, canine, feline, raccoon, and deer remains from between 3,000 and 400 years ago (Winfree 1967).

GEWA has long been a place where visitors have collected fossils, primarily shark teeth, and collecting has persisted to the present (GEWA Figure 6). Postings to "The Fossil Forum" (http://www.thefossilforum.com/) show the collecting community is aware of the monument by name as a collecting site, and also that collecting is forbidden, although the posters are under the impression that collection was permitted



GEWA Figure 6. Pits left by unauthorized collecting (VLS).

in the recent past (see for example post #2 at www.thefossilforum.com/index.php?/topic/30808-virginia-teeth-sites/ and post #9 at http://www.thefossilforum.com/index.php?/topic/4007-norfolkchesapeake-vafossils/, a discussion that also mentions Colonial National Historical Park). Brunner et al. (2010) made reference to the issues of fossil collecting at GEWA. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts, including a discussion of the shark teeth at GEWA.

Paleontological Resource Management, Preliminary Recommendations

- A dedicated paleontological inventory for GEWA could provide guidance for managing the erosion and theft of fossils. Brunner et al. (2010) discuss some of the issues related to coastal fossil theft, including at GEWA.
- Monument staff should be encouraged to observe exposed sedimentary rocks and deposits for fossil material while conducting their usual duties. To promote this, they should also 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, recreation area staff should take advantage of them, if funding and time permit.
- Staff should photodocument 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 by artificially accelerated natural processes or direct human impacts. There is some known human interference at this time in the monument, as shown by postings to fossil collecting forums. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. 2009).
- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist. Any fossil with 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.
- Quaternary fossils and deposits are of interest because they can be used to describe the effects of past climate and sea level changes, and to predict natural responses to future changes. Further study of these fossils and deposits in and around GEWA is encouraged. The nearby cores of Newell et al. (2006) may be of interest.
- Contact the NPS Geologic Resources Division for technical assistance with paleontological resource management issues.

References Cited

Alvarez, R., and S. L. Olson. 1978. A new merganser from the Miocene of Virginia (Aves: Anatidae). *Proceedings of the Biological Society of Washington* 91(2):522–532. Available at http://biodiversitylibrary.org/page/34601793 (accessed February 2014).

Andrews, G. W., L. M. Bybell, and R. A. Christopher. 1977. Mesozoic and Cenozoic biostratigraphy of Oak Grove core, northeastern Virginia. *AAPG Bulletin* 61(5):761. Available at http://www.searchanddiscovery.com/abstracts/html/1977/annual/abstracts/0761.htm (accessed February 2014).

Barrick, R. E., A. G. Fischer, Y. Kolodny, B. Luz, and D. Bohaska. 1992. Cetacean bone oxygen isotopes as proxies for Miocene ocean composition and glaciation. *Palaios* 7(5):521–531.

Barrick, R. E., A. G. Fischer, and D. J. Bohaska. 1993. Paleotemperatures versus sea level: oxygen isotope signal from fish bone phosphate of the Miocene Calvert Cliffs, Maryland. *Paleoceanography* 8(6):845–858.

Berry, E. W. 1906. Pleistocene plants from Virginia. Torreya 6:88–90. Available at http://biodiversitylibrary.org/page/32135850 (accessed February 2014).

Berry, E. W. 1909. Pleistocene swamp deposits in Virginia. *The American Naturalist* 43:432–436. Available at http://biodiversitylibrary.org/page/43286466 (accessed February 2014).

Berry, E. W. 1916. The physical conditions indicated by the flora of the Calvert Formation. U.S. Geological Survey, Washington, DC. Professional Paper 98-F. Available at http://pubs.usgs.gov/pp/0098f/report.pdf (accessed February 2014).

Berry, E. W. 1938. Pleistocene fossils from Westmoreland County, Virginia. *Journal of the Washington Academy of Sciences* 28:58–61.

Browning, J. V., K. G. Miller, P. P. McLaughlin, M. A. Kominz, P. J. Sugarman, D. Monteverde, M. D. Feigenson, and J. C. Hernàndez. 2006. Quantification of the effects of eustasy, subsidence, and sediment supply on Miocene sequences, Mid-Atlantic margin of the United States. *Geological Society of America Bulletin* 118(5/6):567–588.

Brunner, J., J. Kenworthy, and V. Santucci. 2010. Unauthorized fossil collecting from National Park Service shorelines: servicewide policy and perspectives. Pages 319–323 *in* S. Weber, editor. Rethinking protected areas in a changing world: proceedings of the 2009 George Wright Society Conference. The George Wright Society, Hancock, Michigan. Available at http://www.georgewright.org/0956brunner.pdf (accessed February 2014).

Cederstrom, D. J. 1957. Geology and ground-water resources of the York-James Peninsula, Virginia. U.S. Geological Survey, Washington, DC. Water-Supply Paper 1361. Available at http://pubs.er.usgs.gov/publication/wsp1361 (accessed January 2014).

Collins, G. S., and K. Wünnermann. 2005. How big was the Chesapeake Bay impact? Insights from numerical modeling. *Geology* 33(12):925–928.

Colquhoun, D. J., G. H. Johnson, P. C. Peebles, P. F. Huddlestun, and T. Scott. 1991. Quaternary geology of the Atlantic Coastal Plain. Pages 629–650 *in* R. B. Morrison, editor. Quaternary

nonglacial geology: conterminous U.S. The geology of North America K-2. Geological Society of America, Boulder, Colorado.

Domning, D. P. 1985. Fossil sirenians from the Pamunkey River, Virginia. Pages 224–225 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Dooley, A., Jr., and N. Fraser. 2005. A revised faunal list for the Carmel Church Quarry, Caroline County, Virginia. *Journal of Vertebrate Paleontology* 25(supplement to 3):52A.

Dooley, A. C., Jr., N. C. Fraser, and Z.-X. Luo. 2004. The earliest known member of the rorqual-gray whale clade (Mammalia, Cetacea). *Journal of Vertebrate Paleontology* 24(2):453–463.

Emry, R. J., and R. E. Eshelman. 1998. The early Hemingfordian (early Miocene) Pollack Farm local fauna: first Tertiary land mammals described from Delaware. Pages 153–173 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Eshelman, R., and F. Grady. 1986. Quaternary vertebrate localities of Virginia and their avian and mammalian fauna. Pages 43–70 *in* J. N. McDonald and S. O. Bird, editors. The Quaternary of Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 75. Available at http://www.dmme.virginia.gov/commercedocs/PUB_75.pdf (accessed January 2014).

Gernant, R. E. 1970. Paleoecology of the Choptank Formation (Miocene) of Maryland and Virginia. Maryland Geological Survey, Baltimore, Maryland. Report of Investigations 12.

Gibson, T. G. 1982. Depositional framework and paleoenvironments of Miocene strata from North Carolina and Maryland. Pages 1–22 *in* T. M. Scott and S. B. Upchurch, editors. Miocene of the southeastern United States: proceedings of a symposium. Florida Geological Survey, Tallahassee, Florida. Special Publication 25. Available at http://ufdc.ufl.edu/UF00000147/00001 (accessed February 2014).

Gibson, T. G. 1983. Stratigraphy of Miocene through lower Pleistocene strata of the United States central Atlantic Coastal Plain. Smithsonian Contributions to Paleobiology 53:35–80. Available at http://si-pddr.si.edu/dspace/handle/10088/1975(accessed February 2014).

Gibson, T. G., G. W. Andrews, L. M. Bybell, N. O. Frederiksen, T. Hansen, J. E. Hazel, D. M. McLean, R. J. Witmer, and D. S. Van Nieuwenhuise. 1980. Biostratigraphy of the Tertiary strata of the core. Pages 14–30 *in* Geology of the Oak Grove core. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 20. Available at http://www.dmme.virginia.gov/commercedocs/PUB_20.pdf (accessed February 2014).

Glaser, J. D. 1984. Geologic map of the Port Tobacco Quadrangle, Prince Georges and Charles counties, Maryland. Maryland Geological Survey, Baltimore, Maryland. Scale 1:24,000. Available at http://jhir.library.jhu.edu/handle/1774.2/34468 (accessed February 2014).

Godfrey, S. J., and J. B. Smith. 2010. Shark-bitten vertebrate coprolites from the Miocene of Maryland. *Naturwissenschaften* 97(5):461–467.

Gottfried, M. D., D. J. Bohaska, and F. C. Whitmore, Jr. 1994. Miocene cetaceans of the Chesapeake Group. Proceedings of the San Diego *Society of Natural History* 29:229–238. Available at http://biodiversitylibrary.org/page/2888099 (accessed February 2014).

Groot, J. J. 1992. Plant microfossils of the Calvert Formation of Delaware. Delaware Geological Survey, Newark, Delaware. Report of Investigations 50. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/ri50e.pdf (accessed February 2014).

Groot, J. J. 1998. Palynomorphs from the lower Miocene Pollack Farm Site, Delaware. Pages 55–57 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Hay, O. P. 1923. The Pleistocene of North America and its vertebrated animals from the states east of the Mississippi River and from the Canadian provinces east of longitude 95 degrees. Carnegie Institution of Washington, Washington, D.C. Publication 322. Available at https://archive.org/details/pleistoceneofnor00hayouoft (accessed January 2014).

Hollick, A. 1906. Pteridophyta; Spermatophyta. Pages 217-237 *in* Pliocene and Pleistocene. Maryland Geological Survey systematic report. Johns Hopkins Press, Baltimore, Maryland. Available at http://biodiversitylibrary.org/page/35689878 (accessed February 2014).

Holman, J. A. 1998. Reptiles of the lower Miocene (Hemingfordian) Pollack Farm fossil site, Delaware. Pages 141–147 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Hunt, R. K., J. P. Kenworthy, and V. L. Santucci. 2006. A preliminary inventory of fossil fish from National Park Service units. Pages 63–69 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://www.nature.nps.gov/GEOLOGY/paleontology/pub/fossil_conference_7/8%20Hunt%202.pdf (accessed February 2014).

Johnson, G. H., and C. R. Berquist, Jr. 1989. Geology and mineral resources of the Brandon and Norge quadrangles, Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 87. Available at http://www.dmme.virginia.gov/commercedocs/PUB_87.pdf (accessed January 2014).

Johnson, G. H., C. R. Berquist, K. W. Ramsey, and P. C. Peebles. 1981. Guidebook to the late Cenozoic geology and economic geology of the lower York-James Peninsula, Virginia. College of William and Mary, Williamsburg, Virginia. Department of Geology Guidebook 2. 1981 edition.

Johnson, G. H., S. E. Kruse, A. W. Vaughn, J. K. Lucey, C. H. Hobbs, III, and D. S. Powars. 1998. Postimpact deformation associated with the late Eocene Chesapeake Bay impact structure in southeastern Virginia. *Geology* 26(6):507–510.

Kelley, P. H. 1982. The effect of predation on Miocene mollusc populations of the Chesapeake Group. Pages 35–48 *in* T. M. Scott and S. B. Upchurch, editors. Miocene of the southeastern United States: proceedings of a symposium. Florida Geological Survey, Tallahassee, Florida. Special Publication 25. Available at http://ufdc.ufl.edu/UF00000147/00001 (accessed February 2014).

Kelley, P. H. 1992. Evolutionary patterns of naticid gastropods of the Chesapeake Group: an example of coevolution? *Journal of Paleontology* 66(5):794–800.

Kellogg, R. 1966. Fossil marine mammals from the Miocene Calvert Formation of Maryland and Virginia: Part 3, New species of extinct Miocene Sirenia. *U.S. National Museum Bulletin* 247:65–98. Available at http://www.biodiversitylibrary.org/item/102238 (accessed February 2014).

Kenworthy, J. P., and V. L. Santucci. 2003. George Washington Birthplace National Monument. Pages 25–29 *in* J. P. Kenworthy and V. L. Santucci. Paleontological resource inventory and monitoring: Northeast Coastal and Barrier Network. TIC# D-340. National Park Service, Denver, Colorado.

Kenworthy, J. P., and V. L. Santucci. 2006. A preliminary investigation of National Park Service paleontological resources in cultural resource contexts, Part 1: general overview. Pages 70–76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf (accessed January 2014).

Kidwell, S. M., and D. Jablonski. 1983. Taphonomic feedback: ecological consequences of shell accumulation. Pages 195–248 *in* M. J. S. Tevesz, and P. L. McCall, editors. Biotic interactions in Recent and fossil benthic communities. Plenum Press, New York, New York.

Kimmel, P. G., and R. Purdy. 1985. Fossil fish of the Calvert and Eastover formations. Pages 205–215 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Lambert, O., S. J. Godfrey, and A. J. Fuller. 2010. A Miocene ziphilid (Cetacea, Odontoceti) from Calvert Cliffs, Maryland, U.S.A. *Journal of Vertebrate Paleontology* 30(5):1645–1651.

McCartan, L., W. L. Newell, J. P. Owens, and G. M. Bradford. 1996. Geologic map and cross sections of the Leonardtown 30 X 60-minute quadrangle, Maryland and Virginia. U.S. Geological Survey, Reston, Virginia. Open-File Report 95-665. Scale 1:100,000. Available at http://pubs.er.usgs.gov/publication/ofr95665 (accessed February 2014).

McCary, B. C. 1986. Early man in Virginia. Pages 71–78 *in* J. N. McDonald and S. O. Bird, editors. The Quaternary of Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 75. Available at http://www.dmme.virginia.gov/commercedocs/PUB_75.pdf (accessed January 2014).

McLaughlin, P. P., K. G. Miller, J. V. Browning, K. W. Ramsey, R. N. Benson, J. L. Tomlinson, and P. J. Sugarman. 2008. Stratigraphy and correlation of the Oligocene to Pleistocene section at Bethany Beach, Delaware. Delaware Geological Survey, Newark, Delaware. Report of Investigations 75. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/ri75.pdf (accessed February 2014).

Miller, M. F., H. A. Curran, and R. L. Martino. 1998. *Ophiomorpha nodosa* in estuarine sands of the lower Miocene Calvert Formation at the Pollack Farm Site, Delaware. Pages 41–46 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Mirecki, J. E., J. F. Wehmiller, and A. F. Skinner. 1995. Geochronology of Quaternary coastal plain deposits, southeastern Virginia, U.S.A. *Journal of Coastal Research* 11(4):1135–1144.

Mixon, R. B., B. J. Szabo, and Owens, J. P. 1982. U-series dating of mollusks and corals, and age of Pleistocene deposits, Chesapeake Bay area, Virginia and Maryland. U.S. Geological Survey Professional Paper 1067-E. Available at http://pubs.er.usgs.gov/publication/pp1067E (accessed January 2014).

Mixon, R. B., C. R. Berquist, W. L. Newell, and G. H. Johnson. 1989. Geologic map and generalized cross sections of the coastal plain and adjacent parts of the Piedmont, Virginia. U.S. Geological Survey, Reston, Virginia. Miscellaneous Investigations Series Map I-2033. Scale 1:250,000. Available at http://pubs.er.usgs.gov/publication/i2033 (accessed January 2014).

Mixon, R. B., D. S. Powars, R. E. Weems, J. S. Schindler, W. L. Newell, L. E. Edwards, and L. W. Ward. 2000. Upper Mesozoic and Cenozoic deposits of the Atlantic Coastal Plain. Pages 17–28 *in* R. B. Mixon, L. Pavlides, D. S. Powars, A. J. Froelich, R. E. Weems, J. S. Schindler, W. L. Newell, L. E. Edwards, and L. W. Ward. Geologic map of the Fredericksburg 30' x 60' quadrangle, Virginia and Maryland. U.S. Geological Survey, Reston, Virginia. Geologic Investigations Series 2607. Available at http://pubs.er.usgs.gov/publication/i2607 (accessed February 2014).

National Park Service (NPS), Geologic Resources Inventory Program. 2006. Digital geologic map of George Washington Birthplace National Monument and vicinity, Virginia and Maryland (NPS, GRD, GRE, GEWA). NPS Geologic Resources Inventory Program. Lakewood, Colorado. Geospatial Dataset-1041689. Available at https://irma.nps.gov/App/Reference/Profile?Code=1041689 (accessed February 2014).

Newell, W. L., O. P. Bricker, and M. S. Robertson. 2006. Geologic map of the Colonial Beach South 7.5' quadrangle, Virginia. U.S. Geological Survey, Reston, Virginia. Open-File Report 2005-1025. Scale 1:24,000. Available at http://pubs.usgs.gov/of/2005/1025/ (accessed February 2014).

Olson, S. L. 1985a. A brief synopsis of the fossil birds from the Pamunkey River and other Tertiary marine deposits in Virginia. Pages 217–223 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Olson, S. L. 1985b. A new genus of tropicbird (Pelecaniformes: Phaethontidae) from the middle Miocene Calvert Formation of Maryland. *Proceedings of the Biological Society of Washington* 98(4):851–855. Available at http://biodiversitylibrary.org/page/34649140 (accessed February 2014).

Olson, S. L. 2009. A new diminutive species of shearwater of the genus *Calonectris* (Aves, Procellaridae) from the middle Miocene Calvert Formation of Chesapeake Bay. *Proceedings of the Biological Society of Washington* 122(4):466–470.

Olson, S. L. 2011. A new genus and species of unusual tern (Aves, Laridae, Anoinae) from the middle Miocene Calvert Formation of Virginia. *Proceedings of the Biological Society of Washington* 124(4):270–279.

Palmer, A. A. 1986a. Cenozoic radiolarians as indicators of neritic versus oceanic conditions in continental-margin deposits: U.S. mid-Atlantic Coastal Plain. *Palaios* 1(2):122–132.

Palmer, A. A. 1986b. Miocene radiolarian biostratigraphy, U.S. mid-Atlantic Coastal Plain. *Micropaleontology* 32(1):19–31.

Peebles, P. C., G. H. Johnson, and C. R. Berquist. 1984. The middle and late Pleistocene stratigraphy of the outer coastal plain, southeastern Virginia. *Virginia Minerals* 30(2):13–22. Available at http://www.dmme.virginia.gov/DGMR/pdf/vamin/VAMIN_VOL30_NO02.pdf (accessed January 2014).

Poag, C. W. 1997. The Chesapeake Bay bolide impact: a convulsive event in Atlantic Coastal Plain evolution. *Sedimentary Geology* 108(1–4):45–90.

Powars, D. S., and T. S. Bruce. 1999. The effects of the Chesapeake Bay impact crater on the geological framework and correlation of hydrogeologic units of the lower York-James Peninsula, Virginia. U.S. Geological Survey, Reston, Virginia. Professional Paper 1612. Available at http://pubs.er.usgs.gov/publication/pp1612 (accessed January 2014).

Rasmussen, P. C. 1998. Early Miocene avifauna from the Pollack Farm Site, Delaware. Pages 149–151 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Ray, C. E. 1976. *Phoca wymani* and other Tertiary seals (Mammalia: Phocidae) described from the eastern seaboard of North America. Smithsonian Contributions to Paleobiology 28. Available at http://si-pddr.si.edu/dspace/handle/10088/19138 (accessed February 2014).

Ray, C. 1985. Fossil seals from the Calvert Formation of the Pamunkey River, Hanover County, Virginia. Pages 232–235 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado.

Schoonover, L. M. 1941. A Miocene echinoid colony from Maryland. *Journal of Paleontology* 15(1):92–93.

Scott, T. W., D. J. P. Swift, G. R. Whittecar, and G. A. Brook. 2010. Glacio-isostatic influences on Virginia's late Pleistocene coastal plain deposits. *Geomorphology* 116(1–2):175–188.

Shattuck, G. B. 1904. Geological and paleontological relations, with a review of earlier investigations; the Miocene deposits of Maryland. Pages xxxiii–cxxxvii *in* Miocene. Maryland Geological Survey systematic report. Johns Hopkins Press, Baltimore, Maryland. Available at https://archive.org/details/miocene01mary (accessed February 2014).

Tedford, R. H., and M. E. Hunter. 1984. Miocene marine–nonmarine correlations, Atlantic and Gulf coastal plains, North America. *Palaeogeography, Palaeoclimatology, Palaeoecology* 47:129–151.

Teifke, R. H. 1973. Stratigraphic units of the lower Cretaceous through Miocene series. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 83:1–78. Available at http://www.dmme.virginia.gov/commercedocs/BUL_83.pdf (accessed February 2014).

Thomas, R. D. K. 1976. Gastropod predation on sympatric Neogene species of *Glycymeris* (Bivalvia) from the eastern United States. *Journal of Paleontology* 50(3):488–499.

Thornberry-Ehrlich, T. L. 2005. George Washington Birthplace National Monument geologic resource evaluation management issues scoping summary. National Park Service, Geologic Resources Division, Denver, Colorado. Available at http://nature.nps.gov/geology/inventory/publications/s_summaries/GEWA_scoping_summary_20050929.pdf (accessed February 2014).

Thornberry-Ehrlich, T. L. 2009. George Washington Birthplace National Monument and Thomas Stone National Historic Site geologic resources inventory report. Natural Resource Report NPS/NRPC/GRD/NRR—2009/127. National Park Service, Denver, Colorado. Available at http://nature.nps.gov/geology/inventory/publications/reports/gewa-thst_gri_rpt_view.pdf (accessed February 2014).

Trochim, A., and A. C. Dooley, Jr. 2010. Diatom biostratigraphy and paleoecology of vertebrate-bearing Miocene localities in Virginia. *Abstracts with Programs - Geological Society of America* 42(1):167.

Tynan, E. J. 1957. Silicoflagellates of the Calvert Formation (Miocene) of Maryland. *Micropaleontology* 3(2):127–136.

Tynan, E. J. 1960. The Archaeomonadaceae of the Calvert Formation (Miocene) of Maryland. *Micropaleontology* 6(1):33–39.

Virginia Institute of Marine Science, College of William & Mary. 2013. Westmoreland County shoreline management plan, prepared for Westmoreland County and Virginia Coastal Zone Management Program. College of William & Mary, Gloucester Point, Virginia. Available at http://www.vims.edu/research/departments/physical/programs/ssp/_docs/WM_ShoreMan-2013.pdf (accessed February 2014).

Visaggi, C. C., and S. J. Godfrey. 2010. Variation in composition and abundance of Miocene shark teeth from Calvert Cliffs, Maryland. *Journal of Vertebrate Paleontology* 30(1):26–35.

Vogt, P. R., and R. E. Eshelman. 1987. Maryland's Cliffs of Calvert: a fossiliferous record of mid-Miocene inner shelf and coastal environments. Pages 9–14 *in* D. C. Roy, editor. Northeastern section of the Geological Society of America. Geological Society of America, Boulder, Colorado. Centennial Field Guide 5.

Vogt, P. R., and M. Parrish. 2011. Middle Miocene climatic optimum (ca. 15.6 Ma) and Antarctic ice sheet expansion (ca. 13.9 Ma): recorded in upper Calvert Formation exposed along western shore of Chesapeake Bay? *Abstracts with Programs - Geological Society of America* 43(1):61.

Ward, L. W. 1985a. Stratigraphy and characteristic mollusks of the Pamunkey Group (lower Tertiary) and the Old Church Formation of the Chesapeake Group: Virginia Coastal Plain. U.S. Geological Survey, Washington, DC. Professional Paper 1346. Available at http://pubs.er.usgs.gov/publication/pp1346 (accessed February 2014).

Ward, L. W. 1985b. Stratigraphy of outcropping Tertiary beds along the Pamunkey River: central Virginia Coastal Plain. Pages 11–77 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Ward, L. W. 1989. Tertiary stratigraphy of the central Virginia coastal plain. Pages 63–77 *in* Coastal and marine geology of the United States: Upper Cretaceous and Cenozoic geology of the southeastern Atlantic Coastal Plain. Field trips for the 28th International Geological Congress. American Geophysical Union, Washington, DC. Field Trip T172.

Ward, L. W., and G. W. Andrews. 2008. Stratigraphy of the Calvert, Choptank, and St. Marys Formations (Miocene) in the Chesapeake Bay area, Maryland and Virginia. Virginia Museum of Natural History, Martinsville, Virginia. Memoir 9.

Ward, L. W., and D. S. Powars, leaders. 1989. Tertiary stratigraphy and paleontology, Chesapeake Bay region, Virginia and Maryland. Field trips for the 28th international geological congress. American Geophysical Union, Washington, DC. Field Trip 216. Available at http://www.agu.org/books/ft/v216/FT216.pdf (accessed February 2014).

Weems, R. E. 1974. Middle Miocene sea turtles (*Syllomus*, *Procolpochelys*, *Psephophorus*) from the Calvert Formation. *Journal of Paleontology* 48(2):278–303.

Weems, R. E. 1980. *Syllomus aegyptiacus*, a Miocene pseudodont sea turtle. *Copeia* 1980(4):621–625.

Weems, R. E. 1985. Miocene and Pliocene Molidae (*Ranzania*, *Mola*) from Maryland, Virginia, and North Carolina (Pisces: Tetraodontiformes). *Proceedings of the Biological Society of Washington* 98(2):422–438. Available at http://biodiversitylibrary.org/page/34648701 (accessed February 2014).

Weems, R. E., and R. A. George. 2013. Amphibians and nonmarine turtles from the Miocene Calvert Formation of Delaware, Maryland, and Virginia (USA). *Journal of Paleontology* 87(4):570–588.

Wetmore, A. 1938. A Miocene booby and other records from the Calvert Formation of Maryland. *Proceedings of the United States National Museum* 85:21–25. Available at http://biodiversitylibrary.org/page/7721596 (accessed February 2014).

Whitmore, F. C., Jr. 1985. Cetaceans from the Calvert and Eastover formations, Pamunkey River, Virginia. Pages 227–231 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Wijnker, E., and S. L. Olson. 2009. A revision of the fossil genus *Miocepphus* and other Miocene Alcidae (Aves, Charadriiformes) of the western North Atlantic Ocean. *Journal of Systematic Palaeontology* 7(4):471–487.

Winfree, R. W. 1967. The T. Gray Haddon site, King William County, Virginia (44KW4). *Quarterly Bulletin of the Archaeological Society of Virginia* 22(1):2–26.

Wright, D. B., and R. E. Eshelman. 1987. Miocene Tayassuidae (Mammalia) from the Chesapeake Group of the Mid-Atlantic coast and their bearing on marine-nonmarine correlation. *Journal of Paleontology* 61(3):604–618.

Additional References

Benson, R. N. 1998. Radiolarians and diatoms from the Pollack Farm Site, Delaware: marine-terrestrial correlation of Miocene vertebrate assemblages of the Middle Atlantic Coastal Plain. Pages 5–19 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Bohaska, D. J. 1998. Fossil marine mammals of the lower Miocene Pollack Farm Site, Delaware. Pages 179–191 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Cutler, A. H. 1998. A note on the taphonomy of lower Miocene fossil land mammals from the marine Calvert Formation at the Pollack Farm Site, Delaware. Pages 175–178 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Darton, N. H. 1891. Mesozoic and Cenozoic formations of eastern Virginia and Maryland. *Geological Society of America Bulletin* 2:431–450.

Ellwood, B. B. 1996. Geology and America's National Park areas. Prentice Hall, Upper Saddle River, New Jersey.

Harwood, J. M. 2002. An archaeological evaluation of threatened cultural resources within the George Washington Birthplace National Monument. The Colonial Williamsburg Foundation, Department of Archaeological Research, Williamsburg, Virginia.

Jones, D. S., L. W. Ward, P. A. Mueller, and D. A. Hodell. 1998. Age of marine mollusks from the lower Miocene Pollack Farm Site, Delaware, determined by (super 87) Sr/ (super 86) Sr geochronology. Pages 21–25 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Kellogg, R. 1924. A fossil porpoise from the Calvert Formation of Maryland. *Proceedings of the United States National Museum* 63(14). Available at http://biodiversitylibrary.org/page/7716365 (accessed February 2014).

Kellogg, R. 1924. Description of a new genus and species of whalebone whale from the Calvert Cliffs, Maryland. *Proceedings of the United States National Museum* 63(15).

Kellogg, R. 1925. On the occurrence of remains of fossil porpoises of the genus *Eurhinodelphis* in North America. *Proceedings of the United States National Museum* 66(26). Available at http://biodiversitylibrary.org/page/7739159 (accessed February 2014).

Kellogg, R. 1955. Three Miocene porpoises from the Calvert cliffs, Maryland. *Proceedings of the United States National Museum* 105(3354):101–154. Available at http://biodiversitylibrary.org/page/15705161 (accessed February 2014).

Kellogg, R. 1965. Fossil marine mammals from the Miocene Calvert Formation of Maryland and Virginia: Part 1. A new whalebone whale from the Miocene Calvert Formation. *U.S. National Museum Bulletin* 247:1–45. Available at http://www.biodiversitylibrary.org/item/102238 (accessed February 2014).

Kellogg, R. 1965. Fossil marine mammals from the Miocene Calvert Formation of Maryland and Virginia: Part 2. The Miocene Calvert sperm whale *Orycterocetus*. *U.S. National Museum Bulletin* 247:47–63. Available at http://www.biodiversitylibrary.org/item/102238 (accessed February 2014).

Kellogg, R. 1966. Fossil marine mammals from the Miocene Calvert Formation of Maryland and Virginia: Part 3. New species of extinct Miocene Sirenia. *U.S. National Museum Bulletin* 247:65–98. Available at http://www.biodiversitylibrary.org/item/102238 (accessed February 2014).

Kellogg, R. 1966. Fossil marine mammals from the Miocene Calvert Formation of Maryland and Virginia: Part 4. A new odontocete from the Calvert Miocene of Maryland. *U.S. National Museum Bulletin* 247:99–101. Available at http://www.biodiversitylibrary.org/item/102238 (accessed February 2014).

Kellogg, R. 1968. Fossil marine mammals from the Miocene Calvert Formation of Maryland and Virginia: Part 5. Miocene Calvert mysticetes described by Cope. *U.S. National Museum Bulletin* 247:103–132. Available at http://www.biodiversitylibrary.org/item/102238 (accessed February 2014).

Kellogg, R. 1968. Fossil marine mammals from the Miocene Calvert Formation of Maryland and Virginia: Part 6. A hitherto unrecognized Calvert cetothere. *U.S. National Museum Bulletin* 247:133–161. Available at http://www.biodiversitylibrary.org/item/102238 (accessed February 2014).

Kellogg, R. 1968. Fossil marine mammals from the Miocene Calvert Formation of Maryland and Virginia: Part 7. A sharp-nosed cetothere from the Miocene Calvert. *U.S. National Museum Bulletin* 247:163–173. Available at http://www.biodiversitylibrary.org/item/102238 (accessed February 2014).

Kellogg, R. 1968. Fossil marine mammals from the Miocene Calvert Formation of Maryland and Virginia: Part 8. Supplement to description of *Parietobalaena palmeri*. *U.S. National Museum Bulletin* 247:175–197. Available at http://www.biodiversitylibrary.org/item/102238 (accessed February 2014).

Kidwell, S. M. 1989. Stratigraphic condensation of marine transgressive records: origin of major shell deposits in the Miocene of Maryland. *Journal of Geology* 97(1):1–24.

Kidwell, S. M. 1997. Anatomy of extremely thin marine sequences landward of a passive-margin hinge zone: Neogene Calvert Cliffs succession, Maryland, U.S.A. *Journal of Sedimentary Research* 67(2):322–340.

Kidwell, S. M., and D. Jablonski. 1983. Taphonomic feedback: ecological consequences of shell accumulation. Pages 195–248 *in* M. J. S. Tevesz, and P. L. McCall, editors. Biotic interactions in Recent and fossil benthic communities. Plenum Press, New York, New York.

Mayor, A. 2005. Fossil legends of the first Americans. Princeton University Press, Princeton, New Jersey.

McLennan, J. D. 1971. Miocene sharks teeth of Calvert County. Maryland Geological Survey Pamphlet. Available at http://www.mgs.md.gov/geology/fossils/miocene_shark_teeth_fs.html (accessed February 2014).

McLennan, J. D. 1973. Calvert Cliffs, Maryland. Maryland Geological Survey Pamphlet. Available at http://www.mgs.md.gov/geology/fossils/calvert_cliffs_fs.html (accessed February 2014).

Myrick, A. C. 1979. Variation, taphonomy, and adaptation of the Rhabdosteidae. Dissertation. University of California–Los Angeles, Los Angeles, California.

Olsen, S. J. 1971. Zooarchaeology: animal bones in archaeology and their interpretation. Addison-Wesley Publishing Company, New York City, New York.

Parris, D. C., and B. S. Grandstaff. 1993. Quaternary vertebrates from the Virginia coastal plain. *Mosasaur* 5:19–21.

Purdy, R. W. 1998. The early Miocene fish fauna from the Pollack Farm Site, Delaware. Pages 133–139 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Ramsey, K. W. 1998. Depositional environments and stratigraphy of the Pollack Farm Site, Delaware. Pages 27–40 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Richards, H. G. 1936. Fauna of the Pleistocene Pamlico Formation of the southern Atlantic Coastal Plain. *Geological Society of America Bulletin* 47:1611–1656.

Roberts, J. K. 1942. Annotated geological bibliography of Virginia. University of Virginia bibliographical series 2.

Ruhle, J. L. 1965. Geologic literature of the Coastal Plain of Virginia, 1783-1962. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Information Circular 9. Available at http://www.dmme.virginia.gov/commercedocs/IC_9.pdf (accessed January 2014).

Stark, D. S. P. 1983. A new species of pinaceous cones from the Tertiary of Maryland. *American Journal of Botany* 70(5, Part 2):79.

Teifke, R. H. 1973. Stratigraphic units of the lower Cretaceous through Miocene series. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 83:1–78. Available at http://www.dmme.virginia.gov/commercedocs/BUL_83.pdf (accessed February 2014).

Vokes, H. E. 1957. Miocene fossils of Maryland. Maryland Geological Survey, Baltimore, Maryland. Bulletin 20.

Ward, L. W. 1992. Molluscan biostratigraphy of the Miocene, Middle Atlantic Coastal Plain of North America. Virginia Museum of Natural History, Martinsville, Virginia. Memoir 2.

Ward, L. W., and D. S. Powars. 1991. Tertiary lithology and paleontology, Chesapeake Bay region. Pages 161–201 *in* A. Schultz, and E. Compton-Gooding, editors. Geologic evolution of the eastern United States. Virginia Museum of Natural History, Martinsville, Virginia. Guidebook 2.

Weems, R. E., and L. E. Edwards. 2007. The age and provenance of "*Eschrichtius*" *cephalus* Cope (Mammalia, Cetacea). *Journal of Vertebrate Paleontology* 27(3):752–756.

Data Sets

George Washington Birthplace National Monument Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

George Washington Birthplace National Monument Collections
1930–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by GEWA staff; status: Active.

George Washington Birthplace National Monument Digital Geologic Map
2006–present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online. https://irma.nps.gov/App/Reference/Profile?Code=1041689.

U.S. Geological Survey
1950s–present. (locality notes; collection records; maps; etc.). Originated by USGS staff; status: Active.

Sagamore Hill National Historic Site

Sagamore Hill National Historic Site (SAHI) in New York was authorized to protect Theodore Roosevelt's Long Island home, constructed in 1886 and used as his primary residence until his death in 1919. Along with the estate is the Theodore Roosevelt Museum and the undeveloped grounds of the property, including a coastal area. SAHI was authorized July 25, 1962. It encompasses 33.60 ha (83.02 acres), which are all federal.

Geologic Background

SAHI encompasses a narrow strip of land (SAHI Figure 2) in the village of Cove Neck, within the town of Oyster Bay in northeastern Nassau County, New York, adjacent to Suffolk County on the east. Cove Neck forms a short peninsula that separates Oyster Bay Harbor on the west from Cold Spring Harbor (the body of water, not the hamlet) on the east. Cove Neck is one of a number of small projections on the northern margin of Long Island. Centre Island is just across the mouth of Oyster Bay Harbor on the north. On the east, on the other side of Cold Spring Harbor, is another projection nearly split in two, with the southern part known as West Neck and the northern part known as Lloyd Neck. North of these necks is Long Island Sound. SAHI is not noted for its geology, but this area at the northeast corner of Nassau County and the northwest corner of Suffolk County has been described in more than a dozen publications, and plant fossils have been known from the east side of Cold Spring Harbor since the late 19th century. Publications that discuss the geology and paleontology of SAHI and its immediate vicinity include Britton (1885), Hollick (1893, 1894, 1903, 1904), Woodworth (1901), Veatch (1906), Fuller (1914), Grier (1925a, 1925b), Lubke (1964), Isbister (1967), Kenworthy and Santucci (2003), Benotti (2008), NPS (2010), and Thornberry-Ehrlich (2011). The NPS Geologic Resources Division held a scoping meeting for SAHI in June 2010 (Thornberry-Ehrlich 2011) and produced a digital geologic map for the historic site in 2010 (NPS 2010). The initial paleontological resource inventory and summary was prepared by Kenworthy and Santucci (2003).

The following discussion of the geologic background is primarily derived from Stoffer (2003), except where noted. Although the surficial geology of SAHI is limited to upper Quaternary deposits (SAHI Figure 3) (see the Appendix for a geologic time chart), older Quaternary and Cretaceous deposits have been accessed through wells and borings, extending the geologic record of the seashore to about 100 Ma (million years ago). The Atlantic coast of North America has generally been quiet in terms of tectonics since the breakup with Europe and Africa, which occurred during the Late Triassic and Early Jurassic (centered about 200 Ma). The subsurface of central Long Island may contain an ancient rift valley from this time, following the alignment of the Hartford Basin of Connecticut and Massachusetts, and concealed by younger sediments (Rogers et al. 1989). Another rift basin, the Newark Basin, is found west of Long Island, and includes the famous Palisades Sill, a vast igneous intrusion from 200 Ma.



SAHI Figure 1. Looking out from the beach at SAHI to Cold Spring Harbor (NPS).

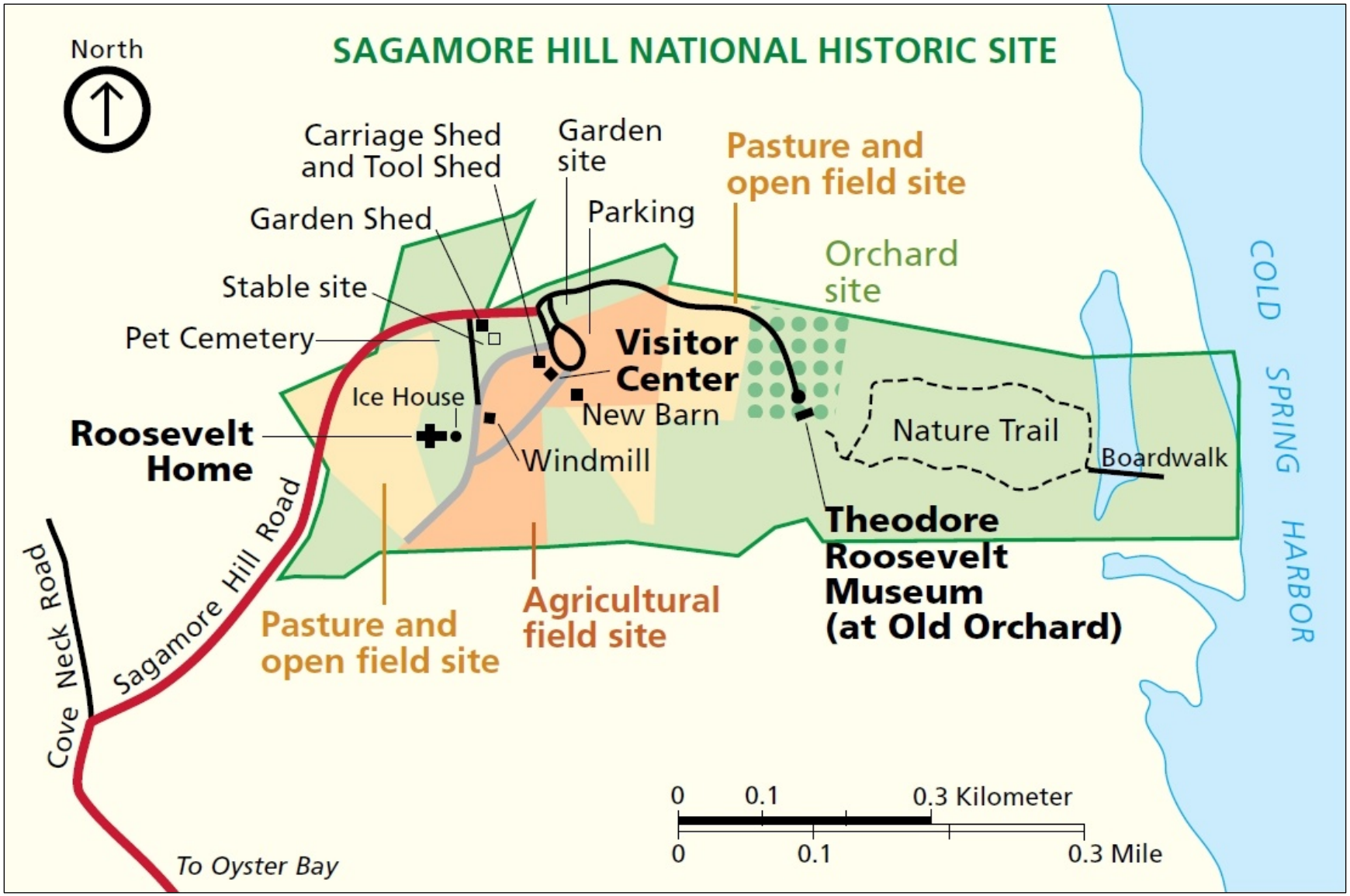
A hiatus in the depositional record follows until about 100 Ma, the onset of some 50 to 60 million years of deposition from the Late Cretaceous to the Eocene that drapes the bedrock of northeastern New Jersey, New York City, and Long Island. These deposits dip to the south, so the thickness of the pile and the total time represented increase going south. Beneath central Long Island, only Cretaceous sediments are found, and going north across the island the youngest Cretaceous sediments disappear (Perlmutter and Todd 1965). The Cretaceous sediments include a number of formations that record a transition from coastal plains to shallow marine settings, with several marine transgression-regression cycles as sea level rose and fell (Sugarman et al. 1995; Miller et al. 2003, 2004). The Long Island area is thought to have been near the strand line of the Cretaceous coastal plain, and would have been a setting of river channels, floodplains, swamps, and marshes (Pluhowski and Kantrowitz 1964). The Cretaceous sediments of the SAHI area were heavily eroded sometime during the Cenozoic, before the glaciations of the Quaternary (Lubke 1964).

The Quaternary geology of the SAHI area is dominated by the influence of glaciers, both direct (such as sediments moved by glaciers) and indirect (such as deposition of glacial outwash and by glacial meltwater lakes and, more broadly speaking, the effects of glaciation, post-glacial adjustment of crust depressed by ice, and glacial melting on sea level). Multiple glacial–interglacial cycles have occurred during the Quaternary, but the evidence for most of them is usually obscured by the effects of the most recent glaciation. Glaciers repeatedly covered the SAHI area, as shown by the locations of moraines (accumulations of glacial debris). Long Island is in large part the remains of two thick glacial terminal moraines, the older Ronkonkoma Moraine present across central Long Island, and the younger Harbor Hill Moraine of northern Long Island. The latter moraine is found a few km or miles south of SAHI (Isbister 1967). The moraines were formed during what is known as the

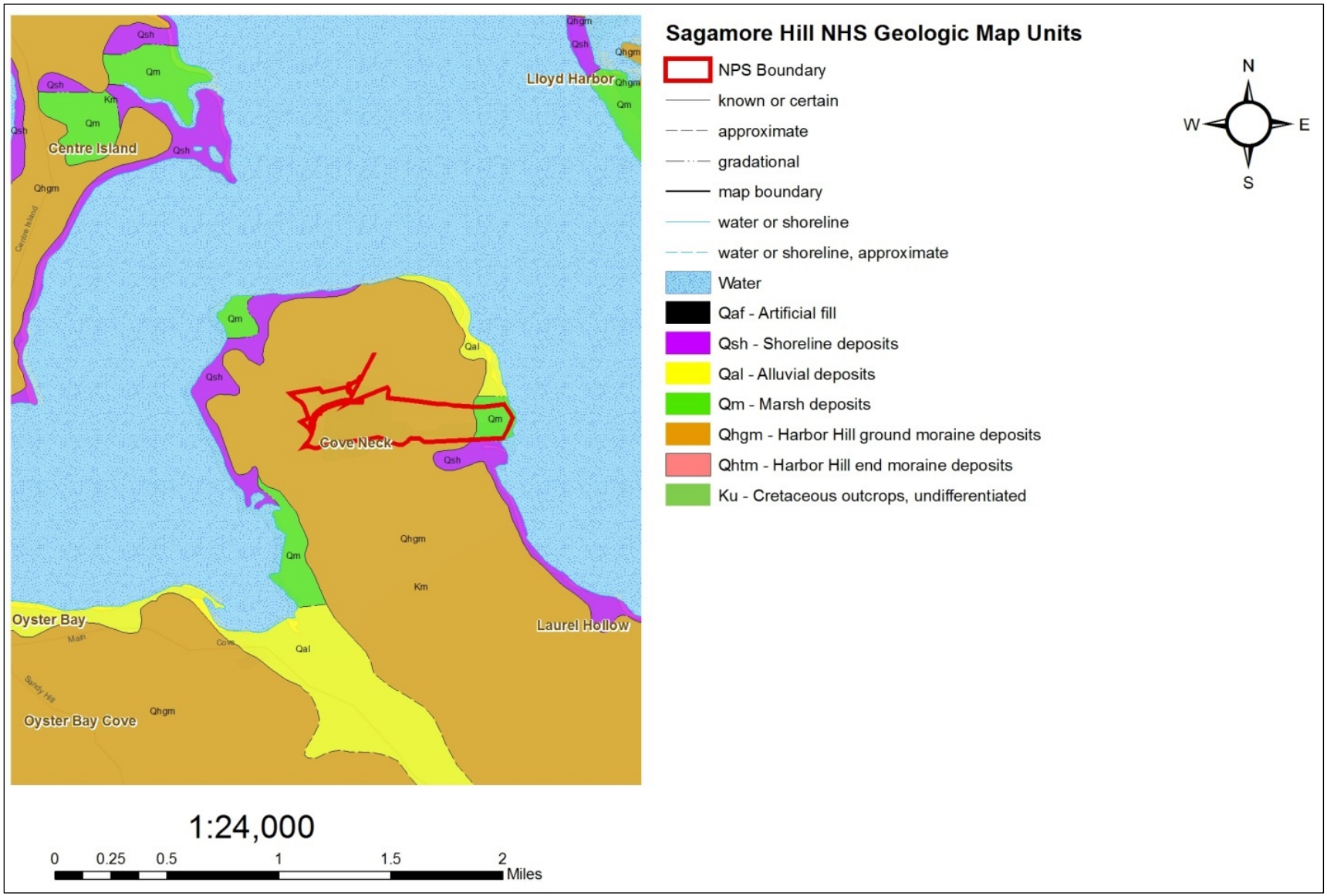
Wisconsinan (or Wisconsin) glaciation, the most recent glacial episode. The Wisconsinan began roughly 85,000 to 75,000 years ago, reached a maximum (the Last Glacial Maximum) about 25,000 to 20,000 years ago, and ended about 11,000 years ago. Immediately before this glacial episode, the prevailing climate and sea level were similar to today; this time is known as the Sangamonian (or Sangamon) interglacial, which began about 125,000 years ago. Marine deposits from this time have been found in New Jersey and to a lesser extent southern New York.

One of the effects of glaciation is to draw down global sea levels, with the effect of extending coastal plains tens of km/miles closer to ocean basins. The extended coastal plain supported a variety of plant and animal life, fossils of which are sometimes dredged from the seafloor (Whitmore et al. 1967; Gallagher et al. 1989; McDonald and Ray 1990). Long Island Sound would have been one of these dry areas until sometime after the glaciers melted. Today, the coastal geography of SAHI exposes it to the consequences of sea level change. Human modification has been important as well. Humans arrived in the New York City area by around 10,000 years ago, and over the past 400 years it has become one of the most anthropogenically altered landscapes in the Western Hemisphere.

The surficial geology of SAHI is made up of upper Pleistocene Harbor Hill ground moraine over most of the historic site, and Holocene shoreline and marsh deposits on the shore (Isbister 1967; NPS 2010) (SAHI Figure 3, Table 1). The subsurface includes, in descending order (young to old), a unit referred to the Gardiners Clay (upper Pleistocene), a unit referred to the Jameco Gravel, the Lloyd Sand Member of the Raritan Formation (Upper Cretaceous), and crystalline bedrock. The Oyster Bay Harbor area has some substantial buried valleys, including one beneath Cove Neck and SAHI, that eliminated much of the local Cretaceous sedimentation. These deposits include more Raritan Formation deposits and an undivided unit tentatively correlated to the younger Magothy Formation (Isbister 1967). None of the deposits at SAHI has yielded fossils to date, although it is likely that the subsurface units would include microfossils if sampled by wells or borings, microfossils and other organic remains may be present in the marsh sediments, glacially transported fossils may be present in glacial deposits, and it is possible that fossils may wash up on the SAHI shore from nearby exposures of Cretaceous sediments.



SAHI Figure 2. Geography of SAHI (NPS).



SAHI Figure 3. Schematic geological map of SAHI. Map graphic adapted from digital geologic map data available at the following URL: https://irma.nps.gov/App/Reference/Profile?Code=2165107.

SAHI Table 1. Summary of SAHI stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text.

Formation	Age	Fossils Within SAHI	Depositional Environment
Surficial Quaternary sediments	latest Pleistocene–Holocene	None to date; microfossils and organic material are possible in the marsh deposits, glacially transported fossils may be found in the glacial deposits, and fossils may wash up on the shore	Primarily deposition by glaciers; also shores and marshes
Subsurface Quaternary sediments	Pleistocene	None to date; microfossils may be recovered from wells and borings into the "Gardiners Clay"	Shallow marine, fluvial, and glacial outwash
Subsurface Cretaceous sediments (lower Raritan Formation)	Late Cretaceous	None to date; microfossils and plants may be recovered from deep wells and borings	Coastal terrestrial

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within SAHI. However, they are known to preserve fossils elsewhere, and future field investigations within the historic site may locate fossils in one or more of them.

Subsurface (Upper Cretaceous and Quaternary)

There does not appear to be any reports of fossils from wells and borings drilled within SAHI, although fossils have been recovered in the immediate vicinity. Because the fossiliferous sediments are buried hundreds of meters or feet below the surface, they are protected from erosion, theft, and vandalism, and would only require management when brought to the surface. As shown in Isbister (1967), the subsurface of SAHI features a buried valley that cut through most of the local Cretaceous sediments and was filled with Pleistocene sediments. Only the Lloyd Sand Member of the Raritan Formation is thought to remain from the Cretaceous units, perhaps 150 m (500 ft) below sea level. The valley fill is made up of deposits assigned to the Jameco Gravel, the overlying "Gardiners Clay", and a thick section of the upper Pleistocene glacial deposits that are found at the surface. Although exhaustive treatment of each unit is not relevant for this work, because of the lack of surface exposures, a short discussion is justified.

Upper Cretaceous units

The Lloyd Sand Member is the lower part of the Raritan Formation in Long Island. In the SAHI area, it is composed of discontinuous beds of sand and gravel and lenses of clay and silt, with scattered lignite particles and layers (Isbister 1967). Nearby areas have thicker Cretaceous sections, including the upper clay member of the Raritan Formation and deposits tentatively correlated to the younger Magothy Formation (Lubke 1964; Isbister 1967). These sediments are thought to have been deposited by sluggish streams on a low swampy coastal plain (Lubke 1964). Deposition occurred at the beginning of the Late Cretaceous, about 100 Ma (Kimyai 1970). A few exposures of the Cretaceous sediments are found in the area, and have produced plant fossils at Cold Spring Harbor and Lloyd Neck. The fossils are discussed in a handful of publications, including Britton (1885),

Hollick (1893, 1894, 1903, 1904), Veatch (1906), and Grier (1925a, 1925b). They are comparable to Cretaceous plant fossils found at other locations in New York City, including Brooklyn and Staten Island (Britton 1885), which also came from Raritan and Magothy formation sediments (Hollick 1906). Hollick's Lloyd Neck plants are mostly angiosperm leaf fossils (Hollick 1893, 1894). Grier (1925a, 1925b) described a larger floral assemblage from the Cold Spring Harbor area, including clay pits on the east side of Cold Spring Harbor, south of Lloyd Neck. The assemblage included diatoms (phytoplankton with cell walls made of silica), ferns, cycads, conifers, and angiosperms. Some of these plants also exhibited insect galls. Lloyd Point at the northern extremity of Lloyd Harbor has also produced plant fossils, from the Lloyd Sand (Veatch 1906). This is within Caumsett State Park, which Stoffer (pers. comm. in Kenworthy and Santucci 2003) noted has produced fossil leaves associated with lignite. Cretaceous sediments of Oyster Bay have also produced fossil conifer and angiosperm leaves (Hollick 1904).

Microfossils are of particular interest for SAHI because the Cretaceous sediments can only be sampled via wells and borings, making microfossils the most likely type of fossils to be recovered. Larger fossils can be recovered, but they are likely to be damaged or incomplete. Types of microfossils known from the Raritan Formation outside of SAHI include foraminifera (single-celled organisms that secrete "shells", typically of calcium carbonate) (Petters and Olsson 1975), diatoms (Grier 1925a, 1925b), dinoflagellates (single-celled organisms that move using one or more whip-like flagella), and spores and pollen representing mosses, lycopods (clubmosses), ferns, bennettitales (cycad-like extinct plants), conifers, and angiosperms (Kimyai 1966, 1970). Kimyai (1970) described an assemblage of plant microfossils recovered between 40 and 58 m (130 and 191 ft) below the land surface, from a well at the isthmus connecting Oak Neck to the mainland about 6.5 km (4 miles) northwest of SAHI. They included spores of mosses, lycopods, and ferns, and pollen of cycads or bennettitales, conifers, and angiosperms. Kimyai attributed the fossils to the Raritan Formation, and interpreted the assemblage as subtropical to temperate.

The Raritan and Magothy formations are especially noted for their plant fossils, representing mosses, ferns, cycads, conifers, a number of angiosperms, and undetermined plants (Newberry 1895; Hollick 1906; Weller 1907; Berry 1911; Penny 1947). These formations are also noted for amber. Fossils found in the amber include feathers and a variety of arthropods, including midges, flies, gnats, wasps, ants, bees, lacewings, beetles, leaf hoppers, scale insects, moths, roaches, mantids, barklice, caddisflies, spiders, mites, and pseudoscorpions (Grimaldi et al. 1989; Gallagher et al. 2001). Other fossils reported from the two formations include corals, bryozoans (moss animals), bivalves, ammonites (extinct nautilus-like shelled animals), gastropods, worm tubes, crabs, mud shrimp, sponge borings, bones of plesiosaurs (extinct sea reptiles), a possible dinosaur bone, and dinosaur footprints (Weller 1907; Richards et al. 1958, 1962; Gallagher 1984). Lubke (1964) noted that a crinoid (sea lily) stem and bryozoan had been recovered from the Lloyd Sand Member in a well near Lloyd Point, and seemed to regard them as in situ, but in the absence of illustrations or additional information it is also possible that the fossils had been eroded out of Paleozoic rocks and redeposited in the Cretaceous sediments.

Quaternary subsurface clay deposits

The Jameco Gravel has historically been used as the name of a sand and gravel deposit found at or near the base of the Quaternary sediments of Long Island. It is interpreted as early glacial outwash in the SAHI area (Isbister 1967), and is not known to contain fossils. The overlying "Gardiners Clay" is a different matter. In the New York City/Long Island region, Quaternary clay beds have historically been lumped together as the Gardiners Clay, but they now appear to include multiple depositional events from different times and settings (Upson 1970; Sirkin 1986). The original Gardiners Clay, named from Gardiners Island, appears to be a block of marine clay transported from elsewhere by glaciers, and has a cold-water fauna. Gardiners Clay deposits mapped from cliffs on the north shore of Long Island are nonmarine and possibly contain varves (annual layers), indicating origin in lakes. Clays called Gardiners Clay in the subsurface of western Long Island contain warm-climate pollen (Sirkin 1986). This type of clay is interpreted as an interglacial marine unit, perhaps from the Sangamonian interglacial (roughly 125,000 to 75,000 years ago) (Soren 1971), or an interglacial as old as 225,000 years (Ricketts 1986). The subsurface "Gardiners Clay" has yielded a variety of fossils, including foraminifera, diatoms, peat, lignite, woody fragments, pollen and spores, bryozoans, bivalves, gastropods, barnacles, and ostracodes (MacClintock and Richards 1936; Weiss 1954; Perlmutter and Geraghty 1963; Soren 1971, 1978). The subsurface deposits below SAHI are interpreted as interglacial marine in origin. They are composed of gray green or brown clay and silt with interbedded sand and gravel. Foraminifera, diatoms, peat, and oyster and clam shells have been found in the SAHI area, including in a well at the northwest tip of Cove Neck, where foraminifera and shells were recovered (Isbister 1967)

Surficial Quaternary Sediments (Upper Pleistocene–Holocene)

The surficial geology of SAHI includes latest Pleistocene glacial deposits left by the glacier that produced the Harbor Hill Moraine to the south, and Holocene shore and beach deposits along the eastern margin of the historic site (Isbister 1967). These deposits are not known to be fossiliferous within SAHI, but there are some categories of fossils that may eventually be found. In the Pleistocene deposits, they include isolated remains of large extinct mammals and fossils transported from elsewhere by glaciers. In the Holocene deposits, they include peat and shelly material, and microfossils useful for paleoecological studies. There is also the possibility that fossils may wash up on SAHI shores.

The fossils of extinct Pleistocene mammals are found throughout Connecticut, New Jersey, and New York, with numerous examples within about 100 km (60 miles) of SAHI (Hartnagel and Bishop 1921; Hay 1923; Jepsen 1960; Lucas 1993). The most common and iconic mammals found in this area are mammoths and mastodons, which are often recognized from their large, distinctive teeth. Mammoth remains have occasionally been found in glacial moraine deposits of the SAHI area (Kenworthy and Santucci 2003).

Reworked fossils are not uncommon in the glacial sediments of New York City, and have attracted interest since the late 19th century (they seem to have been a favorite topic for the Natural Science Association of Staten Island/Staten Island Institute of Arts and Sciences). Rocks from many formations exposed north of New York City have been transported there by glaciers. For example,

Hollick (1908) described fossils from five geologic periods and at least ten formations that had been part of a glacial deposit in Tottenville. The specimens included Ordovician brachiopods, stromatoporoid sponges, and worm tracks; Silurian brachiopods and crustacean tracks; Devonian brachiopods and nautiloids; Triassic trace fossils; and Cretaceous leaves, root traces, and bivalves. Other reworked fossils found on Staten Island include bryozoans, gastropods, trilobites (Gratacap 1894), crinoids (Britton 1881), and Triassic-age horsetail and conifer specimens (Hollick 1900). Marine shells of Quaternary age have also been found in glacial deposits (Desor 1847). Woodworth (1901) noted that silicified Paleozoic fossils and fossiliferous Cretaceous concretions had been found in the glacial deposits of the nearby Oyster Bay Quadrangle, having been transported from up to 320 km (200 miles) away. It is certainly conceivable that glacially transported fossils may be found in SAHI.

The Holocene deposits in the SAHI area have been known to include peat and shells (Isbister 1967), and given the marshy sediments on the eastern margin of SAHI, it is possible that ancient peat is present there. Should ancient peat be found in the historic site, it would be an ideal deposit to examine for microfossils such as pollen. Quaternary microfossils are a common topic of study in the vicinity of New York City, having been applied to topics such as climate change since the end of the most recent glaciation, fire histories, and responses to land-use changes. Microfossils are usually found in the deposits of lakes, swamps, and marshes, typically covering a time frame going back to around 13,000–12,000 years ago. The most commonly studied fossils are spores and pollen of various plants. Algae, mosses, clubmosses, ferns, conifers, and angiosperms are widely represented. Charcoal is utilized for studies of fire history. Pollen sites in New York and New England show a consistent succession from tundra to spruce-dominated vegetation (transition about 13,000 years ago), to pine-dominated vegetation (appearing around 11,000 to 9,000 years ago), to oak-dominated vegetation (appearing around 7,000 years ago). A selection of publications referencing paleoecological sites within about 100 km (60 miles) of SAHI include Donner (1964), Sirkin (1967, 1971), Russell (1980), Connally and Sirkin (1986), Russell et al. (1993), Maenza-Gmelch (1997), Rue and Traverse (1997), Robinson et al. (2003), and Oswald et al. (2010).

Finally, there is the possibility of washed-in fossils. Concretions bearing an assemblage of predominantly shallow marine fossils commonly wash up on the beaches of Gateway National Recreation Area (GATE) in the New York Bight to the west. Common fossils include corals, bivalves, gastropods, barnacles, and bones of fish and marine mammals. Plant roots and debris, sponges, crabs, lobsters, invertebrate burrows, and a crocodilian tooth have also been found. Most of these fossils are probably Holocene to possibly late Pleistocene in age, but some of the material is probably Cretaceous in age (Stoffer et al. 1996, 1999; 2005; Stoffer 2003; Chamberlain et al. 2006). More information can be found in the GATE chapter of this report. The offshore geology of SAHI is not as conducive to such finds, but they are not out of the question. The nearest potential source is probably the fossiliferous Cretaceous sediments on the east side of Cold Spring Harbor.

Park Collections

There are no paleontological specimens in SAHI collections at this time (A. Verone, SAHI curator, pers. comm., April 2014).

Cultural Resource Contexts

Fossils have not been reported from cultural contexts at SAHI. There is some possibility of finding fossils in buried archeological sites, such as faunal remains or fossils and fossiliferous materials used for artifacts. There has been no indication that fossils are present in building stone, or in Roosevelt's collections (although his ranch in North Dakota, now within Theodore Roosevelt National Park, is within a heavily fossiliferous area with easily transported fragments of petrified wood). Amy Verone (pers. comm., April 2014) noted that there are a handful of paleontological books in SAHI collections, mostly related to Roosevelt's friend Henry Fairfield Osborn. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts. Further information about southeastern New York archeological sites can be found in Funk (1976) and Brennan (1977).

Paleontological Resource Management, Preliminary Recommendations

- SAHI staff should be encouraged to observe the beaches and exposed sedimentary deposits for fossil material while conducting their usual duties. To promote this, they should also 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, historic site staff should take advantage of them, if funding and time permit.
- Staff should photodocument and monitor any occurrences of paleontological resources that may be observed in situ. Fossils and their associated geologic context (surrounding rock/sediment) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. 2009).
- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist. Any fossil with 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.
- Quaternary fossils and deposits are of interest because they can be used to describe the effects of past climate and sea level changes, and to predict natural responses to future changes. Further study of these fossils and deposits in and around SAHI is encouraged. An investigation of the shore areas for buried peat deposits may be of interest.
- Contact the NPS Geologic Resources Division for technical assistance with paleontological resource management issues.

References Cited

Benotti, M. J. 2008. Inventory of data sources used for watershed condition assessments of Fire Island National Seashore, Gateway National Recreation Area, and Sagamore Hill National Historic Site, New York and New Jersey. U.S. Geological Survey, Reston, Virginia. Open-File Report 2008-1298. http://pubs.er.usgs.gov/publication/ofr20081298 (accessed March 2014).

Berry, E. W. 1911. Flora of the Raritan Formation. Geological Survey of New Jersey, Trenton, New Jersey. Bulletin 3. Available at http://www.state.nj.us/dep/njgs/enviroed/oldpubs/bulletin3.pdf (accessed March 2014).

Brennan, L. A. 1977. The lower Hudson: the Archaic. *Annals of the New York Academy of Sciences* 288:411–430.

Britton, N. L. 1881. On the geology of Richmond County, New York. *Annals of the New York Academy of Sciences* 2:161–182. Available at http://biodiversitylibrary.org/page/35264703 (accessed March 2014).

Britton, N. L. 1885. Leaf-bearing sandstones on Staten Island, New York. *Transactions of the New York Academy of Sciences* 3:30–31. Available at http://biodiversitylibrary.org/page/12615165 (accessed March 2014).

Chamberlain, J. A., Jr., P. W. Stoffer, and P. Messina. 2006. Fossiliferous nodules from New York Gateway beaches. Page 11 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34.

Connally, G. G., and L. Sirkin. 1986. Woodfordian ice margins, recessional events, and pollen stratigraphy of the mid-Hudson Valley. Pages 50–72 *in* Cadwell, D. H., editor. The Wisconsinan Stage of the First Geological District, eastern New York. New York State Museum, Albany, New York. Bulletin 455. Available at https://www.nysm.nysed.gov/pubsforsale/detail.cfm?pubID=4936 (accessed March 2014).

Desor, E. 1847. Fossils in drift at Brooklyn and at Westport, New York. *Proceedings of the Boston Society of Natural History* 2:247. Available at http://biodiversitylibrary.org/page/9490931 (accessed March 2014).

Donner, J. J. 1964. Pleistocene geology of eastern Long Island, New York. *American Journal of Science* 262(3):355–376.

Fuller, M. L. 1914. The geology of Long Island, New York, U.S. Geological Survey, Washington, DC. Professional Paper 82. Scale 1:125,000. Available at http://pubs.er.usgs.gov/publication/pp82 (accessed March 2014).

Funk, R. E. 1976. Recent contributions to Hudson Valley prehistory. New York State Museum, Albany, New York. Memoir 22. Available at http://purl.org/net/nysl/nysdocs/3078762 (accessed March 2014).

Gallagher, W. B. 1984. Paleoecology of the Delaware Valley region: Part II, Cretaceous to Quaternary. *The Mosasaur* 2:9–43.

Gallagher, W. B., D. C. Parris, B. S. Grandstaff, and C. DeTemple. 1989. Quaternary mammals from the Continental Shelf of New Jersey. *The Mosasaur* 4:101–110.

Gallagher, W. B., D. C. Parris, E. Gilmore, and R. Johnson. 2001. New Jersey's Cretaceous amber deposits. *Northeastern Geology and Environmental Sciences* 23(4):340–345.

Gratacap, L. P. 1894. Additions to the drift fossils of Staten Island. *Proceedings of the Staten Island Institute of Arts and Sciences* 4(5):16-17.

Grier, N. M. 1925a. The fossil flora of the vicinity of Cold Spring Harbor. *American Midland Naturalist* 9(10):513–527.

Grier, N. M. 1925b. The geology of Long Island with especial reference to the Cold Spring Harbor region and its flora. *American Midland Naturalist* 9(11):531–563.

Grimaldi, D., C. W. Beck, and J. J. Boon. 1989. Occurrence, chemical characteristics, and paleontology of the fossil resins from New Jersey. American Museum Novitates 2948. Available at http://hdl.handle.net/2246/5103 (accessed March 2014).

Hartnagel, C. A., and S. C. Bishop. 1921. The mastodons, mammoths and other Pleistocene mammals of New York State. New York State Museum, Albany, NY. Bulletins 241 and 242.

Hay, O. P. 1923. The Pleistocene of North America and its vertebrated animals from the states east of the Mississippi River and from the Canadian provinces east of longitude 95 degrees. Carnegie Institution of Washington, Washington, D.C. Publication 322. Available at https://archive.org/details/pleistoceneofnor00hayouoft (accessed January 2014).

Hollick, C. A. 1893. Preliminary contribution to our knowledge of the Cretaceous formation on Long Island and eastward. *Transactions of the New York Academy of Sciences* 12:222–237. Available at http://biodiversitylibrary.org/page/4560812 (accessed March 2014).

Hollick, C. A. 1894. Additions to the palaeobotany of the Cretaceous formation on Long Island. *Bulletin of the Torrey Botanical Club* 21:49–65. Available at http://biodiversitylibrary.org/page/710706 (accessed March 2014).

Hollick, C. A. 1900. Geological notes [Staten Island, New York]. *Proceedings of the Staten Island Institute of Arts and Sciences* 7(13):30–32. Available at http://biodiversitylibrary.org/page/31128092 (accessed March 2014).

Hollick, C. A. 1903. Field work during 1901 in the Cretaceous beds of Long Island. *Annual Report of the Regents - New York State Museum* 55:48–51. Available at http://biodiversitylibrary.org/page/39348105 (accessed March 2014).

Hollick, C. A. 1904. Additions to the paleobotany of the Cretaceous formation on Long Island, No. II. *Bulletin of the New York Botanical Garden* 3:403–418. Available at http://biodiversitylibrary.org/page/31044150 (accessed March 2014).

Hollick, C. A. 1906. The Cretaceous flora of southern New York, and New England. U.S. Geological Survey, Washington, DC. Monograph 50. Available at https://archive.org/details/cretaceousflorao01holl (accessed March 2014).

Hollick, C. A. 1908. Drift bowlders from the shore at Tottenville. Proceedings of the Staten Island Institute of Arts and Sciences 2:9. Available at http://biodiversitylibrary.org/page/30976156 (accessed March 2014).

Isbister, J. 1967. Geology and hydrology of northeastern Nassau County, Long Island, New York. U.S. Geological Survey, Washington, DC. Water-Supply Paper 1823. Scale 1:48,000. Available at http://pubs.er.usgs.gov/publication/wsp1825 (accessed March 2014).

Jepsen, G. L. 1960. A New Jersey mastodon. New Jersey State Museum, Trenton, New Jersey. Bulletin 6.

Kenworthy, J. P., and V. L. Santucci. 2003. Sagamore Hill National Historic Site. Page 30 *in* J. P. Kenworthy and V. L. Santucci. Paleontological resource inventory and monitoring: Northeast Coastal and Barrier Network. TIC# D-340. National Park Service, Denver, Colorado.

Kenworthy, J. P., and V. L. Santucci. 2006. A preliminary investigation of National Park Service paleontological resources in cultural resource contexts, Part 1: general overview. Pages 70–76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf (accessed January 2014).

Kimyai, A. 1966. New plant microfossils from the Raritan Formation (Cretaceous) in New Jersey. *Micropaleontology* 12(4):461–476.

Kimyai, A. 1970. Plant microfossils from the Raritan Formation (Cretaceous) in Long Island. *Pollen et Spores* 12(2):181–204.

Lubke, E. R. 1964. Hydrogeology of the Huntington-Smithtown area, Suffolk County, New York. U.S. Geological Survey, Washington, DC. Water-Supply Paper 1669-D. Available at http://pubs.er.usgs.gov/publication/wsp1669D (accessed March 2014).

Lucas, S. G. 1993. A Pleistocene horse from Connecticut. *The Mosasaur* 5:43–46.

MacClintock, D., and H. G. Richards. 1936. Correlation of Pleistocene marine and glacial deposits of New Jersey and New York. *Geological Society of America Bulletin* 47:289–338.

Maenza-Gmelch, T. E. 1997. Holocene vegetation, climate, and fire history of the Hudson Highlands, southeastern New York, USA. *The Holocene* 7:25–37.

McDonald, H. G., and C. E. Ray. 1990. The extinct sloth, *Megalonyx*, (Mammalia: Xenarthra), from the United States Mid-Atlantic continental shelf. *Proceedings of the Biological Society of Washington* 103(1):1–5. Available at http://biodiversitylibrary.org/page/34591492 (accessed March 2014).

Miller, K. G., P. J. Sugarman, J. V. Browning, M. A. Kominz, J. C. Hernandez, R. K. Olsson, J. D. Wright, M. D. Feigenson, and W. Van Sickel. 2003. Late Cretaceous chronology of large, rapid sea-level changes; glacioeustasy during the greenhouse world. *Geology* 31(7):585–588.

Miller, K. G., P. J. Sugarman, J. V. Browning, M. A. Kominz, R. K. Olsson, M. D. Feigenson, and J. C. Hernandez. 2004. Upper Cretaceous sequences and sea-level history, New Jersey coastal plain. *Geological Society of America Bulletin* 116(3–4):368–393.

National Park Service (NPS), Geologic Resources Inventory Program. 2010. Digital geologic map of Sagamore Hill National Historic Site and vicinity, New York (NPS, GRD, GRI, SAHI, SAHI digital map). NPS Geologic Resources Inventory Program. Lakewood, Colorado. Available at https://irma.nps.gov/App/Reference/Profile/2202595. (accessed April 2014).

Newberry, J. S. 1895. The flora of the Amboy clays. U.S. Geological Survey, Washington, DC. Monograph 26. Available at https://archive.org/details/floraofamboyclay01newb (accessed March 2014).

Oswald, W. W., D. R. Foster, E. D. Doughty, and D. Macdonald. 2010. A record of Holocene environmental and ecological changes from Wildwood Lake, Long Island, New York. *Journal of Quaternary Science* 25(6):967–974.

Penny, J. S. 1947. Studies on the conifers of the Magothy flora. *American Journal of Botany* 34(5):281–296.

Perlmutter, N. M., and J. J. Geraghty. 1963. Geology and ground-water conditions in southern Nassau and southeastern Queens counties, Long Island, New York. U.S. Geological Survey, Washington, DC. Water-Supply Paper 1613-A. Available at http://pubs.er.usgs.gov/publication/wsp1613A (accessed March 2014).

Perlmutter, N. M., and R. Todd. 1965. Correlation and foraminifera of the Monmouth Group (Upper Cretaceous) Long Island, New York. U.S. Geological Survey, Washington, DC. Professional Paper 483-I. Available at http://pubs.er.usgs.gov/publication/pp483I (accessed March 2014).

Petters, S. W., and R. K. Olsson. 1975. Upper Cretaceous foraminiferal biostratigraphy of the subsurface of the New Jersey coastal plain. *Abstracts with Programs - Geological Society of America* 7(1):105–106.

Pluhowski, E. J., and I. H. Kantrowitz. 1964. Hydrology of the Babylon-Islip area, Suffolk County, Long Island, New York. U.S. Geological Survey, Washington, DC. Water-Supply Paper 1768. Scale 1:62,500. Available at http://pubs.er.usgs.gov/publication/wsp1768 (accessed March 2014).

Richards, H. G., C. W. Cooke, H. F. Garner, B. F. Howell, J. A. Jeletzky, A. K. Miller, H. W. Miller, Jr., R. C. Ramsdell, J. B. Reeside, Jr., H. B. Roberts, and J. W. Wells. 1958. The Cretaceous fossils of New Jersey, Part 1. New Jersey Geological Survey, Bureau of Geology and Topography, Trenton, New Jersey. Bulletin 61. Available at http://www.state.nj.us/dep/njgs/enviroed/oldpubs/bulletin61-I.pdf (accessed March 2014).

Richards, H. G., C. W. Cooke, H. F. Garner, B. F. Howell, J. A. Jeletzky, A. K. Miller, H. W. Miller, Jr., R. C. Ramsdell, J. B. Reeside, Jr., H. B. Roberts, and J. W. Wells. 1962. The Cretaceous fossils of New Jersey, Part 2. New Jersey Geological Survey, Bureau of Geology and Topography, Trenton, New Jersey. Bulletin 61. Available at http://www.state.nj.us/dep/njgs/enviroed/oldpubs/bulletin61-II.pdf (accessed March 2014).

Ricketts, H. C. 1986. Examination in boreholes of the subsurface Gardiners Clay (Pleistocene), in the context of the Cretaceous-Quaternary section of Great Neck, Long Island, New York. *Northeastern Geology* 8(1–2):13–22.

Robinson, G. S., L. P. Burney, and D. A. Burney. 2005. Landscape paleoecology and megafaunal extinction in southeastern New York State. *Ecological Monographs* 75(3):295–315.

Rogers, W. B., M. Aparisi, and L. Sirkin. 1989. Search for clues to Mesozoic graben on Long Island. *Marine Geology* 90(1–2):119–124.

Rue, D. J., and A. Traverse. 1997. Pollen analysis of the Hackensack, New Jersey Meadowlands tidal marsh. *Northeastern Geology and Environmental Sciences* 19(3):211–215.

Russell, E. W. B. 1980. Vegetational change in northern New Jersey from precolonization to the present: a palynological interpretation. *Bulletin of the Torrey Botanical Club* 107(3):432–446.

Russell, E. W. B., R. B. Davis, R. S. Anderson, T. E. Rhodes, and D. S. Anderson. 1993. Recent centuries of vegetational change in the glaciated north-eastern United States. *Journal of Ecology* 81:647–664.

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado.

Sirkin, L. A. 1967. Late-Pleistocene pollen stratigraphy of western Long Island and eastern Staten Island, New York. Pages 249–274 *in* E. J. Cushing and H. E. Wright, editors. Quaternary paleoecology. Yale University Press, New Haven, Connecticut. International Association for Quaternary Research, Proceedings of the 7th Congress.

Sirkin, L. A. 1971. Surficial glacial deposits and postglacial pollen stratigraphy in central Long Island, New York. *Pollen et Spores* 13(1):93–100.

Sirkin, L. 1986. Pleistocene stratigraphy of Long Island, New York. Pages 6–21 *in* Cadwell, D. H., editor. The Wisconsinan Stage of the First Geological District, eastern New York. New York State Museum, Albany, New York. Bulletin 455. Available at https://www.nysm.nysed.gov/pubsforsale/detail.cfm?pubID=4936 (accessed March 2014).

Soren, J. 1971. Ground-water and geohydrologic conditions in Queens County, Long Island, New York. U.S. Geological Survey, Washington, DC. Water-Supply Paper 2001-A. Scale 1:62,500. Available at http://pubs.er.usgs.gov/publication/wsp01A (accessed March 2014).

Soren, J. 1978. Subsurface geology and paleogeography of Queens County, Long Island, New York. U.S. Geological Survey, Washington, DC. Water-Resources Investigations 77-34. Available at http://pubs.er.usgs.gov/publication/wri7734 (accessed March 2014).

Stoffer, P. 2003. Geology of the New York City region: a preliminary regional field-trip guidebook. U.S. Geological Survey, Reston, Virginia. Available at http://3dparks.wr.usgs.gov/nyc/index.html (accessed March 2014; online only).

Stoffer, P. W., P. Messina, and J. A. Chamberlain, Jr. 1996. Fossils from beaches in Gateway National Recreation Area: implications for the geologic history of the New York Bight. *Abstracts with Programs - Geological Society of America* 28(7):A–143.

Stoffer, P. W., P. Messina, and J. A. Chamberlain, Jr. 1999. Fossiliferous concretions from New York Bight beaches: implications for late Pleistocene and Holocene coastal environments around Sandy Hook and western Long Island. Pages 119–143 *in* J. H. Puffer, editor. New Jersey beaches and coastal processes from geologic and environmental perspectives. Geological Association of New Jersey, Newark, NJ. Annual Field Conference 16.

Stoffer, P. W., J. A. Chamberlain, Jr., R. Scal, and P. Messina. 2005. Late Quaternary and early Holocene fossils from New York City beaches: implications for stability in coastal environments in western Long Island and New Jersey. *Abstracts with Programs - Geological Society of America* 37(7):366.

Sugarman, P. J., K. G. Miller, D. Bukry, and M. D. Feigenson. 1995. Uppermost Campanian-Maestrichtian strontium isotopic, biostratigraphic, and sequence stratigraphic framework of the New Jersey coastal plain. *Geological Society of America Bulletin* 107(1):19–37.

Thornberry-Ehrlich, T. L. 2011. Geologic resource inventory scoping summary, Sagamore Hill National Historic Site. National Park Service, Geologic Resources Division, Denver, Colorado. Available at http://nature.nps.gov/geology/inventory/publications/s_summaries/SAHI_Scoping_Summary_2011-0927.pdf (accessed March 2014).

Upson, J. E. 1970. The Gardiners Clay of eastern Long Island, New York: a reexamination. Pages B157–B160 in Geological Survey research 1970, Chapter B. U.S. Geological Survey, Washington, DC. Professional Paper 700-B. Available at http://pubs.er.usgs.gov/publication/pp700B (accessed March 2014).

Veatch, A. C. 1906. Outlines of the geology of Long Island. Pages 15–52 *in* Veatch, A. C., C. S. Slichter, I. Bowman, W. O. Crosby, and R. E. Horton. Underground water resources of Long Island, New York. U.S. Geological Survey, Washington, DC. Professional Paper 44. Available at http://pubs.er.usgs.gov/publication/pp44 (accessed March 2014).

Weiss, L. 1954. Foraminifera and origin of the Gardiners Clay (Pleistocene), eastern Long Island, New York. U.S. Geological Survey, Washington, DC. Professional Paper 254-G. Available at http://pubs.er.usgs.gov/publication/pp254G (accessed March 2014).

Weller, S. 1907. A report on the Cretaceous paleontology of New Jersey. Geological Survey of New Jersey, Trenton, New Jersey. Paleontology Series 4. Available at https://archive.org/details/reportonpaleontopt104newjiala (accessed March 2014).

Whitmore, F. C., Jr., K. O. Emery, H. B. S. Cooke, and D. J. P. Swift. 1967. Elephant teeth from the Atlantic Continental Shelf. *Science* 156(3781):1477–1481.

Woodworth, J. B. 1901. Pleistocene geology of portions of Nassau County and Borough of Queens. *Bulletin of the New York State Museum* 48:618–670. Available at http://biodiversitylibrary.org/page/34879415 (accessed March 2014).

Additional References

Brunner, J., J. Kenworthy, and V. Santucci. 2010. Unauthorized fossil collecting from National Park Service shorelines: servicewide policy and perspectives. Pages 319–323 *in* S. Weber, editor. Rethinking protected areas in a changing world: proceedings of the 2009 George Wright Society Conference. The George Wright Society, Hancock, Michigan. Available at http://www.georgewright.org/0956brunner.pdf (accessed February 2014).

Coch, N. K., and D. Weiss. 1989. Environmental geology and geological development of the lower Hudson Estuary and New York Harbor. Pages 15–25 *in* C. A. Baskerville, editor. Environmental, engineering, and urban geology in the United States. Volume 1, New York and Washington, D.C.: geology and engineering geology of the New York metropolitan area. Field trips for the 28th International Geological Congress. American Geophysical Union, Washington, DC. Field Trip T361.

Doriski, T. P., and F. Wilde-Katz. 1983. Geology of the “20-foot” clay and Gardiners Clay in southern Nassau and southwestern Suffolk counties, Long Island, New York. U.S. Geological Survey, Reston, Virginia. Water-Resources Investigations 82-4056. Available at http://pubs.er.usgs.gov/publication/wri824056 (accessed March 2014).

Ellwood, B. B. 1996. Geology and America's National Park areas. Prentice Hall, Upper Saddle River, New Jersey.

Gustavson, T. C. 1976. Paleotemperature analysis of the marine Pleistocene of Long Island, New York, and Nantucket Island, Massachusetts. *Geological Society of America Bulletin* 87(1):1–8.

Mayor, A. 2005. Fossil legends of the first Americans. Princeton University Press, Princeton, New Jersey.

Minard, J. P. 1969. Geology of the Sandy Hook Quadrangle in Monmouth County, New Jersey. U.S. Geological Survey, Washington, DC. Bulletin 1276. Available at http://pubs.er.usgs.gov/publication/b1276 (accessed March 2014).

Olsen, S. J. 1971. Zooarchaeology: animal bones in archaeology and their interpretation. Addison-Wesley Publishing Company, New York City, New York.

Rampino, M. R., and J. E. Sanders. 1981. Upper Quaternary stratigraphy of southern Long Island, New York. *Northeastern Geology* 3(2):116–128.

Sanford, J. H. 1938. Report on the geology and hydrology of Kings and Queens counties, Long Island. State of New York Department of Conservation, Division of Water Power and Control, Water Power and Control Commission, Albany, New York. Bulletin GW-7. Available at https://ia601000.us.archive.org/18/items/usgswaterresourcesnewyork-bull_gw_7/bull_gw7.pdf (accessed March 2014).

Sirkin, L. 1996. Field trip 1: Deglaciation of central Long Island. Pages 159–165 *in* Geology of Long Island and metropolitan New York. SUNY at Stony Brook, Long Island Geologists, Stony Brook, New York. Available at http://dspace.sunyconnect.suny.edu/handle/1951/48042?show=full (accessed March 2014).

Smolensky, D. A., H. T. Buxton, and P. K. Shernoff. 1990. Hydrologic framework of Long Island, New York. U.S. Geological Survey, Reston, Virginia. Hydrologic Investigations Atlas 709. Scale 1:250,000. Available at http://pubs.er.usgs.gov/publication/ha709 (accessed March 2014).

Suter, R., W. de Laguna, and N. M. Perlmutter. 1949. Mapping of geologic formations and aquifers of Long Island, New York. State of New York Department of Conservation, Division of Water Power and Control, Water Power and Control Commission, Albany, New York. Bulletin GW-18. Available at https://archive.org/details/mappingofgeologi00sute (accessed April 2014).

Swarzenski, W. V. 1963. Hydrogeology of northwestern Nassau and northeastern Queens counties, Long Island, New York. U.S. Geological Survey, Washington, DC. Water-Supply Paper 1657. Available at http://pubs.er.usgs.gov/publication/wsp1657 (accessed March 2014).

Veatch, A. C. 1906. Outlines of the geology of Long Island. Pages 15–52 *in* Veatch, A. C., C. S. Slichter, I. Bowman, W. O. Crosby, and R. E. Horton. Underground water resources of Long Island, New York. U.S. Geological Survey, Washington, DC. Professional Paper 44. Available at http://pubs.er.usgs.gov/publication/pp44 (accessed March 2014).

Waage, K. M., C. MacClintock, and L. J. Hickey. 2001. Post-glacial fossils from Long Island Sound off West Haven, Connecticut. Postilla 225. Available at http://www.biodiversitylibrary.org/part/83201#/summary (accessed March 2014).

Data Sets

Sagamore Hill National Historic Site Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Sagamore Hill National Historic Site Digital Geologic Map
2010–present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active.
https://irma.nps.gov/App/Reference/Profile?Code=2165107.

Thomas Stone National Historic Site

Thomas Stone National Historic Site (THST) preserves Haberdeventure, the 1771 estate of Thomas Stone, one of the signers of the Declaration of Independence and a delegate to the Continental Congress (THST Figure 1). THST was authorized November 10, 1978. It encompasses 132.84 ha (328.25 acres), all but 2.54 ha (6.28 acres) of which are federal.

Geologic Background

THST is located in south-central Charles County, southern Maryland. It is adjacent to the Port Tobacco River on the east, which drains into the Potomac River to the south. Hoghole Run, which lies along the western boundary of the historic site, leads into the Port Tobacco River (THST Figure 2). The historic site is near the town of Port Tobacco, which had been a large seaport before the river silted. St. Charles is less than 14 km (9 miles) to the northeast. The geology of the region including THST has been described in Clark (1888), Maryland Geological Survey (1901), Dryden and Overbeck (1948), Glaser (1984), McCartan et al. (1996), Kenworthy and Santucci (2003), Thornberry-Ehrlich (2005, 2009), and NPS (2006). The NPS Geologic Resources Division coordinated a Geologic Resource Inventory workshop for THST in July 2005 (Thornberry-Ehrlich 2005) and produced a digital geologic map for the historic site in 2006 (NPS 2006) and a geologic resource evaluation report in 2009 (Thornberry-Ehrlich 2009). The initial paleontological resource inventory and summary was prepared by Kenworthy and Santucci (2003).



THST Figure 1. Haberdeventure, the Thomas Stone estate (NPS).

Southwestern Maryland has been tectonically quiet since North America rifted from Africa and Europe in the early Mesozoic (see the Appendix for a geologic time scale). There has been one major disruption of the rocks and sediments in the vicinity since then: around 35 Ma (million years ago), a meteor impacted the future Chesapeake Bay (Poag 1997; Johnson etal. 1998; Powars and Bruce 1999). The resulting crater was up to 90 km (56 miles) across and 1.3 km (0.8 miles) deep, with an area of 6,400 km^2 (2,500 $miles^2$) (Poag 1997) (but see Collins and Wünnermann [2005], which interprets the original structure as less than half that size). The outer rim of the structure is south of THST, so the greatest effects of the impact were somewhat remote from the area of the historic site. This impact occurred between the deposition of two formations visible at THST, the Early Eocene-age Nanjemoy Formation and the Early–Middle Miocene-age Calvert Formation.

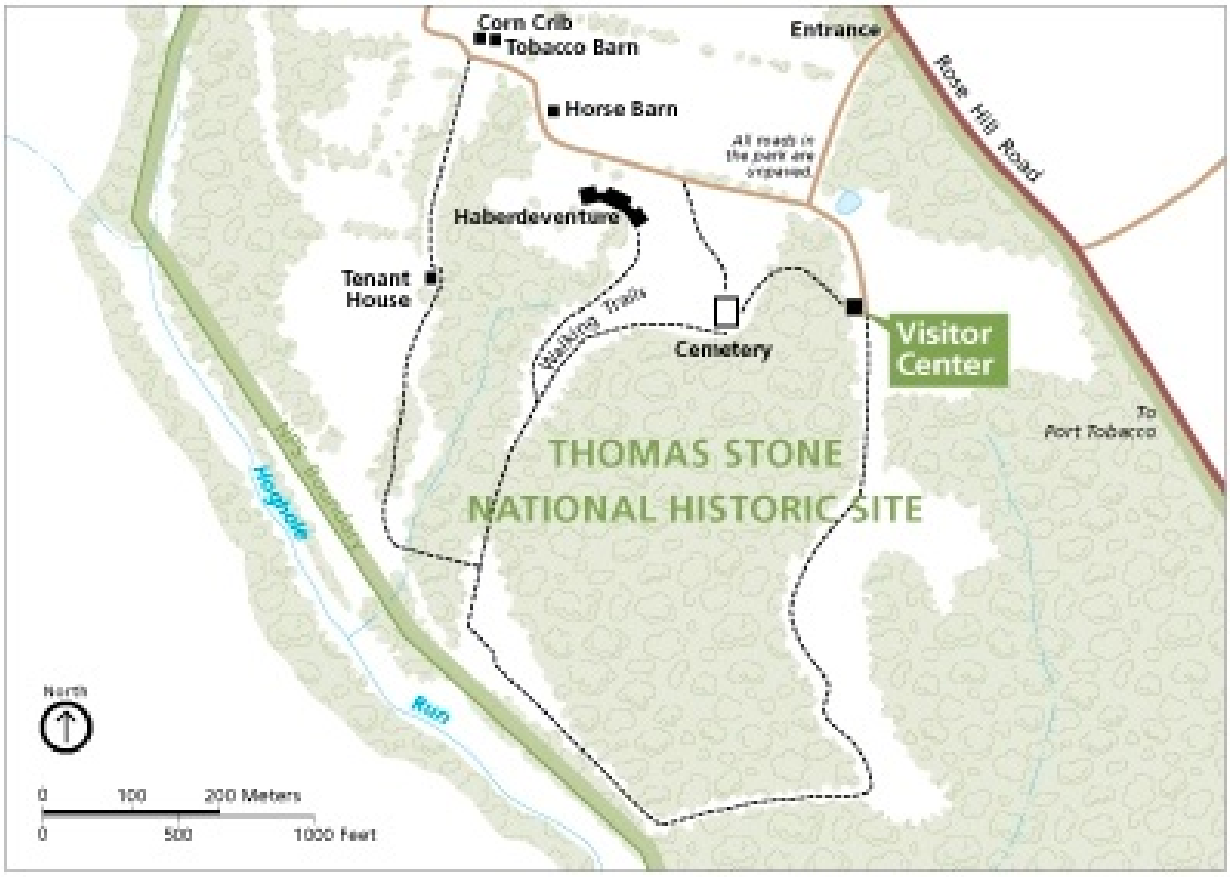
Surficial geologic units at THST belong to four general periods of deposition: the Early Eocene, about 50 Ma; the Early–Middle Miocene, about 20 to 15 Ma; an uncertain time between the Middle Miocene and middle Pleistocene; and the past ten thousand years. The oldest deposits belong to the Nanjemoy Formation, a shallow marine formation. The Nanjemoy Formation's sea arrived from the northeast. Topographic highs were present south and east of the Nanjemoy basin, preventing mixing with Gulf Coast faunas (Ward and Powars 1989). The topography makes a map of the formation's deposition resemble a "dogleg" (see for example Ward [1985a]). This topographic arrangement persisted for millions of years; the succeeding Miocene Calvert Formation traces a similar "dogleg" going west across Delaware and then turning south through eastern Virginia east of the Fall Line, although eventually the sea overtopped the high in the Delmarva area and spread more widely (Ward and Powars 1989).

Above the Nanjemoy Formation is the Calvert Formation, deposited after a lengthy hiatus that includes most of the Eocene and all of the Oligocene. This formation is well-known from the western Chesapeake Bay coast of Maryland (the Calvert Cliffs). It reflects the numerous fluctuations of a shallow sea stretched across the northern Chesapeake Bay and surrounding lowlands. Shallow and deeper deposition alternated (Gibson 1982, 1983; Ward and Powars 1989). The climate was warmer than present (Gottfried et al. 1994), but the growth and shrinking of polar ice appears to have been important enough to affect sea level. Quasi-cyclic deposition of this formation and those above it on the Calvert Cliffs suggest the influence of glaciation on sea level in response to cyclic changes of the Earth's orbital parameters (Milankovitch cycles (Browning et al. 2006; Vogt and Parrish 2011). Stable isotopes in the bones of cetaceans (whale, dolphins, and porpoises) suggest substantial ice volume variations during the Miocene, although this is controversial (Barrick et al. 1992), and isotopes in fish and shark teeth and bones show opposite patterns (Barrick et al. 1993).

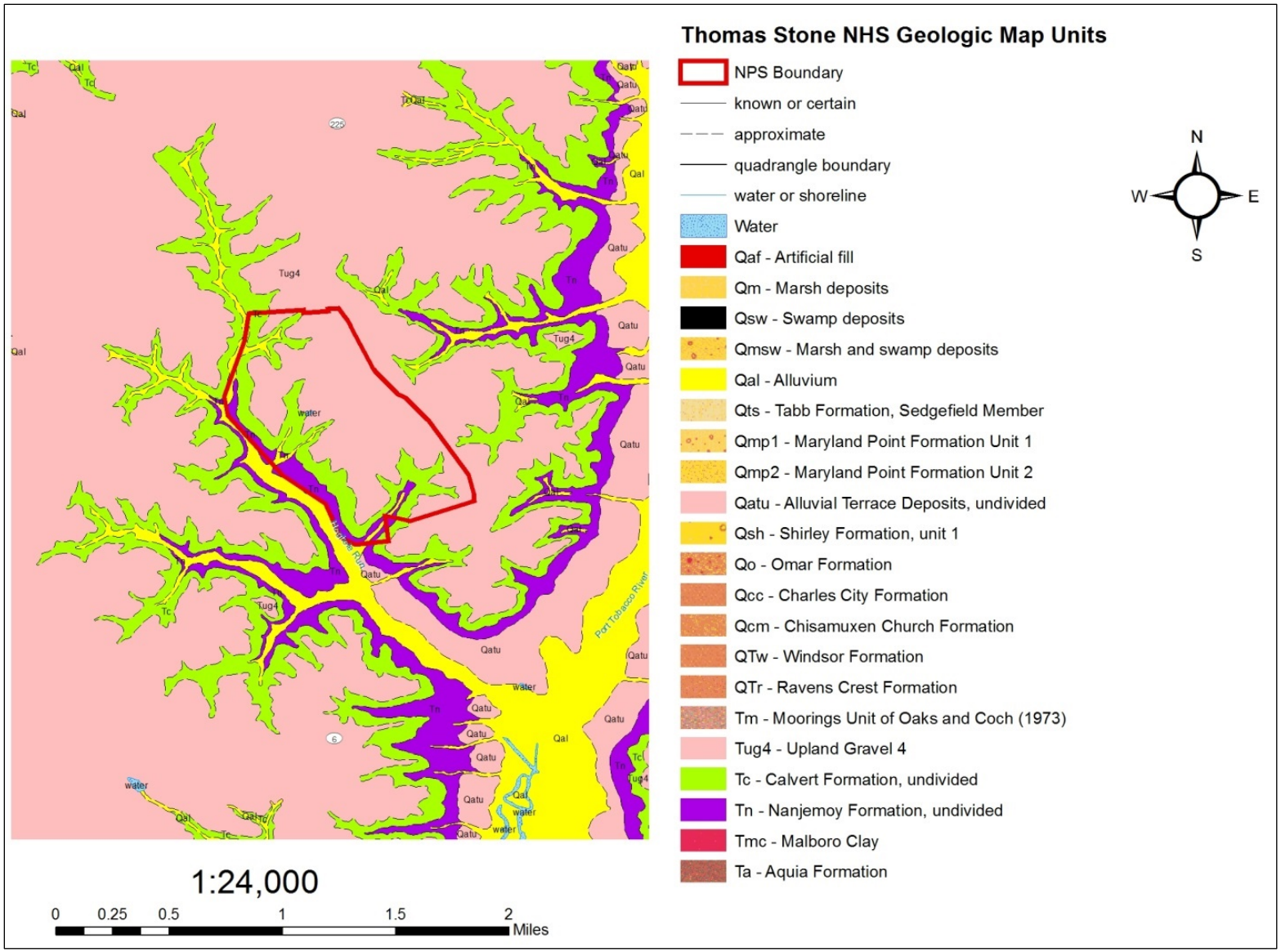
Following the deposition of the Calvert Formation, a river system, probably an ancestral form of the Potomac River, left several beds of coarse deposits across the higher ground of southwestern Maryland (Hack 1955; Schloe 1957). One such deposit of uncertain age is present in THST (Glaser 1984). The most recent deposition in the historic site dates from the past ten thousand years, after sea level rose following the most recent glacial maximum. Humans had arrived in the area sometime shortly before this period of deposition; projectile points of the Clovis culture (about 12,000 to

10,000 years old) have been found in counties of Virginia just across the Potomac River (McCary 1986).

Geological formations exposed in THST include the following, in ascending order: the Nanjemoy Formation (Lower Eocene) of the Pamunkey Group; the Calvert Formation (Lower–Middle Miocene) of the Chesapeake Group; unnamed upland gravels (the Brandywine Formation of Glaser [1984]); and unnamed Holocene alluvium (Glaser 1984; NPS 2006) (THST Figure 3, Table 1). None of these formations are known to be fossiliferous within THST, but they are known to be fossiliferous in the vicinity. There is a record of a possible bone fragment found in the historic site, but its identity has not been confirmed and the geologic horizon is unknown.



THST Figure 2. Geography of central THST (NPS).



THST Figure 3. Schematic geological map of THST. Map graphic adapted from digital geologic map data available at the following URL: https://irma.nps.gov/App/Reference/Profile?Code=1041110.

THST Table 1. Summary of THST stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text.

Formation	Age	Fossils Within THST	Depositional Environment
Quaternary sediments	Holocene	None to date; plant fossils are most likely	Fluvial, overbank, and marsh
Upland gravel	Late Miocene?–early Pleistocene?	None to date; plant fossils are most likely	Fluvial
Calvert Formation	Early–Middle Miocene	None to date; microfossils, mollusks, shark teeth, and marine mammal bones are most likely	Shallow marine
Nanjemoy Formation	Early Eocene	None to date; mollusks are most likely	Shallow marine

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within THST. However, they are known to preserve fossils elsewhere, and future field investigations within the historic site may locate fossils in one or more of them.

Jason Kenworthy (GRD) and Rijk Moräwe (GEWA–THST; now Organ Pipe Cactus National Monument) found a possible bone fragment in a stream leading to Hoghole Run within THST. The geological provenance of the specimen is undetermined, but both the Nanjemoy and Calvert formations are present in the area (Kenworthy and Santucci 2003). Because of the uncertainty of whether it is a fossil, THST has not been listed as a fossil park (J. Kenworthy, pers. comm., September 2012).

Pamunkey Group: Nanjemoy Formation (Lower Eocene)

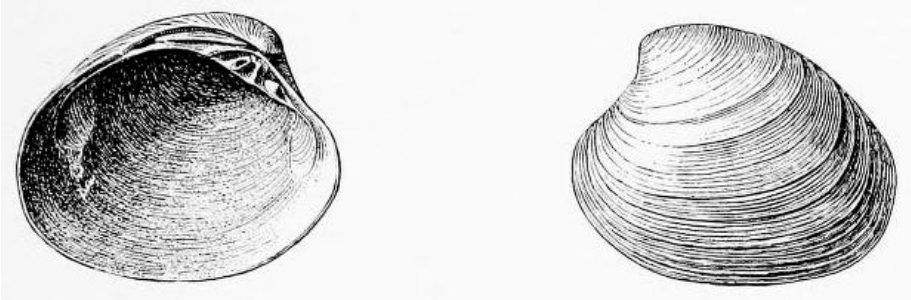
The Nanjemoy Formation is a shallow marine unit that includes two members, the Potapaco Member and overlying Woodstock Member. The two members differ most visibly in the amount of clay: there is less clay in the Woodstock Member than the Potapaco Member (McCartan et al. 1996; Mixon et al. 2000a). Coincidentally, the name of the Potapaco Member is a reference to Port Tobacco (Clark and Martin 1901a). In the Port Tobacco 7.5 minute quadrangle, the Nanjemoy Formation is between 1 and 30 m (3 and 100 ft) thick and is mostly composed of very fine to medium sand that is poorly sorted and includes significant clay and glauconite (greensand). It is medium gray to dark greenish gray when freshly exposed, weathering to paler grays and tans. Sand is interbedded with thin beds of dark gray silty clay. Fossils are common, with burrows throughout and the bivalve *Venericardia* as the most common shelly fossil. The depositional environment in the quadrangle is interpreted as an inner shelf with relatively shallow water. It is mapped as present in the lower part of the Hoghole Run ravine, which forms the western boundary of the historic site (Glaser 1984). It is similar to the overlying Calvert Formation, but is more silty compared to the sandier overlying unit (Self-Trail 2011).

The Nanjemoy Formation was named by Clark and Martin (1901a), but its sediments were recognized earlier as part of the Pamunkey Formation, later raised to a group. At that time, the deposits were divided into beds or zones (Clark 1896). These divisions are no longer commonly used

except along the Potomac River (Ward 1985a). The Nanjemoy Formation was given beds 10 to 17, with beds 10 to 15 in the Potapaco Member and beds 16 to 17 in the Woodstock Member (Clark and Martin 1901a). The base of Bed 10 was later designated the Marlboro Clay and removed from the Nanjemoy Formation (Ward 1984). The Potapaco Member is sometimes divided into informal units following Ward's A-B-C-D scheme (see Ward [1984, 1985a, 1989]; Ward and Powars [1989]), with refinements (Weems and Grimsley 1999; Mixon et al. 2000a). The lower and upper contacts of the formation are disconformable, as well as the contacts between the Potapaco and Woodstock members, and between major beds in the Potapaco Member (Weems and Grimsley 1999; Mixon et al. 2000a). There are many minor depositional hiatuses in the formation, probably from small marine transgressions (the sea advancing over the land) (Mixon et al. 2000a), and the informal units of the Potapaco Member are probably the result of separate transgressions (Ward 1984).

The Nanjemoy Formation was deposited during the Early Eocene, perhaps about 54.5 to 49.5 Ma, although the many internal hiatuses mean it was not deposited continuously over that time (Weems and Grimsley 1999). It is typically assigned to the Ypresian series (56.0 to 47.8 Ma) (Goodman 1984; Edwards et al. 1984). The mammals pertain to the Wasatchian North American Land Mammal Age (approximately 55.8 to 50.3 Ma). Deposition occurred on a shallow marine shelf (Ward 1984), with clayey beds as quiet water and sandy beds reflecting more wave or current activity (McCartan et al. 1996). As noted above, there were probably numerous small-scale marine transgressions and regressions (marine retreats) throughout deposition (Ward 1984; Mixon et al. 2000a). The rate of deposition was slow (Dischinger 1987). The climate is thought to have been warm temperate (Ward and Powars 1989). Deposition of the formation was followed by a marine regression and a period of exposure to the open air (Ward and Powars 1989).

The Nanjemoy Formation is not currently known to be fossiliferous in THST, but it is fossiliferous in the immediate vicinity. Clark (1888) observed common examples of a bivalve he identified as *Cardita planicosta* (now generally in the genus *Venericor* or *Venericardia*) in the Port Tobacco region. In the vicinity of Port Tobacco, bivalves (THST Figure 4, 5), scaphopods, and gastropods have been found in the Potapaco Member, and the upper Potapaco Member has a distinct fauna (Clark and Martin 1901a). A characteristic Nanjemoy Formation fossil, the bivalve *Venericardia potapacoensis*, was named from a specimen found in the Potapaco Member west of Port Tobacco (THST Figure 5) (Clark and Martin 1901b). Eastman (1901) reported fish otoliths from Port Tobacco.



THST Figure 4. Two views of the bivalve *Meretrix ovata* var. *ovata*, based on a specimen recovered from the Nanjemoy Formation west of Port Tobacco (Maryland Geological Survey 1901:Plate XXXIV).

Both members of the Nanjemoy Formation have yielded a variety of fossils. In the Potapaco Member, microfossils include calcareous nannofossils, foraminifera ("amoebae with shells"), dinoflagellates (single-celled organisms that move using one or more whip-like flagella), and pollen (Ward 1984). Plant body fossils include lignite (Vredenburg 1985), wood (Ward 1989), and angiosperm fruit and seeds, including the common Nanjemoy Formation fossil fruit *Wetherellia* (Tiffney 1999). These fossil fruits are spherical and about 9 to 17 mm (0.4 to 0.7 in) in diameter (Tiffney 1984). Invertebrates are represented by body fossils of bryozoans (moss animals), bivalves, gastropods, scaphopods (tusk shells) (Clark and Martin 1901a), and ostracodes (seed shrimp) (Ward 1984), and trace fossils such as burrows and bioturbation (disruption of sediment by burrowers) (Ward and Powars 1989). Mollusk diversity is relatively low in the Potapaco Member, with the bivalve *Venericardia potapacoensis* (THST Figure 5) being by far the most abundant form, and leaching is common, leading to natural molds and casts of shells (Ward 1984). Vertebrates are represented by sharks (Kent 1999a), rays and relatives (Kent 1999b), bony fish (Weems 1999a), turtles, lizards, sea snakes, crocodilians (Weems 1999b), a small fauna of sea and land birds (Olson 1999), and a handful of terrestrial mammals, most of which belonged to now-extinct lineages of early placental mammals (Rose 1999, 2010).



THST Figure 5. The holotype of the common Nanjemoy Formation bivalve *Venericardia potapacoensis*, from the Potapaco Member west of Port Tobacco (Maryland Geological Survey 1901:Plate XXXL).

One of the best fossil sites in the Potapaco Member and the formation as a whole is the Fisher/Sullivan site in the "B bed" of the member, about 38 km (24 miles) southwest of THST near Muddy Creek near Fredericksburg, Virginia (Weems and Grimsley 1999). This site has yielded a variety of plants, invertebrates, and marine, freshwater, and terrestrial vertebrates. It is notable for its terrestrial fossils, having yielded the only known Lower Eocene mammal fauna on the East Coast (Rose 2010). Plants are represented by fruit and seeds of nine species of mangroves, vines, trees, and shrubs, similar to plants in the Lower Eocene London Clay in England (Tiffney 1999), and wood fragments (Weems and Grimsley 1999). Invertebrates are represented by shells, including *Venericardia potapacoensis*, and there are also burrows (Weems and Grimsley 1999). Cartilaginous and bony fish include sharks (Kent 1999a), rays, guitarfish, sawfish (Kent 1999b), sturgeons, gars, pycnodonts, bowfins, bonytongues, elopiforms, eels, catfish, aulopiforms, perciforms, and tetradontiforms (Weems 1999a). Reptiles and birds include turtles, tortoises, lizards, sea snakes, crocodilians (Weems 1999b), and eleven species of birds, including pseudodontorns (large extinct seabirds with tooth-like nodes in their beaks), shorebirds, and land birds, implying nearby tropical forests (Olson 1999). Mammals are represented by marsupials (Rose 2010), nyctitheriid insectivores, rodents, pantolestid and tillodont cimolestans (extinct early placental mammals), miacids (extinct

marten-like carnivores), hyopsodont condylarths (small extinct insectivores), and the extinct tapir-like *Homogalax* (Rose 1999, 2010). Many of the plants and vertebrates have European affinities (Kent 1999a, 1999b; Tiffney 1999; Weems 1999a, 1999b).

The Woodstock Member has yielded slightly different fossils. Mollusk diversity increased, with *Venericardia ascia* becoming the most characteristic form (Ward 1985a). Microfossils include acritarchs (organic microfossils that cannot be classified as anything else) (Goodman 1979), calcareous nannofossils (DiMarzio 1985), foraminifera, dinoflagellates, spores, and angiosperm pollen (Goodman 1979). Plant macrofossils include logs, branches, and nuts (Ward 1984), particularly of *Wetherellia* (Ward 1985a). Plant fossils are most common in the lower part of the member (Ward 1985a). Invertebrates are represented by corals, bivalves, cephalopods (squids, octopuses, and relatives), gastropods, scaphopods, and ostracodes (Clark and Martin 1901a). Vertebrates include sharks, rays (Clark and Martin 1901a; Horman and Weems 1976; Weems 1985), bony fish (Horman and Weems 1976; Weems and Horman 1983), turtles (Horman and Weems 1976), the sea snake *Palaeophis* (Weems 1985), and crocodilians (Horman and Weems 1976). Finally, there are also reports of worm tubes (Dischinger 1987) and echinoids (sea urchins) (Zachos and Levin 2010), not assigned to a specific member.

Chesapeake Group: Calvert Formation (Lower–Middle Miocene)

The Calvert Formation is an extensively fossiliferous shallow marine formation, generally divided, in ascending order, into the Fairhaven, Plum Point, and Calvert Beach members. In the Port Tobacco quadrangle, the Calvert Formation is between 1 and 21 m (3 and 70 ft) thick and is composed of very fine to fine sand, silt, diatomaceous silt, and clay. It is olive green or brown to gray when freshly exposed, weathering to tans and browns. The lower part of the formation is a diatomaceous silt bed up to 3 m (10 ft) thick, with the rest of the formation a more homogeneous unit of sand and silty sand. Fossils include burrows and molds and casts of mollusks. All of the formation in the quadrangle is thought to belong to the Fairhaven Member. The depositional environment in the quadrangle is interpreted as a restricted marine basin in relatively deep water. It is mapped as present in the upper part of the Hoghole Run ravine (Glaser 1984).

The Calvert Formation was described by Shattuck (1904), who also divided the formation into two members. The lower member, composed of sand overlain by a thicker section of diatomaceous deposits, was named the Fairhaven Diatomaceous Earth, generally known today more simply as the Fairhaven Member. The clay, sand, and sandy clay above it was named the Plum Point Marl Member, also known as the Plum Point Member. Shattuck divided the Miocene sediment of the Chesapeake Group into a number of zones. The Fairhaven Member included his Zones 1 through 3, and the Plum Point Member included Zones 4 through 15. Zone 16 at the base of the overlying Choptank Formation, named the Calvert Beach Member by Gernant (1970), was later moved into the Calvert Formation under that name, becoming the upper member of the Calvert Formation (Ward 1985b). This member now includes Zones 14 to 16 (Ward 1985b). Gibson (1982, 1983) introduced new terminology (the Dunkirk beds and the Popes Creek Sand Member) for Zones 1 and 2, but these names have not generally been accepted. The most recent assessment of the formation, Ward and Andrews (2008), formally designated the zones as beds within the formation. The three widely

recognized members (Fairhaven, Plum Point, and Calvert Beach members) have unconformable contacts and were deposited in overlapping but distinct basins (Mixon et al. 2000a). The upper and lower contacts of the formation are also disconformable (Ward 1989).

The Calvert Formation is a shallow marine unit. Muddy inner to middle shelf deposits alternate with heavily fossiliferous shoreface and inner shelf sands (Godfrey and Smith 2010). Diatomaceous sediments represent deposition in deeper basins (Ward and Powars 1989). The formation is punctuated with disconformities (Kidwell and Jablonski 1983), and is interpreted as having been deposited under multiple marine pulses over time. Ward and Powars (1989) interpreted the Fairhaven Member as including two marine pulses (Bed 1 and Bed 2 into lower 3), and the Plum Point and Calvert Beach members as four more pulses (Beds 4 to 9, 10 to 11, 12 to 13, and 14 to 16) (their description is somewhat contradictory, describing the formation in terms of three pulses at another point). Deposition appears to have been somewhat cyclic, with sequences on the order of 1.27 million years in duration, probably due to glacial effects on sea level in response to the cycles of the Earth's orbital parameters (Browning et al. 2006; Vogt and Parrish 2011).

The Fairhaven Member (including the Popes Creek Sand) was first deposited in middle-shelf settings beneath an open ocean, at depths of up to perhaps 80 m (260 ft). Sea level then decreased to less than 30 m (100 ft), and deposition occurred in sublittoral, shallow marine, and restricted marginal settings (Gibson 1982, 1983). Microfossils suggest that there was marine upwelling (Palmer 1986). The overlying Plum Point Member was deposited in a variety of shallow marine settings under a fluctuating sea level. During middle Plum Point time (beds 5 to 9), a delta system formed in the southern New Jersey area and influenced deposition. In the THST area, the lower Plum Point Member is interpreted as having been deposited in a protected embayment setting (Gibson 1982, 1983). Depth increased after this, reaching 40 to 50 m (130 to 160 ft) in beds 11 and 12 (Godfrey and Smith 2010). The prevailing climate during deposition of the formation is thought to have been warmer than the present, with subtropical to warm tropical estuarine and shallow marine waters (Gottfried et al. 1994), and a warm temperate coastal flora, like that found today on the coasts of South Carolina and Georgia, or along the Gulf from Florida to Texas (Berry 1916). Extensive shell beds are present in several zones, and plausibly represent cyclic deposition tied to the Earth's orbital parameters (i.e. Milankovitch cycles) (Vogt and Eshelman 1987). The presence of fossils of terrestrial turtles and mammals shows the existence of land nearby (Kellogg 1966). Petrified wood and land mammal fossils represent terrestrial remains that were washed out to sea (Vogt and Eshelman 1987).

The age of the formation is generally considered to be Early to Middle Miocene, but absolute dating has proven difficult. A sampling of different authors provides almost as many estimates as authors. Part of the difficulty is the numerous internal disconformities. It may encompass deposition from about 22 or 21 Ma to about 14 or 13 Ma, with substantial internal hiatuses (Gottfried et al. 1994; Dooley and Fraser 2005; Wijnker and Olson 2009). The terrestrial mammals documented from this formation range in age from the Late Arikareean or Early Hemingfordian North American Land Mammal Ages (between approximately 23.8 and 17.5 Ma) to the Late Barstovian (14.8 to 12.5 Ma) (Wright and Eshelman 1987).

The Calvert Formation is exceedingly fossiliferous in general, although it is not known to be fossiliferous within THST at this time. It has yielded diverse types of fossils from marine, freshwater, and terrestrial settings. The best-known deposits are found at the Calvert Cliffs of Maryland. These cliffs, made up of the Calvert Formation and overlying Choptank and St. Mary's formations, present the best Middle Miocene record in the northeastern United States (Vogt and Eshelman 1987). The presence of fossils of terrestrial turtles and mammals shows the existence of land nearby (Kellogg 1966). Petrified wood and land mammal fossils represent terrestrial remains that were washed out to sea (Vogt and Eshelman 1987). Microfossils are represented by calcareous nannofossils (McLaughlin et al. 2008), foraminifera, radiolarians (another group of "amoebae with shells"), diatoms (Shattuck 1904), silicoflagellates (another type of algae that form body structures out of silica) (Tynan 1957), other siliceous "algae" (Tynan 1960), dinoflagellates (Gibson et al. 1980), fern spores, and pollen of conifers and angiosperms (Groot 1998; McLaughlin et al. 2008). Reworked Eocene foraminifera are sometimes found at the base of the formation (Gibson 1983). In terms of pollen, oak, hickory, and pine pollen are most common, with some subtropical and tropical exotic forms, and relatively few reworked Cretaceous and Paleocene grains (Groot 1992). Plants are represented by the pollen and spores mentioned above, and by body fossils of ferns, cypresses, pines, and about two dozen species of dicot angiosperms, dominated by legumes and oaks (Berry 1916). Invertebrates are represented by sponges (Tynan 1957), corals, hydrozoans (relatives of jellyfish and corals), bryozoans, brachiopods (lamp shells), chitons, bivalves, cephalopods (squids, octopuses, and relatives), gastropods, scaphopods, annelid worm tubes, barnacles, ostracodes, crabs (Shattuck 1904) and echinoids (Schoonover 1941). Shells are sometimes leached away, being represented by molds and casts (Shattuck 1904). Trace fossils are represented by bioturbation (disruption of sediments by burrowers) (McCartan et al. 1996), burrows (Glaser 1984), snail borings (Thomas 1976; Kelley 1982, 1992), shark teeth marks on bones (Kellogg 1966), invertebrate pellets (Miller et al. 1998), and vertebrate coprolites (fossil feces) (Godfrey and Smith 2010).

Vertebrates are represented by sharks, rays (Shattuck 1904), bony fish (Kimmel and Purdy 1985), salamanders (Weems and George 2013), reptiles (Shattuck 1904), birds (Olson 1985a; Rasmussen 1998), marine mammals (Shattuck 1904; Whitmore 1985; Gottfried et al. 1994), and terrestrial mammals (Tedford and Hunter 1984; Emry and Eshelman 1998). Bony fish include sturgeons, sea catfish, tilefish, sailfish, wakeo, and ocean sunfish (Kimmel and Purdy 1985). Reptiles include turtles (Weems 1974), tortoises, glass lizards, snakes, and crocodilians (Holman 1998). Birds reported from the formation include phasianids (ground fowl), jaegers, auks, shorebirds, ducks, pseudodontorns, gannets, albatrosses, shearwaters, loons (Olson 1985a), tropicbirds (Olson 1985b), and doves (Wetmore 1938). Marine mammals include seals (Ray 1976, 1985), sirenians (Kellogg 1966; Domning 1985), and diverse mysticetes (baleen whales) and odontocetes (toothed whales) (Whitmore 1985; Gottfried et al. 1994), with peak diversity in Beds 12 and 14 (Gottfried et al. 1994). The Calvert Cliffs have sometimes been proposed as a calving ground for whales (Vogt and Eshelman 1987), but this is questionable (Gottfried et al. 1994). Terrestrial mammals include shrews, hedgehogs, rodents, bats (Emry and Eshelman 1998), dogs, amphicyonids ("beardogs") (Tedford and Hunter 1984), bears, procyonids (raccoons and relatives) (Emry and Eshelman 1998), the elephant relative *Gomphotherium* (Tedford and Hunter 1984), chalicotheres (extinct ungulates with long clawed arms) (Emry and Eshelman 1998), tapirs, rhinoceroses, horses (Tedford and Hunter 1984),

anthracotheres (extinct hippo-like ungulates) (Emry and Eshelman 1998), peccaries, dromomerycids (small extinct ungulates) (Tedford and Hunter 1984), deer-like moschids, oreodonts (Emry and Eshelman 1998), and camels (Tedford and Hunter 1984). The best terrestrial vertebrate site is the Pollack Farm site near Cheswold, Delaware, over 150 km (93 miles) northeast of THST. This site has yielded remains of turtles, tortoises, glass lizards, snakes, crocodilians (Holman 1998), shrews, hedgehogs, rodents, bats, dogs, amphicyonids, bears, procyonids, chalicotheres, horses, rhinoceroses, anthracotheres, peccaries, moschids, and oreodonts (Emry and Eshelman 1998).

Upland Gravels (Upper Miocene?–Lower Pleistocene?)

Most of THST is draped by deposits known as upland gravels. These sediments were called the Brandywine Formation on Glaser's 1984 map of the Port Tobacco quadrangle. That name is no longer in use; instead, Mixon et al. (2000b) described the same deposits as informal Upland Gravel Unit 4. The unit described by Glaser (1984) as the Brandywine Formation is 1 to 12 m (3 to 40 ft) and composed mostly of sand, pebbly sand, and gravel, sometimes with a sandy loam cap up to 5 m (15 ft) thick. It is tan, orange-brown or reddish brown in color, and is interpreted as deposits of an ancestral version of the Potomac River (Glaser 1984).

There are several distinct upland gravels in Maryland, thought to be fluvial deposits that correlate to various shallow marine formations (McCartan 1990; Mixon et al. 2000b). They were previously lumped together under many different names, including the Appomattox Formation, Brandywine Formation/Terrace-Formation, Bryn Mawr Formation, Columbia Formation, Lafayette Formation, and Sunderland Formation/Terrace-Formation (Schloe 1957), with the Brandywine Formation historically the most common designation. Upland gravels are typically divided into a lower gravel member and an upper loam member (Hack et al. 1948; Hack 1955; Schloe 1957). They were formerly thought to be deposits on marine terraces, but they are now known to be terrestrial (Schloe 1957), with the gravel as river channel deposits and the loam as floodplain deposits (Hack 1955). Some eolian (wind-driven) deposition may also be included (Hack et al. 1948). Upland Gravel Unit 4 has been variously interpreted as the fluvial equivalent to the St. Mary's Formation (Middle–Late Miocene) (McCartan 1990), the Yorktown Formation (Pliocene) (McCartan et al. 1996), and the Bacons Castle Formation (lower Pleistocene) and informal Moorings unit of Oaks and Coch (1973) (Mixon et al. 2000b).

The age of the deposits is not known for certain; anything from the Late Miocene to the early Pleistocene is possible (Hack 1955; Schloe 1957), with the lower end more likely for THST. A plant site near Brandywine, Maryland, 25 km (16 miles) northeast of THST, possibly from Upland Gravel Unit 4, could date to the Late Miocene (McCartan 1990; McCartan et al. 1990). The plants indicate a temperate climate with a high water table and even seasonal rains, perhaps similar to coastal North and South Carolina (McCartan et al. 1990).

Fossils are uncommon in the upland gravels, and have not been reported from THST. Hay (1923) attributed some remains of horses, mammoths, and mastodons to the Brandywine and Sunderland terraces, so they may pertain to one or more of the upland gravel units. Schloe (1957) observed only one fossil, a shell of the tropical sea snail *Cassis madagascariensis spinella*. Schloe suspected that the shell was not in situ, instead having been buried by Indians. Reworked fossils are sometimes

reported (Clark 1915; Hack 1955), including pebbles with Devonian brachiopods (Schloe 1957). The best fossils are from the Brandywine plant site. At this site, 49 plant taxa are represented by leaves, seeds, fruits, pollen, spores, and wood found in a clay deposit in a channel. Most of the species are angiosperms, but quillworts and a few conifers (the bald cypress *Taxodium*) have also been identified (McCartan et al. 1990). The site may be from Upland Gravel Unit 4 or 3, with a Late Miocene age (McCartan 1990).

Unnamed Quaternary Sediments (Holocene)

Holocene alluvium in the Port Tobacco quadrangle is composed of sand, gravel, silt, and clay, 1 to 5 m (3 to 15 ft) thick. Organic debris including leaves, twigs, logs, and peat is sometimes found in the silt and clay. These sediments were deposited in stream channels, floodplains, and marshes over the past 10,000 years. Mappable deposits in THST are limited to the lower reaches of Hoghole Run (Glaser 1984). The deposits are not known to be fossiliferous within THST, but there is the possibility of finding plant material. Comparable but slightly older late Pleistocene fossil plant sites have been described in the vicinity, including just downstream of Popes Creek in Virginia near George Washington Birthplace National Monument (GEWA) about 38 km (24 miles) south of THST (Berry 1938), near Port Royal, Virginia, about 40 km (25 miles) south-southwest of THST, and Tappahannock, Virginia, about 68 km (42 miles) south-southeast of THST (Berry 1906, 1909). Similar fossils from Maryland were described by Hollick (1906). These sites preserve fossils of cypresses, water plants, vines, beech, birch, hackberry, hickory, holly, oaks, and other plants. THST appears to lack late Pleistocene deposits, which limits the chances of finding fossils of large extinct Ice Age mammals such as mammoths and mastodons.

There is also the potential to find various faunal remains at archeological sites. Examples from the vicinity include: the Shepard site, on the Potomac River probably within Chesapeake and Ohio Canal National Historical Park south of Poolesville, Maryland, about 70 km (45 miles) northwest of THST, with charcoal, maize kernels, bivalve shells, and remains of reptiles, birds, opossums, rodents, rabbits, bears, raccoons, felines, canines, and deer from between 8,000 and 400 years ago (MacCord et al. 1957); and the T. Gray Haddon site, over 80 km (50 miles) south of THST in the vicinity of Aylett, Virginia, with remains of fish, reptiles, opossums, rodents, canines, felines, raccoons, and deer from between 3000 and 400 years ago (Winfree 1967).

Park Collections

Kenworthy and Santucci (2003) reported that no fossils were in THST collections.

Cultural Resource Contexts

THST has the potential for fossil-cultural resource associations, but none have been recognized yet. The most likely possibility for the historic site is faunal materials at an archeological site, similar to those described in the Holocene section above. Fossil shark teeth are also sometimes found in regional shell middens. They may have been used as scrapers (Visaggi and Godfrey 2010). Examples have been found at GEWA (Kenworthy and Santucci 2006). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- Historic site staff should be encouraged to observe exposed sedimentary rocks and deposits for fossil material while conducting their usual duties. To promote this, they should also 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, recreation area staff should take advantage of them, if funding and time permit.
- Staff should photodocument and monitor any occurrences of paleontological resources that may be observed in situ. Fossils and their associated geologic context (surrounding rock/sediment) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts. A Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. 2009).
- Fossils found in a cultural context should be documented like other fossils, but will also require the input of an archeologist. Any fossil with 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.
- Quaternary fossils and deposits are of interest because they can be used to describe the effects of past climate and sea level changes, and to predict natural responses to future changes. Further study of these fossils and deposits in and around THST is encouraged.
- The possible fossil from 2012 should be reevaluated.
- Contact the NPS Geologic Resources Division for technical assistance with paleontological resource management issues.

References Cited

Barrick, R. E., A. G. Fischer, Y. Kolodny, B. Luz, and D. Bohaska. 1992. Cetacean bone oxygen isotopes as proxies for Miocene ocean composition and glaciation. *Palaios* 7(5):521–531.

Barrick, R. E., A. G. Fischer, and D. J. Bohaska. 1993. Paleotemperatures versus sea level: oxygen isotope signal from fish bone phosphate of the Miocene Calvert Cliffs, Maryland. *Paleoceanography* 8(6):845–858.

Berry, E. W. 1906. Pleistocene plants from Virginia. Torreya 6:88–90. Available at http://biodiversitylibrary.org/page/32135850 (accessed February 2014).

Berry, E. W. 1909. Pleistocene swamp deposits in Virginia. *The American Naturalist* 43:432–436. Available at http://biodiversitylibrary.org/page/43286466 (accessed February 2014).

Berry, E. W. 1916. The physical conditions indicated by the flora of the Calvert Formation. U.S. Geological Survey, Washington, DC. Professional Paper 98-F. Available at http://pubs.usgs.gov/pp/0098f/report.pdf (accessed February 2014).

Berry, E. W. 1938. Pleistocene fossils from Westmoreland County, Virginia. *Journal of the Washington Academy of Sciences* 28:58–61.

Browning, J. V., K. G. Miller, P. P. McLaughlin, M. A. Kominz, P. J. Sugarman, D. Monteverde, M. D. Feigenson, and J. C. Hernàndez. 2006. Quantification of the effects of eustasy, subsidence, and sediment supply on Miocene sequences, *Mid-Atlantic margin of the United States. Geological Society of America Bulletin* 118(5/6):567–588.

Clark, W. B. 1888. On three geological excursions made during the months of October and November, 1887, into the southern counties of Maryland. *The Johns Hopkins University Circular* 65:65–67. Available at http://books.google.com/books?id=YXQrAAAAYAAJ (accessed March 2014).

Clark, W. B. 1896. The Potomac River section of the middle Atlantic Coast Eocene. *American Journal of Science, 4th series* 1(5):365–374. Available at http://biodiversitylibrary.org/page/40344179 (accessed February 2014).

Clark, W. B. 1915. The Brandywine Formation of the middle Atlantic Coastal Plain. *American Journal of Science* 40(239):499–506. Available at http://biodiversitylibrary.org/page/40389505 (accessed February 2014).

Clark, W. B., and G. C. Martin. 1901a. The Eocene deposits of Maryland. Pages 21–92 *in* Eocene. Maryland Geological Survey systematic report. Johns Hopkins Press, Baltimore, Maryland. Available at https://archive.org/details/cu31924004594812 (accessed February 2014).

Clark, W. B., and G. C. Martin. 1901b. Mollusca. Pages 122–303 *in* Eocene. Maryland Geological Survey systematic report. Johns Hopkins Press, Baltimore, Maryland. Available at https://archive.org/details/cu31924004594812 (accessed February 2014).

Collins, G. S., and K. Wünnermann. 2005. How big was the Chesapeake Bay impact? Insights from numerical modeling. *Geology* 33(12):925–928.

DiMarzio, J. A. 1985. Calcareous nannofossils from the Piney Point Formation, Pamunkey River, Virginia. Pages 111–116 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Dischinger, J. B., Jr. 1987. Late Mesozoic and Cenozoic stratigraphic and structural framework near Hopewell, Virginia. U.S. Geological Survey, Reston, Virginia. Bulletin 1567. Available at http://pubs.er.usgs.gov/publication/b1567 (accessed February 2014).

Domning, D. P. 1985. Fossil sirenians from the Pamunkey River, Virginia. Pages 224–225 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Dooley, A., Jr., and N. Fraser. 2005. A revised faunal list for the Carmel Church Quarry, Caroline County, Virginia. Journal of Vertebrate Paleontology 25(supplement to 3):52A.

Dryden, A. L., Jr., and R. M. Overbeck. 1948. Detailed geology. Pages 29–127 *in* The physical features of Charles County. Maryland Department of Geology, Mines, and Water Resources. County Report 13.

Eastman, C. R. 1901. Pisces. Pages 98–115 *in* Eocene. Maryland Geological Survey systematic report. Johns Hopkins Press, Baltimore, Maryland. Available at https://archive.org/details/cu31924004594812 (accessed February 2014).

Edwards, L. E., D. K. Goodman, and R. J. Witmer. 1984. Lower Tertiary (Pamunkey Group) dinoflagellate biostratigraphy, Potomac River area, Virginia and Maryland. Pages 137–152 *in* N. O. Frederiksen and K. Krafft, editors. Cretaceous and Tertiary stratigraphy, paleontology, and structure, southwestern Maryland and northeastern Virginia. American Association of Stratigraphic Palynologists, Reston, Virginia.

Emry, R. J., and R. E. Eshelman. 1998. The early Hemingfordian (early Miocene) Pollack Farm local fauna: first Tertiary land mammals described from Delaware. Pages 153–173 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Gernant, R. E. 1970. Paleoecology of the Choptank Formation (Miocene) of Maryland and Virginia. Maryland Geological Survey, Baltimore, Maryland. Report of Investigations 12.

Gibson, T. G. 1982. Depositional framework and paleoenvironments of Miocene strata from North Carolina and Maryland. Pages 1–22 *in* T. M. Scott and S. B. Upchurch, editors. Miocene of the southeastern United States: proceedings of a symposium. Florida Geological Survey, Tallahassee, Florida. Special Publication 25. Available at http://ufdc.ufl.edu/UF00000147/00001 (accessed February 2014).

Gibson, T. G. 1983. Stratigraphy of Miocene through lower Pleistocene strata of the United States central Atlantic Coastal Plain. *Smithsonian Contributions to Paleobiology* 53:35–80. Available at http://si-pddr.si.edu/dspace/handle/10088/1975(accessed February 2014).

Gibson, T. G., G. W. Andrews, L. M. Bybell, N. O. Frederiksen, T. Hansen, J. E. Hazel, D. M. McLean, R. J. Witmer, and D. S. Van Nieuwenhuise. 1980. Biostratigraphy of the Tertiary strata of the core. Pages 14–30 *in* Geology of the Oak Grove core. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 20. Available at http://www.dmme.virginia.gov/commercedocs/PUB_20.pdf (accessed February 2014).

Glaser, J. D. 1984. Geologic map of the Port Tobacco Quadrangle, Prince Georges and Charles counties, Maryland. Maryland Geologic Survey, Baltimore, Maryland. Scale 1:24,000.

Godfrey, S. J., and J. B. Smith. 2010. Shark-bitten vertebrate coprolites from the Miocene of Maryland. *Naturwissenschaften* 97(5):461–467.

Goodman, D. K. 1979. Dinoflagellate "communities" from the lower Eocene Nanjemoy Formation of Maryland, U.S.A. *Palynology* 3:169–190.

Goodman, D. K. 1984. Dinoflagellate biostratigraphy of the Nanjemoy Formation at Popes Creek, southeastern Maryland. Pages 153–161 *in* N. O. Frederiksen and K. Krafft, editors. Cretaceous and Tertiary stratigraphy, paleontology, and structure, southwestern Maryland and northeastern Virginia. American Association of Stratigraphic Palynologists, Reston, Virginia.

Gottfried, M. D., D. J. Bohaska, and F. C. Whitmore, Jr. 1994. Miocene cetaceans of the Chesapeake Group. Proceedings of the San Diego Society of Natural History 29:229–238. Available at http://biodiversitylibrary.org/page/2888099 (accessed February 2014).

Groot, J. J. 1992. Plant microfossils of the Calvert Formation of Delaware. Delaware Geological Survey, Newark, Delaware. Report of Investigations 50. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/ri50e.pdf (accessed February 2014).

Groot, J. J. 1998. Palynomorphs from the lower Miocene Pollack Farm Site, Delaware. Pages 55–57 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Hack, J. T. 1955. Geology of the Brandywine area and origin of the upland of southern Maryland. U.S. Geological Survey, Washington, DC. Professional Paper 267-A. Available at http://pubs.er.usgs.gov/publication/pp267A (accessed February 2014).

Hack, J. T., R. M. Lindvall, and J. G. Cady. 1948. Probable aeolian deposits in the Brandywine Formation of the Coastal Plain of Maryland. Geological Society of America Bulletin 59(12, Part 2):1328.

Hay, O. P. 1923. The Pleistocene of North America and its vertebrated animals from the states east of the Mississippi River and from the Canadian provinces east of longitude 95 degrees. Carnegie Institution of Washington, Washington, D.C. Publication 322. Available at https://archive.org/details/pleistoceneofnor00hayouoft (accessed January 2014).

Hollick, A. 1906. Pteridophyta; Spermatophyta. Pages 217-237 *in* Pliocene and Pleistocene. Maryland Geological Survey systematic report. Johns Hopkins Press, Baltimore, Maryland. Available at http://biodiversitylibrary.org/page/35689878 (accessed February 2014).

Holman, J. A. 1998. Reptiles of the lower Miocene (Hemingfordian) Pollack Farm fossil site, Delaware. Pages 141–147 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Horman, S. R., and R. E. Weems. 1976. Eocene fish and reptiles from the Nanjemoy Formation in Maryland. *Abstracts with Programs - Geological Society of America* 8(2):198.

Johnson, G. H., S. E. Kruse, A. W. Vaughn, J. K. Lucey, C. H. Hobbs, III, and D. S. Powars. 1998. Postimpact deformation associated with the late Eocene Chesapeake Bay impact structure in southeastern Virginia. *Geology* 26(6):507–510.

Kelley, P. H. 1982. The effect of predation on Miocene mollusc populations of the Chesapeake Group. Pages 35–48 *in* T. M. Scott and S. B. Upchurch, editors. Miocene of the southeastern United States: proceedings of a symposium. Florida Geological Survey, Tallahassee, Florida. Special Publication 25. Available at http://ufdc.ufl.edu/UF00000147/00001 (accessed February 2014).

Kelley, P. H. 1992. Evolutionary patterns of naticid gastropods of the Chesapeake Group: an example of coevolution? *Journal of Paleontology* 66(5):794–800.

Kellogg, R. 1966. Fossil marine mammals from the Miocene Calvert Formation of Maryland and Virginia: Part 3, New species of extinct Miocene Sirenia. *U.S. National Museum Bulletin* 247:65–98. Available at http://www.biodiversitylibrary.org/item/102238 (accessed February 2014).

Kent, B. W. 1999a. Sharks from the Fisher/Sullivan site. Pages 11-37 *in* R. E. Weems and G. J. Grimsley, editors. Early Eocene vertebrates and plants from the Fisher/Sullivan Site (Nanjemoy Formation), Stafford County, Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 152. Available at http://www.dmme.virginia.gov/commercedocs/PUB_152.pdf (accessed February 2014).

Kent, B. W. 1999b. Rays from the Fisher/Sullivan site. Pages 39-51 *in* R. E. Weems and G. J. Grimsley, editors. Early Eocene vertebrates and plants from the Fisher/Sullivan Site (Nanjemoy Formation), Stafford County, Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 152. Available at http://www.dmme.virginia.gov/commercedocs/PUB_152.pdf (accessed February 2014).

Kenworthy, J. P., and V. L. Santucci. 2003. Thomas Stone National Historic Site. Page 31 *in* J. P. Kenworthy and V. L. Santucci. Paleontological resource inventory and monitoring: Northeast Coastal and Barrier Network. TIC# D-340. National Park Service, Denver, Colorado.

Kenworthy, J. P., and V. L. Santucci. 2006. A preliminary investigation of National Park Service paleontological resources in cultural resource contexts, Part 1: general overview. Pages 70–76 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf (accessed January 2014).

Kidwell, S. M., and D. Jablonski. 1983. Taphonomic feedback: ecological consequences of shell accumulation. Pages 195–248 *in* M. J. S. Tevesz, and P. L. McCall, editors. Biotic interactions in Recent and fossil benthic communities. Plenum Press, New York, New York.

Kimmel, P. G., and R. Purdy. 1985. Fossil fish of the Calvert and Eastover formations. Pages 205–215 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Lambert, O., S. J. Godfrey, and A. J. Fuller. 2010. A Miocene ziphilid (Cetacea, Odontoceti) from Calvert Cliffs, Maryland, U.S.A. *Journal of Vertebrate Paleontology* 30(5):1645–1651.

MacCord, H. A., K. Schmitt, and R. G. Slattery. 1957. The Shepard site study (18MO3) Montgomery County, Maryland. *Archeological Society of Maryland Bulletin* 1:1–32.

Maryland Geological Survey. 1901. Eocene. Maryland Geological Survey systematic report. Johns Hopkins Press, Baltimore, Maryland. Available at https://archive.org/details/cu31924004594812 (accessed February 2014).

McCartan, L. 1990. Geologic map of the coastal plain and upland deposits, Washington West Quadrangle, Washington, D.C., Maryland, and Virginia. U.S. Geological Survey, Reston, Virginia. Open-File Report 90-654. Scale 1:24,000. Available at http://pubs.er.usgs.gov/publication/ofr90654 (accessed February 2014).

McCartan, L., B. H. Tiffney, J. A. Wolfe, T. A. Ager, S. L. Wing, L. A. Sirkin, L. W. Ward, and J. Brooks. 1990. Late Tertiary floral assemblage from upland gravel deposits of the southern Maryland coastal plain. *Geology* 18(4):311–314. Available at http://www.mnh.si.edu/Ete/_LooyVersion/_img_ete/pubpdfs/McCartan%20et%20al%201990%20Geology%20Brandywine%20flora.pdf (accessed February 2014).

McCartan, L., W. L. Newell, J. P. Owens, and G. M. Bradford. 1996. Geologic map and cross sections of the Leonardtown 30 X 60-minute quadrangle, Maryland and Virginia. U.S. Geological Survey, Reston, Virginia. Open-File Report 95-665. Scale 1:100,000. Available at http://pubs.er.usgs.gov/publication/ofr95665 (accessed February 2014).

McCary, B. C. 1986. Early man in Virginia. Pages 71–78 *in* J. N. McDonald and S. O. Bird, editors. The Quaternary of Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 75. Available at http://www.dmme.virginia.gov/commercedocs/PUB_75.pdf (accessed January 2014).

McLaughlin, P. P., K. G. Miller, J. V. Browning, K. W. Ramsey, R. N. Benson, J. L. Tomlinson, and P. J. Sugarman. 2008. Stratigraphy and correlation of the Oligocene to Pleistocene section at Bethany Beach, Delaware. Delaware Geological Survey, Newark, Delaware. Report of Investigations 75. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/ri75.pdf (accessed February 2014).

Miller, M. F., H. A. Curran, and R. L. Martino. 1998. *Ophiomorpha nodosa* in estuarine sands of the lower Miocene Calvert Formation at the Pollack Farm Site, Delaware. Pages 41–46 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Mixon, R. B., D. S. Powars, R. E. Weems, J. S. Schindler, W. L. Newell, L. E. Edwards, and L. W. Ward. 2000a. Upper Mesozoic and Cenozoic deposits of the Atlantic Coastal Plain. Pages 17–28 *in* R. B. Mixon, L. Pavlides, D. S. Powars, A. J. Froelich, R. E. Weems, J. S. Schindler, W. L. Newell, L. E. Edwards, and L. W. Ward. Geologic map of the Fredericksburg 30' x 60' quadrangle, Virginia and Maryland. U.S. Geological Survey, Reston, Virginia. Geologic Investigations Series 2607. Available at http://pubs.er.usgs.gov/publication/i2607 (accessed February 2014).

Mixon, R. B., L. Pavlides, D. S. Powars, A. J. Froelich, R. E. Weems, J. S. Schindler, W. L. Newell, L. E. Edwards, and L. W. Ward. 2000b. Geologic map of the Fredericksburg 30' x 60' quadrangle, Virginia and Maryland. U.S. Geological Survey, Reston, Virginia. Geologic Investigations Series 2607. Scale 1:100,000. Available at http://pubs.er.usgs.gov/publication/i2607 (accessed February 2014).

National Park Service (NPS), Geologic Resources Inventory Program. 2006. Digital geologic map of Thomas Stone National Historic Site and vicinity, Virginia and Maryland (NPS, GRD, GRE, THST). NPS Geologic Resources Inventory Program. Lakewood, Colorado. Geospatial Dataset-1041110. Available at https://irma.nps.gov/App/Reference/Profile?Code=1041110 (accessed February 2014).

Oaks, R. Q., Jr., and N. K. Coch. 1973. Post-Miocene stratigraphy and morphology, southeastern Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 82. Available at http://www.dmme.virginia.gov/commercedocs/BUL_82.pdf (accessed February 2014).

Olson, S. L. 1985a. A brief synopsis of the fossil birds from the Pamunkey River and other Tertiary marine deposits in Virginia. Pages 217–223 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Olson, S. L. 1985b. A new genus of tropicbird (Pelecaniformes: Phaethontidae) from the middle Miocene Calvert Formation of Maryland. *Proceedings of the Biological Society of Washington* 98(4):851–855. Available at http://biodiversitylibrary.org/page/34649140 (accessed February 2014).

Olson, S. L. 1999. Early Eocene birds from eastern North America: a faunule from the Nanjemoy Formation of Virginia. Pages 123–132 *in* R. E. Weems and G. J. Grimsley, editors. Early Eocene vertebrates and plants from the Fisher/Sullivan Site (Nanjemoy Formation), Stafford County, Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 152. Available at http://www.dmme.virginia.gov/commercedocs/PUB_152.pdf (accessed February 2014).

Palmer, A. A. 1986. Cenozoic radiolarians as indicators of neritic versus oceanic conditions in continental-margin deposits: U.S. mid-Atlantic Coastal Plain. *Palaios* 1(2):122–132.

Poag, C. W. 1997. The Chesapeake Bay bolide impact: a convulsive event in Atlantic Coastal Plain evolution. *Sedimentary Geology* 108(1–4):45–90.

Powars, D. S., and T. S. Bruce. 1999. The effects of the Chesapeake Bay impact crater on the geological framework and correlation of hydrogeologic units of the lower York-James Peninsula, Virginia. U.S. Geological Survey, Reston, Virginia. Professional Paper 1612. Available at http://pubs.er.usgs.gov/publication/pp1612 (accessed January 2014).

Rasmussen, P. C. 1998. Early Miocene avifauna from the Pollack Farm Site, Delaware. Pages 149–151 *in* R. N. Benson, editor. Geology and paleontology of the lower Miocene Pollack Farm fossil site. Delaware Geological Survey, Newark, Delaware. Special Publication 21. Available at http://www.dgs.udel.edu/sites/dgs.udel.edu/files/publications/SP21.pdf (accessed February 2014).

Ray, C. E. 1976. *Phoca wymani* and other Tertiary seals (Mammalia: Phocidae) described from the eastern seaboard of North America. Smithsonian Contributions to Paleobiology 28. Available at http://si-pddr.si.edu/dspace/handle/10088/19138 (accessed February 2014).

Ray, C. 1985. Fossil seals from the Calvert Formation of the Pamunkey River, Hanover County, Virginia. Pages 232–235 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Rose, K. D. 1999. Fossil mammals from the early Eocene Fisher/Sullivan Site. Pages 133–138 *in* R. E. Weems and G. J. Grimsley, editors. Early Eocene vertebrates and plants from the Fisher/Sullivan Site (Nanjemoy Formation), Stafford County, Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 152. Available at http://www.dmme.virginia.gov/commercedocs/PUB_152.pdf (accessed February 2014).

Rose, K. D. 2010. New marsupial from the early Eocene of Virginia. *Journal of Paleontology* 84(3):561–565.

Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado.

Schlee, J. S. 1957. Upland gravels of southern Maryland. *Geological Society of America Bulletin* 68(10):1371–1409.

Schoonover, L. M. 1941. A Miocene echinoid colony from Maryland. *Journal of Paleontology* 15(1):92–93.

Self-Trail, J. M. 2011. Paleogene calcareous nannofossils of the South Dover Bridge core, southern Maryland (USA). *Journal of Nannoplankton Research* 32(1):1–28.

Shattuck, G. B. 1904. Geological and paleontological relations, with a review of earlier investigations; the Miocene deposits of Maryland. Pages xxxiii–cxxxvii *in* Miocene. Maryland Geological Survey systematic report. Johns Hopkins Press, Baltimore, Maryland. Available at https://archive.org/details/miocene01mary (accessed February 2014).

Tedford, R. H., and M. E. Hunter. 1984. Miocene marine–nonmarine correlations, Atlantic and Gulf coastal plains, North America. *Palaeogeography, Palaeoclimatology, Palaeoecology* 47:129–151.

Thomas, R. D. K. 1976. Gastropod predation on sympatric Neogene species of *Glycymeris* (Bivalvia) from the eastern United States. *Journal of Paleontology* 50(3):488–499.

Thornberry-Ehrlich, T. L. 2005. Thomas Stone National Historic Site geologic resource evaluation management issues scoping summary. National Park Service, Geologic Resources Division, Denver, Colorado. Available at http://nature.nps.gov/geology/inventory/publications/s_summaries/THST_scoping_summary_20051003.pdf (accessed February 2014).

Thornberry-Ehrlich, T. L. 2009. George Washington Birthplace National Monument and Thomas Stone National Historic Site geologic resources inventory report. Natural Resource Report NPS/NRPC/GRD/NRR—2009/127. National Park Service, Denver, Colorado. Available at http://nature.nps.gov/geology/inventory/publications/reports/gewa-thst_gri_rpt_view.pdf (accessed February 2014).

Tiffney, B. H. 1984. Fossil fruits from the Woodstock Member of the Nanjemoy Formation, Maryland and Virginia. Pages 169–173 *in* N. O. Frederiksen and K. Krafft, editors. Cretaceous and Tertiary stratigraphy, paleontology, and structure, southwestern Maryland and northeastern Virginia. American Association of Stratigraphic Palynologists, Reston, Virginia.

Tiffney, B. H. 1999. Fossil fruit and seed flora from the early Eocene Fisher/Sullivan Site. Pages 139–159 *in* R. E. Weems and G. J. Grimsley, editors. Early Eocene vertebrates and plants from the Fisher/Sullivan Site (Nanjemoy Formation), Stafford County, Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 152. Available at http://www.dmme.virginia.gov/commercedocs/PUB_152.pdf (accessed February 2014).

Tynan, E. J. 1957. Silicoflagellates of the Calvert Formation (Miocene) of Maryland. *Micropaleontology* 3(2):127–136.

Tynan, E. J. 1960. The Archaeomonadaceae of the Calvert Formation (Miocene) of Maryland. *Micropaleontology* 6(1):33–39.

Visaggi, C. C., and S. J. Godfrey. 2010. Variation in composition and abundance of Miocene shark teeth from Calvert Cliffs, Maryland. *Journal of Vertebrate Paleontology* 30(1):26–35.

Vogt, P. R., and R. E. Eshelman. 1987. Maryland's Cliffs of Calvert: a fossiliferous record of mid-Miocene inner shelf and coastal environments. Pages 9–14 *in* D. C. Roy, editor. Northeastern section of the Geological Society of America. Geological Society of America, Boulder, Colorado. Centennial Field Guide 5.

Vogt, P. R., and M. Parrish. 2011. Middle Miocene climatic optimum (ca. 15.6 Ma) and Antarctic ice sheet expansion (ca. 13.9 Ma): recorded in upper Calvert Formation exposed along western shore of Chesapeake Bay?. *Abstracts with Programs - Geological Society of America* 43(1):61.

Vredenburg, S. E. 1985. Foraminiferal paleoenvironments and biostratigraphy of Eocene Nanjemoy Formation, Virginia and Maryland. *AAPG Bulletin* 69(2):314. Available at http://archives.datapages.com/data/bulletns/1984-85/data/pg/0069/0002/0300/0314a.htm (accessed February 2014).

Ward, L. W. 1984. Stratigraphy and molluscan assemblages of the Pamunkey and Chesapeake groups, upper Potomac River. Pages 3–77 *in* N. O. Frederiksen and K. Krafft, editors. Cretaceous and Tertiary stratigraphy, paleontology, and structure, southwestern Maryland and northeastern Virginia. American Association of Stratigraphic Palynologists, Reston, Virginia.

Ward, L. W. 1985a. Stratigraphy and characteristic mollusks of the Pamunkey Group (lower Tertiary) and the Old Church Formation of the Chesapeake Group: Virginia Coastal Plain. U.S. Geological Survey, Washington, DC. Professional Paper 1346. Available at http://pubs.er.usgs.gov/publication/pp1346 (accessed February 2014).

Ward, L. W. 1985b. Stratigraphy of outcropping Tertiary beds along the Pamunkey River: central Virginia Coastal Plain. Pages 11–77 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Ward, L. W. 1989. Tertiary stratigraphy of the central Virginia coastal plain. Pages 63–77 *in* Coastal and marine geology of the United States: Upper Cretaceous and Cenozoic geology of the southeastern Atlantic Coastal Plain. Field trips for the 28th International Geological Congress. American Geophysical Union, Washington, DC. Field Trip T172.

Ward, L. W., and D. S. Powars, leaders. 1989. Tertiary stratigraphy and paleontology, Chesapeake Bay region, Virginia and Maryland. Field trips for the 28th international geological congress. American Geophysical Union, Washington, DC. Field Trip 216. Available at http://www.agu.org/books/ft/v216/FT216.pdf (accessed February 2014).

Ward, L. W., and G. W. Andrews. 2008. Stratigraphy of the Calvert, Choptank, and St. Marys Formations (Miocene) in the Chesapeake Bay area, Maryland and Virginia. Virginia Museum of Natural History, Martinsville, Virginia. Memoir 9.

Weems, R. E. 1974. Middle Miocene sea turtles (*Syllomus*, *Procolpochelys*, *Psephophorus*) from the Calvert Formation. *Journal of Paleontology* 48(2):278–303.

Weems, R. E. 1985. Vertebrate biozones of the Pamunkey Group (Paleocene and Eocene, Maryland and Virginia). Pages 198–204 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Weems, R. E. 1999a. Actinopterygian fishes from the Fisher/Sullivan site. Pages 53–99 *in* R. E. Weems and G. J. Grimsley, editors. Early Eocene vertebrates and plants from the Fisher/Sullivan Site (Nanjemoy Formation), Stafford County, Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 152. Available at http://www.dmme.virginia.gov/commercedocs/PUB_152.pdf (accessed February 2014).

Weems, R. E. 1999b. Reptile remains from the Fisher/Sullivan Site. Pages 101–121 *in* R. E. Weems and G. J. Grimsley, editors. Early Eocene vertebrates and plants from the Fisher/Sullivan Site (Nanjemoy Formation), Stafford County, Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 152. Available at http://www.dmme.virginia.gov/commercedocs/PUB_152.pdf (accessed February 2014).

Weems, R. E., and R. A. George. 2013. Amphibians and nonmarine turtles from the Miocene Calvert Formation of Delaware, Maryland, and Virginia (USA). *Journal of Paleontology* 87(4):570–588.

Weems, R. E., and G. J. Grimsley. 1999. Introduction, geology, and paleogeographic setting. Pages 1–10 *in* R. E. Weems and G. J. Grimsley, editors. Early Eocene vertebrates and plants from the Fisher/Sullivan Site (Nanjemoy Formation), Stafford County, Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 152. Available at http://www.dmme.virginia.gov/commercedocs/PUB_152.pdf (accessed February 2014).

Weems, R. E., and S. R. Horman. 1983. Teleost fish remains (Osteoglossidae, Blochiidae, Scombridae, Triodontidae, Diodontidae) from the lower Eocene Nanjemoy Formation of Maryland. *Proceedings of the Biological Society of Washington* 96(1):38–49. Available at http://biodiversitylibrary.org/page/34593081 (accessed February 2014).

Wetmore, A. 1938. A Miocene booby and other records from the Calvert Formation of Maryland. *Proceedings of the United States National Museum* 85:21–25. Available at http://biodiversitylibrary.org/page/7721596 (accessed February 2014).

Whitmore, F. C., Jr. 1985. Cetaceans from the Calvert and Eastover formations, Pamunkey River, Virginia. Pages 227–231 *in* L. W. Ward and K. Krafft, editors. Stratigraphy and paleontology of the outcropping Tertiary beds in the Pamunkey River region, central Virginia Coastal Plain. Atlantic Coastal Plain Geological Association, Norfolk, Virginia. 1984 field trip guidebook.

Wijnker, E., and S. L. Olson. 2009. A revision of the fossil genus *Miocepphus* and other Miocene Alcidae (Aves, Charadriiformes) of the western North Atlantic Ocean. *Journal of Systematic Palaeontology* 7(4):471–487.

Winfree, R. W. 1967. The T. Gray Haddon site, King William County, Virginia (44KW4). *Quarterly Bulletin of the Archaeological Society of Virginia* 22(1):2–26.

Wright, D. B., and R. E. Eshelman. 1987. Miocene Tayassuidae (Mammalia) from the Chesapeake Group of the Mid-Atlantic coast and their bearing on marine-nonmarine correlation. *Journal of Paleontology* 61(3):604–618.

Zachos, L. G., and D. Levin. 2010. Rediscovery of figured Paleogene echinoid specimens from Clark and Martin (1901). *Journal of Paleontology* 84(1):148.

Additional References

Brunner, J., J. Kenworthy, and V. Santucci. 2010. Unauthorized fossil collecting from National Park Service shorelines: servicewide policy and perspectives. Pages 319–323 *in* S. Weber, editor. Rethinking protected areas in a changing world: proceedings of the 2009 George Wright Society Conference. The George Wright Society, Hancock, Michigan. Available at http://www.georgewright.org/0956brunner.pdf (accessed February 2014).

Colquhoun, D. J., G. H. Johnson, P. C. Peebles, P. F. Huddlestun, and T. Scott. 1991. Quaternary geology of the Atlantic Coastal Plain. Pages 629–650 *in* R. B. Morrison, editor. Quaternary nonglacial geology: conterminous U.S. The geology of North America K-2. Geological Society of America, Boulder, Colorado.

Darton, N. H. 1891. Mesozoic and Cenozoic formations of eastern Virginia and Maryland. *Geological Society of America Bulletin* 2:431–450.

Davis, A. M., C. S. Southworth, J. E. Reddy, and J. S. Schindler. 2001. Geologic map database of the Washington DC area featuring data from three 30 X 60 minute quadrangles: Frederick, Washington West, and Fredericksburg. U.S. Geological Survey, Reston, Virginia. Open-File Report 2001-227. Available at http://pubs.er.usgs.gov/publication/ofr01227 (accessed February 2014).

Ellwood, B. B. 1996. Geology and America's National Park areas. Prentice Hall, Upper Saddle River, New Jersey.

Eshelman, R., and F. Grady. 1986. Quaternary vertebrate localities of Virginia and their avian and mammalian fauna. Pages 43–70 *in* J. N. McDonald and S. O. Bird, editors. The Quaternary of Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Publication 75. Available at http://www.dmme.virginia.gov/commercedocs/PUB_75.pdf (accessed January 2014).

Hunt, R. K., J. P. Kenworthy, and V. L. Santucci. 2006. A preliminary inventory of fossil fish from National Park Service units. Pages 63–69 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's antiquities: 100 years of managing fossils on federal lands. New Mexico Museum of Natural History and Science, Albuquerque, New Mexico. Bulletin 34. Available at http://www.nature.nps.gov/GEOLOGY/paleontology/pub/fossil_conference_7/8%20Hunt%202.pdf (accessed February 2014).

Mayor, A. 2005. Fossil legends of the first Americans. Princeton University Press, Princeton, New Jersey.

McLennan, J. D. 1971. Miocene Sharks Teeth of Calvert County. Maryland Geological Survey Pamphlet. Available at http://www.mgs.md.gov/geology/fossils/miocene_shark_teeth_fs.html (accessed February 2014).

McLennan, J. D. 1973. Calvert Cliffs, Maryland. Maryland Geological Survey Pamphlet. Available at http://www.mgs.md.gov/geology/fossils/calvert_cliffs_fs.html (accessed February 2014).

Mixon, R. B., B. J. Szabo, and Owens, J. P. 1982. U-series dating of mollusks and corals, and age of Pleistocene deposits, Chesapeake Bay area, Virginia and Maryland. U.S. Geological Survey Professional Paper 1067-E. Available at http://pubs.er.usgs.gov/publication/pp1067E (accessed January 2014).

Olsen, S. J. 1971. Zooarchaeology: animal bones in archaeology and their interpretation. Addison-Wesley Publishing Company, New York City, New York.

Richards, H. G. 1936. Fauna of the Pleistocene Pamlico Formation of the southern Atlantic Coastal Plain. *Geological Society of America Bulletin* 47:1611–1656.

Roberts, J. K. 1942. Annotated geological bibliography of Virginia. University of Virginia bibliographical series 2.

Ruhle, J. L. 1965. Geologic literature of the Coastal Plain of Virginia, 1783-1962. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Information Circular 9. Available at http://www.dmme.virginia.gov/commercedocs/IC_9.pdf (accessed January 2014).

Teifke, R. H. 1973. Paleogeology of early Cretaceous through Miocene time. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 83:79–101. Available at http://www.dmme.virginia.gov/commercedocs/BUL_83.pdf. (accessed February 2014).

Teifke, R. H. 1973. Stratigraphic units of the lower Cretaceous through Miocene series. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 83:1–78. Available at http://www.dmme.virginia.gov/commercedocs/BUL_83.pdf (accessed February 2014).

Vokes, H. E. 1957. Miocene fossils of Maryland. Maryland Geological Survey, Baltimore, Maryland. Bulletin 20.

Ward, L. W. 1992. Molluscan biostratigraphy of the Miocene, Middle Atlantic Coastal Plain of North America. Virginia Museum of Natural History, Martinsville, Virginia. Memoir 2.

Ward, D. J., and R. L. Wiest, Jr. 1990. A checklist of Palaeocene and Eocene sharks and rays (Chondrichthyes) from the Pamunkey Group, Maryland and Virginia, USA. *Tertiary Research* 12(2):81–88.

Ward, L. W., and D. S. Powars. 1991. Tertiary lithology and paleontology, Chesapeake Bay region. Pages 161–201 *in* A. Schultz, and E. Compton-Gooding, editors. Geologic evolution of the eastern United States. Virginia Museum of Natural History, Martinsville, Virginia. Guidebook 2.

Data Sets

Thomas Stone National Historic Site Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Thomas Stone National Historic Site Digital Geologic Map
2006–present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online. https://irma.nps.gov/App/Reference/Profile?Code=1041110.

Non-I&M network units within the NCBN

There are a number of NPS units and affiliated areas geographically within the NCBN, but not included in the Inventory and Monitoring program. Most of these non-network units comprise small areas (<20 ha [50 acres]), often commemorate cultural resources, and are located in urban areas. The non-network parks are unlikely to contain fossils beyond specimens in building stone or microfossils from deep wells, or possibly something washing up on the shore if there is a border with a body of water. There are also some units that were added to the NPS after the I&M program was established, as well as three units of the Wild and Scenic River system.

Non-network NPS units within the NCBN that have a low likelihood of including fossils include the following: New Bedford Whaling National Historic Park (NEBE) in Bristol County, Massachusetts; African Burial Ground National Monument (AFBG), Federal Hall National Memorial (FEHA), General Grant National Memorial (GEGR), Hamilton Grange National Memorial (HAGR), Saint Paul's Church National Historic Site (SAPA), and Theodore Roosevelt Birthplace National Historic Site (THRB) in New York City, New York; Edgar Allan Poe National Historic Site (EDAL) and Thaddeus Kosciuszko National Memorial (THKO) in Philadelphia, Pennsylvania; and Roger Williams National Memorial (ROWI) in Providence, Rhode Island. Four NPS-affiliated areas also fall under this category: Benjamin Franklin National Memorial and Gloria Dei (Old Swedes') Church National Historic Site in Philadelphia; Lower East Side Tenement National Historic Site in New York City; and Touro Synagogue National Historic Site, Newport, Rhode Island. The New York City units are also discussed with Gateway National Recreation Area (GATE), which can serve as a master chapter for New York City.

A handful of non-network units deserve further comment. Two units, First State National Monument (FRST) in Delaware and Harriet Tubman Underground Railroad National Monument (HATU) in Dorchester County, Maryland, are recent additions to the NPS and have not been previously evaluated for geologic or paleontologic resources. HATU is of particular interest because part of it is within the Blackwater National Wildlife Refuge, which could contain Quaternary paleoecological fossils such as pollen. A third unit, Hampton National Historic Site (HAMP) near Baltimore, Maryland, is larger than most of the other non-network units at 25.11 ha (62.04 acres) and includes significant natural resources, making it more likely to include paleontologic resources than most of the other non-network units.

Three units in New York City comprise islands with surficial glacial deposits, and have some possibility of washed-in fossils, transported fossils in glacial drift, or fossils in archeological contexts. They are Castle Clinton National Monument (CACL), Governors Island National Monument (GOIS), and Statute of Liberty National Monument (STLI). The GATE chapter of this report can be taken as a model for what may be found in these units.

Three units in the Wild and Scenic River system are within the NBCN. They are Great Egg Harbor Scenic and Recreational River (GREG), in Atlantic, Gloucester, and Camden counties, New Jersey; Maurice Scenic and Recreational River, Cumberland and Salem counties, New Jersey; and White Clay Creek Wild and Scenic River in New Castle County, Delaware, and Chester County,

Pennsylvania (also in the Eastern Rivers and Mountains Network [ERMN]). Like many of the river units in the NPS, the geologic and fossil resources of these rivers have not been formally assessed. They may include fossils. For example, the Morie Company's sand and gravel pit on the west flank of the Maurice River near Delaware Bay has Pleistocene mollusks (O'Neal et al. 1998; see the Appendix for a geologic time scale), and middle–late Holocene leaves (estimated 3,000 to 500 years old) have been found on a stream cut on the eastern branch of White Clay Creek in Chester County (Miller 2010). There is also one NPS-affiliated unit with significant natural resources: New Jersey Pinelands National Reserve (PINE) in New Lisbon, New Jersey. The New Jersey Coastal Heritage Trail Route would have also fallen under this classification, but its affiliation ended September 30, 2011. The three river units and New Jersey Pinelands National Reserve are all worthy of further exploration.

Two of the non-I&M units in the NCBN have fossil resources: Fort Monroe National Monument (FOMR) and Independence National Historical Park (INDE). A third unit, Fort McHenry National Monument and Historic Shrine (FOMC), has a record of lignite found in a well, and could be included as a fossil-producing NPS unit, but lignite is marginal as a paleontological resource. Thomas Edison National Historical Park (EDIS), technically within the neighboring Northeast Temperate Network (NETN), is also discussed here briefly because of a recent find.

Fort McHenry National Monument and Historic Shrine (FOMC)

Tyson (1862) described a new artesian well drilled within Fort McHenry. It reached a 4 m (13 ft) thick layer of lead-colored clay with lignite between 36 and 40 m (117 and 130 ft) below the surface, and was stopped at 44 m (145 ft) after contending with a resistant bed of "red ochre." In Scharf (1881:219), there is a note that "in August, 1861, an attempt was made to supply Fort McHenry with water by means of an artesian well, but after boring to the depth of one hundred and twenty-five feet [38 m] the work was stopped by a thick layer of oyster shells." This does not appear to be consistent with Tyson's report, but the timing is the same, and given the elapse of years and the different aims of the two authors, it is possible that what Tyson reported as red ochre at 145 feet was accidentally transmuted into a 125-foot oyster layer in Scharf's work. Per Reinhardt and Crowley (1979), which includes a cross section adjacent to FOMC, the monument is built on the sand facies of the Patapsco Formation, overlying the clay facies of the Arundel Formation, the sand facies of the Patuxent Formation, and ancient crystalline basement rocks. Aside from the basement rocks, these are unconsolidated Early Cretaceous-age coastal plain formations noted for plant fossils. The depth of the lignite is consistent with the upper Patuxent Formation.

Fort Monroe National Monument (FOMR)

Although the surficial geology of FOMR is unpromising for fossils, being composed of Holocene sand and artificial fill (Mixon et al. 1989), its subsurface has proven quite productive. Three wells have been drilled at Fort Monroe, and each has yielded a variety of fossils ranging in age from at least Eocene to Pliocene (FOMR Table 1). A brief history of the drilling efforts can be found in Sanford (1913). The first well was begun in 1845. Construction ceased in July 1846 after a pipe break, reaching a depth of 58 m (189 ft). Fossils from this well were studied by Jacob Whitman Bailey, the pioneering American microscopist. They included coal, foraminifera, bivalves,

scaphopods, ostracodes, echinoid spines, and unidentified fragments of macroscopic shells. Fossils were abundant from 15 to 33 m down (48 to 108 ft) in a fine greenish gray sandy unit, interpreted as Miocene based on the presence of the bivalve *Pectunculus subovatus* [*Glycymeris subovata*] and scaphopod *Dentalium attenuatum* (Fontaine 1882). These taxa, present in the Yorktown Formation, would now be described as Pliocene in age (Campbell 1993); see the Colonial National Historical Park (COLO) chapter in this document for more information on the Yorktown Formation. Because Bailey's collections went to the Boston Society of Natural History, it is possible that some material from this boring went with it, to what is now known as the Museum of Science in Boston.

The second well was begun in 1864 within the walls of the fort (Woolman 1899) and reached 276 m (907 ft) by September 1869 (Rogers 1882). Construction then ceased, apparently due to a lack of funds. Unfortunately, the borings were not described in detail at the time of construction (Fontaine 1882). The primary description comes from William Barton Rogers (1882). Rogers' description begins at 46 m (151 ft) below the parade grounds of the fort, where fragments of shells were found in a fine yellowish gray sand. Gray marl and sand encountered between 49 and 52 m (160 and 171 ft) included fragments of bivalves, gastropods, and barnacles. Fragments of bivalves and gastropods were frequently encountered between this section and about 122 m (400 ft). At 169 m (555 ft) down, a gray brown clay with foraminifera was found. At 170 m (558 ft), an "infusorial earth" [diatomaceous earth] was found with abundant diatoms. Cetacean bone was found at 175 m (574 ft). Rogers regarded the base of the Miocene as present between 176 and 178 m (577 and 583 ft). Near this part of the section, between 177 and 180 m (580 and 590 ft), shark teeth were found. Fossils were not reported from deeper levels. The diatoms were described by Samuel Wells, who identified 40 species and found the assemblage similar to that found in Richmond, interpreted as older (Rogers 1882). Fontaine (1882) suggested that Cretaceous sediments were reached by 259 m (851 ft) down. Darton (1896) reprinted the stratigraphic information complied by Fontaine and Rogers, and attempted to restudy the material, but could only find samples from 183 to 267 m (600 to 877 ft). Riley (1880) briefly mentioned diatoms from 152 m (500 ft) down, comparing the deposit to the diatomaceous earth of Richmond.

The third and final well was drilled in 1902 and penetrated to 687 m (2,254 ft), reaching crystalline bedrock (Darton 1902). Darton divided the sediments found in the 1864 and 1902 wells into several units: the Columbia Formation (now various Pleistocene formations), base at 13 to 15 m (43 to 50 ft) down; Chesapeake Formation (now Chesapeake Group, with several Miocene and Pliocene formations), base at 180 to 186 m (590 to 610 ft); Pamunkey Formation (now Pamunkey Group, with several Paleocene and Eocene formations), base at 253 to 254 m (830 to 840 ft); marine Cretaceous, base at about 288 m (945 ft); Potomac Formation (now Potomac Group, with several Cretaceous formations), base at 685 m (2,246 ft); and bedrock. The diatomaceous earth of the 1864 well was assigned to the lower Chesapeake Formation, and a shell bed was present at about 73 m (240 ft) down within this formation (Darton 1902).

The 1902 well produced a number of fossils of bivalves, gastropods, scaphopods, and barnacles between about 15 to 30 m (50 to 100 ft), in upper Chesapeake Formation beds (Darton 1902). Richards (1945) reported foraminifera of Calvert Formation (Miocene) affinities from 180 m (600 ft)

down, and later reported the gastropod *Turritella variabilis* of Pliocene age at 37 m (120 ft) down (Richards 1947). Cederstrom (1945) reexamined the samples from the well and suggested that Upper Cretaceous sediments were not present below the fort. Eocene foraminifera were found from 184 to 439 m (604 to 1,440 ft) down, and Eocene fossils *Eupsammia conradi* (coral, now in *Balanophyllia*) and *Ostrea sellaeformis* (bivalve) were present at 439 m (1,440 ft), but no Upper Cretaceous fossils were found. Cederstrom attributed the absence of Upper Cretaceous sediments to pre-Eocene channeling. Cederstrom (1957) later suggested that the coral and bivalve fossils may have fallen down the well from higher levels, but still interpreted the Upper Cretaceous as missing.

The evolving understanding of the subsurface stratigraphy differed from author to author, as shown above. What was not known until the late 1980s is that FOMR is within the area affected by the Chesapeake Bay meteor or comet impact of about 35 million years ago. Therefore, a significant portion of the stratigraphic section is a jumble of material excavated and redeposited by the impact event (Powars 2000). This explains the difficulties authors had interpreting the deposits below about 260 m (850 ft). A more modern interpretation of the subsurface sediments below FOMR finds the Yorktown Formation (Pliocene) to just above 30 m (100 ft) down; the Eastover Formation (Miocene) to just above 90 m (300 ft) down; the St. Marys Formation (Miocene) to just below 150 m (500 ft) down; the upper Calvert Formation (Miocene) to about 180 m (600 ft) down, undivided Calvert Formation and Oligocene beds to above 200 m (650 ft) down; the Chickahominy Formation (Eocene) to above 260 m (850 ft) down; Exmore tsunami-breccia to about 460 m (1,500 ft) down; and megablocks from the crater itself down to bedrock (Powars 2000). The impact event is also indirectly responsible for the numerous wells drilled at the fort: it disrupted the underlying aquifers in the region, so no matter how far down wells went, only salty water was found (Powars and Bruce 1999; Powars 2000). Aside from the sediments directly related to the impact, the Eocene through Pliocene formations are shallow coastal marine deposits left by numerous cycles of rising and falling sea level (Ward and Powars 1989, 2004).

Specimens from Fort Monroe may be in museum collections. The borings may all be lost by this time, although at least some of the 1902 well borings must have been extant for Cederstrom's work in the 1940s and 1950s. A shell conglomerate collected by F. J. Giacchetti in 1887 in 1.5 m (5 ft) of water in Chesapeake Bay near FOMR was given to the National Museum of Natural History as accession 18698 (Anonymous 1889), but no such specimen appears to be in their online collections database. Per the records of the Academy of Natural Sciences of Drexler University (formerly the Academy of Natural Sciences of Philadelphia), A. H. Smith donated "four species of Fossil Shells, from the boring of an Artesian well at Fortress Monroe" to the museum on April 8, 1862, and a "Collection of Fossils, from an Artesian well, 500 feet [150 m] deep, at Fortress Monroe" were donated from the collections of the late Dr. J. Le Conte on August 5 (Anonymous 1863). It is unclear what this well is, because it is too deep to be the 1845 well and too old to be the 1864 well. Possibilities include early work on the 1864 well and a well drilled somewhere nearby. Both are unsatisfactory; none of the historical documents suggest that the 1864 well was begun before 1864, and it seems unlikely that a nearby well would have been overlooked by the various geologists who described the other wells of the Fort Monroe area. Interestingly, money was appropriated for an artesian well at the fort in 1857 and 1860 (United States Department of the Treasury 1882), and there

is also a reference to a well from this time period at “Old Point Comfort” in Ruffin (1861). In this well, shells were common between about 75 and 82 m (245 and 269 ft) down. This phantom well and the known wells of Fort Monroe should not be confused with another well, drilled in 1895–1896 at “The Chamberlin” nearby in Old Point Comfort (Woolman 1899).

Pliocene coquina from Yorktown (Colonial National Historical Park) was once used for fill at Fort Monroe, but it deteriorated quickly and was replaced by Petersburg granite (Frye 1986). It would not be surprising if remnants of this material were present within FOMR.

FOMR also includes a coastal parcel, the North Beach. Similar settings are often underlain by Quaternary peat beds, and storms occasionally transport fossils to them, from elsewhere along the coast or from offshore sources (see for example the Assateague Island National Seashore [ASIS] chapter of this document).

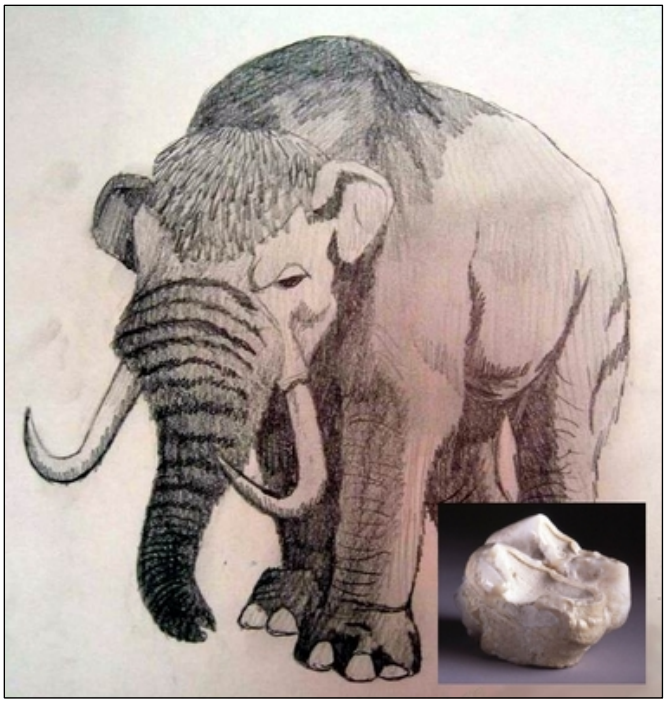
FOMR Table 1. Fossils reported from FOMR wells.

Well	Depth below surface	Formation (extrapolated from Powars 2000)	Age	Fossils reported
1 (1845)	Mostly 15–33 m (49–108 ft)	Yorktown Formation	Pliocene	Coal, foraminifera, bivalves, scaphopods, ostracodes, echinoids, shell fragments
2 (1864)	49–52 m (160–171 ft)	Eastover Formation	Late Miocene	Bivalves, gastropods, barnacles
	52–122 m (171–400 ft)	Eastover and St. Marys formations	Late Miocene	Bivalve and gastropod fragments
	169 m (555 ft)	Calvert Formation	Early–Middle Miocene	Foraminifera
	170 m (558 ft)	Calvert Formation	Early–Middle Miocene	Diatoms
	175 m (574 ft)	Calvert Formation	Early–Middle Miocene	Cetacean bone
	177–180 m (580–590 ft)	Oligocene undivided to Calvert Formation	Oligocene–Middle Miocene	Shark teeth
3 (1902)	15–30 m (50–100 ft)	Yorktown Formation	Pliocene	Bivalves, gastropods, scaphopods, barnacles
	37 m (120 ft)	Yorktown Formation?	Pliocene?	Gastropod
	180 m (600 ft)	Calvert Formation	Early–Middle Miocene	Foraminifera
	184–439 m (604–1,440 ft)	Pre-impact to Calvert Formation	Eocene or older to Middle Miocene	Foraminifera (at least some Eocene)
	439 m (1,440 ft)	Pre-impact	Eocene fossils	Coral, bivalve

Independence National Historical Park (INDE)

INDE’s fossil record is based on a mastodon tooth fragment found by archeologists during an excavation of the courtyard adjacent to Benjamin Franklin’s property, within INDE (INDE Figure 1). It was not in situ, but was associated with cultural materials that date to Franklin’s time. This specimen is of historic interest: Franklin received mastodon fossils and wrote of them, and the archeological context of this specimen is appropriate for it to have possibly been one that was owned by Franklin. The specimen is now in INDE collections. Franklin, like Thomas Jefferson (whose paleontological interests are more widely known), was a party to debates of geographic and national

chauvinism against European intellectuals who considered the Americas inferior, including in terms of their fauna. Mastodons, with their heavily pointed teeth that led to initial interpretations as carnivores, were a counter-argument to the European viewpoint (Thomson 2008). Coincidentally, Independence Hall in INDE once housed Charles Willson Peale's museum, including his famous mastodon skeleton, as depicted in his 1822 self-portrait *The Artist in His Museum*.



INDE Figure 1. The mastodon tooth fragment from INDE (inset), with a life restoration of a mastodon (photo by Peter Harholdt, illustration by Sarah Jeppsen).

Thomas Edison National Historical Park

Thomas Edison National Historical Park (EDIS), in West Orange, New Jersey, is probably just within the Northeast Temperate Network (NETN), but because there are no plans to revisit the NETN paleontological resources summary at this time, and because it is very near the NCBN (in particular the New York City-area units), it is included here. It is another non-network park with fossil resources. The material in question is a small dark fragment of sedimentary rock with several natural molds or casts of apparent brachiopod shells (they also resemble some bivalve shells, but the prominent ribbing and bilateral symmetry suggest brachiopods) (EDIS Figure 1). The specimen was discovered on the grounds of the Edison estate in early 2013. The underlying bedrock of EDIS is the Passaic Formation (Volkert 2007) of the Upper Triassic (beneath the Orange Mountain Basalt of 201.3 million years ago) (Blackburn et al.2013). It is a rift valley formation not known for brachiopods or bivalves (Olsen 1980), so it is likely that the specimen was transported from elsewhere, perhaps by glaciers. The surficial geology of EDIS is composed of glacial deposits (Sanford 2000).



EDIS Figure 1. The fossiliferous stone from EDIS (VLS).

References Cited

Anonymous. 1863. Donations to museum, 1862. *Proceedings of the Academy of Natural Sciences of Philadelphia* 1863:600–602. Available at http://books.google.com/books?id=nIEOAQAAIAAJ (accessed April 2014).

Anonymous. 1889. List of accessions. Pages 597–725 in Annual report of the board of regents of the Smithsonian Institution showing operations, expenditures, and condition of the institution for the period ending June 30, 1887, Part II. Government Printing Office, Washington, DC. Available at http://books.google.com/books?id=D6wAAAAAYAAJ (accessed April 2014).

Blackburn, T. J., P. E. Olsen, S. A. Bowring, N. M. McLean, D. V. Kent, J. Puffer, G. McHone, E. T. Rasbury, and M. Et-Touhami. 2013. Zircon U-Pb geochronology links the end-Triassic extinction with the Central Atlantic Magmatic Province. *Science* 340(6135):941–945. Available at http://www.ldeo.columbia.edu/~polsen/nbcp/Science-2013-Blackburn-941-5_small.pdf (accessed April 2014).

Campbell, L. D. 1993. Pliocene molluscs from the Yorktown and Chowan River formations in Virginia. Virginia Division of Geology and Mineral Resources, Charlottesville, Virginia. Bulletin 127. Available at http://www.dmme.virginia.gov/commercedocs/PUB_127.pdf (accessed January 2014).

Cederstrom, D. J. 1945. Structural geology of southeastern Virginia. *Bulletin of the American Association of Petroleum Geologists* 29(1):71–95.

Cederstrom, D. J. 1957. Geology and ground-water resources of the York-James Peninsula, Virginia. U.S. Geological Survey, Washington, DC. Water-Supply Paper 1361. Available at http://pubs.er.usgs.gov/publication/wsp1361 (accessed January 2014).

Darton, N. H. 1896. Artesian well prospects in the Atlantic Coastal Plain region. U.S. Geological Survey, Washington, DC. Bulletin 138. Available at http://pubs.er.usgs.gov/publication/b138 (accessed April 2014).

Darton, N. H. 1902. Norfolk folio, Virginia-North Carolina. U.S. Geological Survey, Washington, DC. Folio of the Geologic Atlas 80. Available at http://pubs.er.usgs.gov/publication/gf80 (accessed April 2014).

Fontaine, W. M. 1882. The artesian well at Fort Monroe, Va. *The Virginias* 3(2):18–19. Available at http://books.google.com/books?id=LrBMAAAAYAAJ (accessed April 2014).

Frye, K. 1986. Roadside geology of Virginia. Mountain Press Publishing Company, Missoula, Montana.

Miller, C. 2010. A pre-settlement flora of White Clay Creek, PA. *Abstracts with Programs - Geological Society of America* 42(5):606.

Mixon, R. B., C. R. Berquist, W. L. Newell, and G. H. Johnson. 1989. Geologic map and generalized cross sections of the coastal plain and adjacent parts of the Piedmont, Virginia. U.S. Geological Survey, Reston, Virginia. Miscellaneous Investigations Series Map I-2033. Scale 1:250,000. Available at http://pubs.er.usgs.gov/publication/i2033 (accessed January 2014).

O'Neal, M. L., J. F. Wehmiller, and W. L. Newell. 1998. Amino acid geochronology of Delaware Bay Quaternary coastal terrace deposits: Morie Pit, southern New Jersey, USA. *Abstracts with Programs - Geological Society of America* 30(7):284.

Olsen, P. E. 1980. Triassic and Jurassic formations of the Newark Basin. Pages 2–39 *in* W. Manspeizer, editor. Field studies of New Jersey geology and guide to field trips: 52nd annual meeting of the New York State Geological Association. New York State Geological Association, Staten Island, New York. Available at http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_formations_80_sm.pdf (accessed April 2014).

Powars, D. S. 2000. The effects of the Chesapeake Bay impact crater on the geologic framework and the correlation of hydrogeologic units of southeastern Virginia, south of the James River. U.S. Geological Survey, Reston, VA. Professional Paper 1622. Available at http://pubs.usgs.gov/pp/p1622/ (accessed April 2014).

Powars, D. S., and T. S. Bruce. 1999. The effects of the Chesapeake Bay impact crater on the geological framework and correlation of hydrogeologic units of the lower York-James Peninsula, Virginia. U.S. Geological Survey, Reston, Virginia. Professional Paper 1612. Available at http://pubs.er.usgs.gov/publication/pp1612 (accessed January 2014).

Reinhardt, J. and W. P. Crowley. 1979. Geologic map of the Baltimore East quadrangle, Maryland. Maryland Geological Survey, Baltimore, Maryland. Quadrangle Geologic Map. Scale 1:24,000. Available at https://jscholarship.library.jhu.edu/handle/1774.2/33717 (accessed April 2014).

Richards, H. G. 1945 Subsurface stratigraphy of Atlantic Coastal Plain between New Jersey and Georgia. *Bulletin of the American Association of Petroleum Geologists* 29(7):885–955.

Richards, H. G. 1947. Invertebrate fossils from deep wells along the Atlantic Coastal Plain. *Journal of Paleontology* 21(1):23–37.

Riley, C. V. 1880.The Richmond diatomaceous earth. *Science* 1(18):222. Available at http://www.jstor.org/stable/2900721 (accessed April 2014).

Rogers, W. B. 1882. Infusorial deposit of Virginia in the Fort Monroe artesian well. The Virginias 3(10):151-152. Reprinted in Geology of the Virginias, 1884, pp. 733-736. Available at http://books.google.com/books?id=JR85AAAAMAAJ (accessed April 2014).

Ruffin, E. 1861. Agricultural, geological, and descriptive sketches of lower North Carolina, and the similar adjacent lands. Institution for the Deaf & Dumb & Blind, Raleigh, North Carolina. Available at http://docsouth.unc.edu/nc/ruffin/ruffin.html (accessed April 2014).

Sanford, S. 1913. The underground water resources of the coastal plain province of Virginia. Virginia Geological Survey, Charlottesville, Virginia. Bulletin 5. Available at http://www.dmme.virginia.gov/commercedocs/BUL_5.pdf (accessed April 2014).

Stanford, S. D. 2002. Surficial geology of the Orange quadrangle, Essex, Passaic, Hudson, and Bergen counties, New Jersey. New Jersey Geological Survey, Trenton, New Jersey. Open-file Map 41. Scale 1:24,000. Available at http://www.state.nj.us/dep/njgs/pricelst/ofmap/ofm41.pdf (accessed April 2014).

Scharf, J. T. 1881. History of Baltimore City and County, from the earliest period to the present day. Louis H. Everts, Philadelphia, Pennsylvania. Available at http://books.google.com/books?id=6tF4AAAAMAAJ (accessed April 2014).

Thomson, K. 2008. The legacy of the mastodon: the golden age of fossils in America. Yale University Press, New Haven, Connecticut.

Tyson, P. T. 1862. Second report of Philip T. Tyson, state agricultural chemist, to the house of delegates of Maryland. Thomas J. Wilson, Annapolis, Maryland. Available at http://books.google.com/books?id=98wQAAAAIAAJ (accessed April 2014).

United States Department of the Treasury. 1882. Statement of appropriations and expenditures for public buildings, rivers and harbors, forts, arsenals, armories, and other public works from March 4, 1789, to June 30, 1882. Government Printing Office, Washington, DC. Available at http://books.google.com/books?id=KGRJAAAAYAAJ (accessed April 2014).

Volkert, R. A. 2007. Bedrock geologic map of the Orange quadrangle, Essex, Passaic, Bergen, and Hudson counties, New Jersey. New Jersey Geological Survey, Trenton, New Jersey. Geologic Map Series 07-1. Scale 1:24,000. Available at http://www.state.nj.us/dep/njgs/pricelst/gmseries/gms07-1.pdf (accessed April 2014).

Ward, L. W., and D. S. Powars, leaders. 1989. Tertiary stratigraphy and paleontology, Chesapeake Bay region, Virginia and Maryland. Field trips for the 28th international geological congress. American Geophysical Union, Washington, DC. Field Trip 216. Available at http://www.agu.org/books/ft/v216/FT216.pdf (accessed February 2014).

Ward, L. W., and D. S. Powars. 2004. Tertiary lithology and paleontology, Chesapeake Bay region. Pages 263–297 *in* S. Southworth and W. Burton, editors. Geology of the National Capital Region—field trip guidebook. U.S. Geological Survey, Reston, Virginia. Circular 1264. Available at http://pubs.usgs.gov/circ/2004/1264/pdf/trip9.pdf (accessed January 2014).

Woolman, L. 1899. Artesian wells in New Jersey. Pages 59–144 *in* Annual report of the State Geologist for the year 1898. Geological Survey of New Jersey, Trenton, New Jersey. Available at http://www.state.nj.us/dep/njgs/enviroed/oldpubs/SG-Annual-Report-1898.pdf (accessed April 2014).

Additional References

Cederstrom, D. J. 1945. Selected well logs in the Virginia Coastal Plain north of the James River. Virginia Geological Survey, Charlottesville, Virginia. Circular 3.

Cederstrom, D. J. 1945. Geology and ground-water resources of the Coastal Plain in southeastern Virginia. Virginia Geological Survey, Charlottesville, Virginia. Bulletin 63. Available at http://www.dmme.virginia.gov/commercedocs/BUL_63.pdf (accessed April 2014).

Cederstrom, D. J. 1950. Upper Cretaceous beds in the Coastal Plain of Virginia. *Proceedings of the Virginia Academy of Science* 1(4):381–382.

Newell, W. L., and J. S. Wyckoff. 2010. Paleohydrology of four watersheds in the New Jersey coastal plain. Pages 23–28 in G. S. Gohn, editor. Proceedings of the 1988 U.S. Geological Survey workshop on the Geology and geohydrology of the Atlantic Coastal Plain. U.S. Geological Survey, Reston, Virginia. Circular 1059. Available at http://pubs.er.usgs.gov/publication/cir1059 (accessed April 2014).

Woolman, L. 1898. Fossil mollusks and diatoms from the Dismal Swamp, Virginia and North Carolina; indication of the geological age of the deposit. *Proceedings of the Academy of Natural Sciences of Philadelphia* 50:414–428. Available at http://www.jstor.org/stable/4062432 (accessed April 2014).

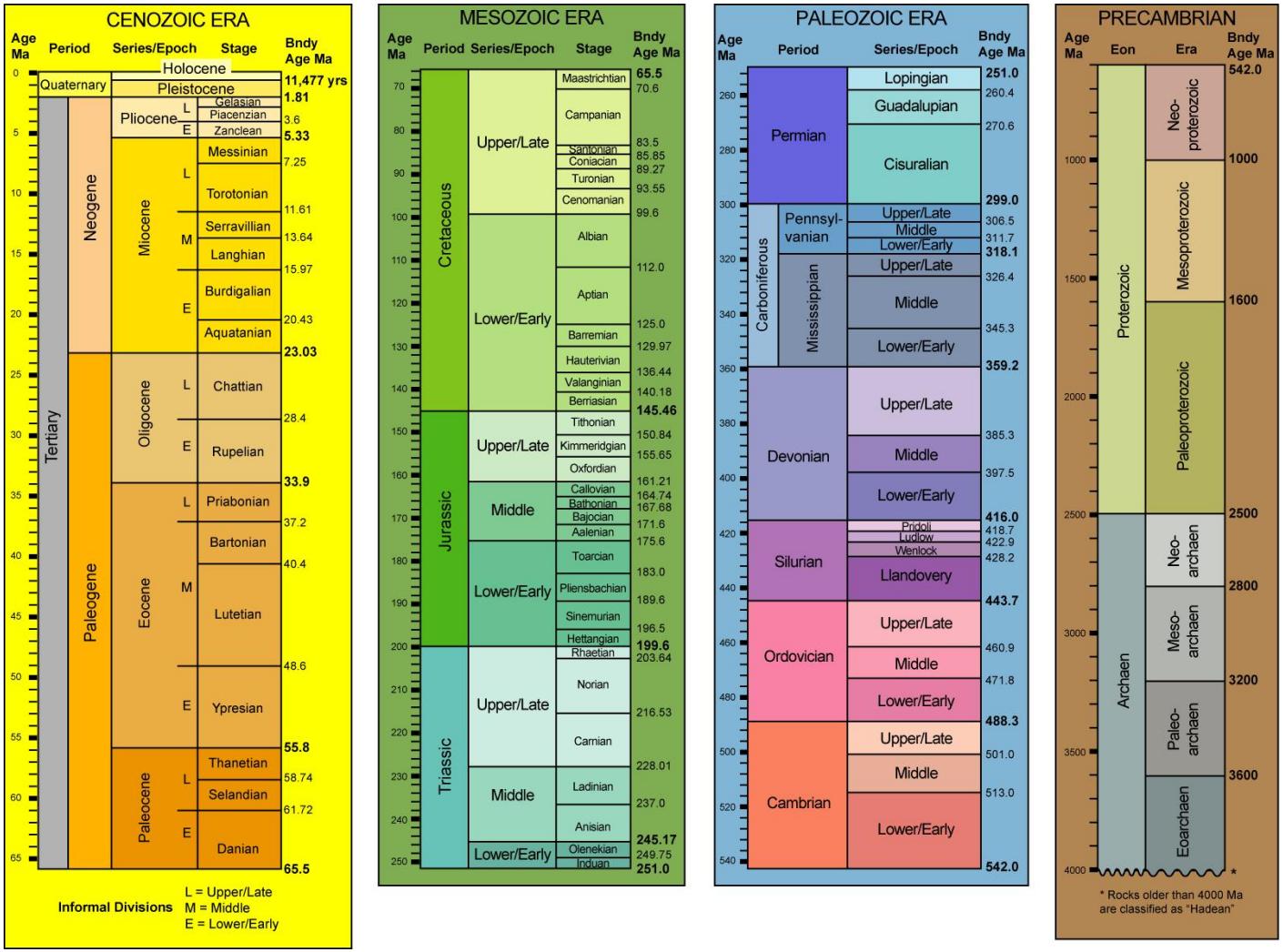
Data Sets

Fort Monroe National Historic Site Paleontological Archives
1/2014–present. (hard copy data; reports; electronic data; photographs; maps; publications).
Originated by Santucci, Vincent; status: Active.

Independence National Historical Park Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications).
Originated by Santucci, Vincent; status: Active.

Thomas Edison National Historical Park Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications).
Originated by Santucci, Vincent; status: Active.

Appendix: Geologic Time Scale



Ma=Millions of year old. Bndy Age=Boundary Age. Colors are standard USGS colors for geologic maps. Modified from 1999 Geological Society of America Timescale (www.geosociety.org/science/timescale/timescl.pdf). Dates and additional information from 2004 International Commission on Stratigraphy (www.stratigraphy.org/gssp.htm) and USGS Fact Sheet 2007-3015 (http://pubs.usgs.gov/fs/2007/3015/).

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 962/125676, August 2014

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov