National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Paleontological Resource Inventory and Monitoring

Northeast Temperate Network

Natural Resource Technical Report NPS/NRPC/NRTR—2010/326



ON THE COVER
Top: Woolly mammoths (pictured) and mastodons are common in Pleistocene "ice age" deposits throughout the Northeast. Many discoveries have been made near NETN parks. One particularly complete mastodon was discovered near Eleanor Roosevelt National Historic Site and Home of Franklin D. Roosevelt National Historic Site (both part of the Roosevelt-Vanderbilt National Historic Sites). Artwork from the National Park Service/HFCA Commissioned Art Collection/artist Juan Barberis; courtesy Wade Myers, NPS Harpers Ferry Center.

Left: This fossil fish (*Priscacara liops*) is in the museum collections of Marsh-Billings-Rockefeller National Historical Park. Such fossil fish are not known from the NETN, but are common in southwestern Wyoming near Fossil Butte National Monument. This specimen was likely purchased by the Billings or Rockefeller families during the late 1800s or early 1900s. Photo courtesy Janet Houghton, Marsh-Billings-Rockefeller National Historical Park.

Right: The femur of the holotype specimen of *Anchisaurus polyzelus*, ACM 41109, recovered from the Watershops of Springfield Armory. Photo courtesy Kate Wellspring, Amherst College Museum of Natural History, The Trustees of Amherst College.

For more information refer to the respective park section(s).

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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.

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Abstract

Paleontological resources (fossils) are any remains of past life preserved in a geologic context. Paleontological resources are non-renewable resources found in at least 224 National Park System units. Despite the abundance and diversity of these resources throughout the National Park Service (NPS), until recently few parks have adequate baseline paleontological resource data.

The NPS National Inventory and Monitoring 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 a paleontological resource summary for the parks of the Northeast Temperate Network (NETN). The summary was compiled through extensive literature reviews and interviews with park staff and professional geologists and paleontologists. Preliminary paleontological resource management recommendations are also included for each park. Including this report, summaries have been prepared for 29 of 32 NPS Inventory and Monitoring Networks. The National Inventory and Monitoring Program has provided funding to complete paleontological resource summaries for each of the remaining networks.

The paleontological resources of the parks of the NETN are relatively uncommon, and many occurrences have not yet been studied in detail. In situ fossils are typically Lower Paleozoic marine invertebrate fossils, Pleistocene marine invertebrate fossils, or Quaternary paleoecological materials. There are a few less typical resources as well, including enigmatic soft-bodied organisms from the Precambrian at Boston Harbor Islands National Recreation Area (BOHA), fossil resources in cultural resource contexts at Acadia National Park (ACAD) and BOHA, and a partial dinosaur skeleton associated with Springfield Armory National Historic Site (SPAR), not officially a part of the network but geographically within it. There is also one case of a fossil from one NPS unit in the collections of another as a cultural resource: a fossil fish from within or near what is now Fossil Butte National Park (FOBU) in the collections of Marsh-Billings-Rockefeller National Historical Park (MABI).

The most diverse fossil resources are found at BOHA, which not only has Precambrian (more than 542 million years old) soft-bodied organisms and fossils found in cultural contexts, but a rich Quaternary (younger than 2.6 million years old) fossil record dominated by shelly marine invertebrates. ACAD also has Quaternary fossils and fossils from cultural contexts, but its fossils are not as well known as those of BOHA. The specimen associated with SPAR, the holotype or name-bearing specimen of the small dinosaur *Anchisaurus polyzelus*, is the only other fossil resource associated with a NETN unit to have been described in detail. Of the other occurrences, most are undescribed Paleozoic (between 542 and 251 million years old) marine fossils. The fossil record of the Appalachian National Scenic Trail (APPA) is so far limited to Lower Paleozoic marine trace fossils and possibly some shells. Undescribed shell impressions are present at the Roosevelt-Vanderbilt national historic sites (ROVA); included sites are Eleanor Roosevelt National Historic Site (ELRO), Home of Franklin D. Roosevelt National Historic Site (HOFR), and Vanderbilt Mansion National Historic Site (VAMA). ELRO and HOFR are also adjacent to a mastodon site. Undescribed marine invertebrates are also known from Saratoga National Historical Park (SARA). The only other park with known fossil resources is MABI, which has in its collections plant specimens from on-site Holocene marl, a fish from FOBU, and a few other items that may be fossils. Minute Man National Historical Park (MIMA), Morristown National Historical Park (MORR), Saint-Gaudens National Historic Site (SAGA), Saugus Iron Works National Historic Site (SAIR), and Weir Farm National Historic Site (WEFA) do not appear to contain paleontological resources at this time.

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Dedication



We dedicate the Northeast Temperate Network paleontological resource inventory to Bruce Heise (right) and Tim Connors (left) of the NPS Geologic Resources Division. Bruce and Tim recognized the importance and Servicewide need to undertake paleontological resource inventories from their initial work on the Geologic Resource Inventories. Since Bruce and Tim extended the opportunity to join their geologic scoping of the NPS areas in Utah, they opened the door to further paleontological inventories throughout the NPS, including this report.

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 great scientific, educational, and interpretive value. In the National Park Service there are three fossil context categories: in situ (fossils found in 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 224 units have been identified with paleontological resources, few parks have adequate baseline paleontological resource data.

In conjunction with the NPS Geologic Resources Division and the NPS Inventory and Monitoring (I&M) Program, paleontological resource inventories have been initiated in dozens of parks Servicewide 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 Temperate I&M Network (NETN).

The NETN includes 13 units as shown in Figure 1. Four are found in eastern New York, three are located in eastern Massachusetts, one is present in each of Connecticut, Maine, New Hampshire, New Jersey, and Vermont, and one, the Appalachian National Scenic Trail, passes through 14 states and five other I & M networks. The NETN parks are: Acadia National Park (ACAD); Appalachian National Scenic Trail (APPA); Boston Harbor Islands National Recreation Area (BOHA); Marsh-Billings-Rockefeller National Historical Park (MABI); Minute Man National Historical Park (MIMA); Morristown National Historical Park (MORR); the three Roosevelt-Vanderbilt national historic sites (ROVA), including Eleanor Roosevelt National Historic Site (ELRO), Home of Franklin D. Roosevelt National Historic Site (HOFR), and Vanderbilt Mansion National Historic Site (VAMA); Saint-Gaudens National Historic Site (SAGA); Saratoga National Historical Park (SARA); Saugus Iron Works National Historic Site (SAIR); and Weir Farm National Historic Site (WEFA). Another 12 NPS units are geographically within the Northeast Temperate Network; the majority of these are unlikely to have fossil resources. Two exceptions are the recently-expanded Martin Van Buren National Historic Site (MAVA), and Springfield Armory National Historic Site (SPAR), where a partial dinosaur skeleton was found during the early 1850s. MAVA is addressed with the ROVA parks while SPAR is covered in its own section.

The NETN parks detailed in this report range in size from 3 ha (8.5 acres) (SAIR) to nearly 92,000 ha (227,000 acres) (APPA). Most were established to protect cultural resources, including sites related to the American Revolution (MIMA, MORR, and SARA), specific cultural figures (ELRO, HOFR, and VAMA), art (SAGA and WEFA), early industry (SAIR), and the early history of conservation (MABI). ACAD and APPA were established primarily in recognition of their natural resources, and BOHA includes diverse cultural and natural resources. The parks of the NETN are within the temperate deciduous forest biome, a mid-latitude biome found throughout much of the eastern United States. It has four distinct seasons, including a hot wet summer and a cold winter, with 75 to 150 cm (30 to 60 in) of precipitation annually, and an average temperature of 10° C (50° F). Broadleaf trees such as oak, maple, beech, hickory, and chestnut dominate the forests. Environments range from the bare High Peaks of the Adirondack Mountains, to the rugged Maine coast, to river valleys, to plains dotted with lakes and marshes that represent the basins of glacial lakes, to tidal wetlands.

NETN Geological Background

The geology of the NETN (discussed in detail in the appropriate park summaries) was shaped by hundreds of millions of years of continental collisions and rifting. The incorporation of island chains and

continental fragments, the uplift of mountain ranges, folding, faulting, volcanic eruptions, intrusions of magma, and extensive metamorphism combined to produce the bedrock geology. Glacial activity over the last 2.6 million years then sculpted much of the land into its present form. The episodes of mountain building and continental collisions were responsible for two conditions that have given the NETN a relatively sparse fossil record: elevation, which leads to erosion, both destroying preserved fossils and precluding the formation of new fossils; and intense metamorphism, which distorts and destroys fossils. Exceptions at NETN units include Precambrian-age marine rocks underlying BOHA, Ordovician-age marine rocks underlying the ROVA parks and SARA, and the Triassic-Jurassic rift valley rocks of MORR and SPAR (see the appendix for a geologic time scale). Late Pleistocene and Holocene fossils are also common throughout the NETN, especially in areas of former glacial lakes and other postglacial wetlands (MABI, MIMA, MORR, the ROVA parks, SAGA, SARA, and SPAR are associated with such settings), and coastal regions (ACAD, BOHA, and SAIR).

The early geologic history of the NETN is complex, because much of the bedrock originated elsewhere. New England in particular is largely made up of exotic accreted terranes, which are blocks of crust that originated somewhere other than their present location and are demonstrably different from surrounding rocks. The timing of assembly and the origins of the various terranes are heavily debated. Of the earliest part of the history, Precambrian rocks are present at BOHA, MIMA, MORR, and SAIR, and are found in the vicinity of MABI. These include both rocks from the North American continental core (a "craton;" the proto-North American continent is often referred to as Laurentia in the technical literature), and from one of the most prominent exotic terranes, the Avalon terrane (also known as Avalonia).

The oldest rocks in a NETN park are found in MORR, and were formed and deformed near the coast of Laurentia over a period of time between 1350 and 990 Ma (million years ago), during the multi-stage Grenville Orogeny (mountain-building event). The Grenville Orogeny was part of a larger tectonic cycle that resulted in the formation of a supercontinent known as Rodinia. Because of the multiple episodes of deformation undergone by the rocks formed at this time, the events of the Grenville Orogeny are only partially known. It appears that the Laurentian continental margin began the Grenville Orogeny as an active, Andean-style continental margin where the continental plate was overriding an oceanic plate. The subducting oceanic plate melted in the mantle and provided magma to fuel a volcanic arc in the overlying part of Laurentia. As the oceanic crust was destroyed, the tectonic setting changed to a continent-continent collision. MORR has rocks from the early volcanic phase of the Grenville Orogeny, and a more recent phase marked by granitic intrusion. Grenville-age rocks are also present near MABI, represented by the Green Mountains.

Rodinia began to break up approximately 760 Ma, leading to rift basins and intrusions of dikes, and the formation of an ocean (the Iapetus Ocean). The Precambrian rocks of BOHA, MIMA, and SAIR date to approximately 600 Ma, during the breakup, and derive from the Avalon Terrane. These rocks formed in a rift basin during the waning stages of the larger Avalonian Orogeny, shortly before the Avalon Terrane separated from West Africa (approximately 550 Ma). Some of the rocks exposed at BOHA contain impressions of enigmatic soft-bodied organisms, which represent the earliest known evidence of life in the NETN parks. The breakup of Rodinia concluded by the early Cambrian, leading to a passive continental margin similar to the present Atlantic coast of North America, where the continental crust is attached to a substantial amount of oceanic crust, and there is no crustal subduction or collision occurring. The stage was now set for another round of continental collisions and supercontinent formation that would dominate the next 300 million years.

At the beginning of the Paleozoic Era, what is now the northeastern region of the United States consisted of a passive continental margin and a series of volcanic island arcs and continental fragments in the neighboring ocean. The formation of a subduction zone somewhere off the coast of Laurentia set in motion a sort of "conveyor belt" that transported the small landmasses into collision and accretion with the larger continent. For many years, the basic interpretation of the assembly of the east coast of North America was as a three-stage process. In the first event, during the Ordovician, the Iapetus Ocean began subducting under Laurentia, carrying along with it an island arc that was added to the continent. The

associated mountain-building event is known as the Taconic Orogeny. Then, during the Devonian, the Iapetus Ocean finished subducting, and the Avalon Terrane collided with Laurentia; this is known as the Acadian Orogeny. Finally, during the Pennsylvanian, the continent Gondwana (a large continent that included most of today's Southern Hemisphere landmasses) collided with Laurentia, by now including almost all of the present North America, with the landmass that now forms Africa in contact with the east coast. This event is known as the Alleghenian Orogeny, and was the culmination of a process that ended in the formation of the supercontinent Pangaea. As research continues, this basic three-orogeny sequence has been refined to include additional events and small landmasses. For example, it is now known that there were numerous terranes, and that some may have collided with North America during the late Ordovician and early Silurian, as part of an event called the Salinic Orogeny, or over both the Salinic Orogeny and the Acadian Orogeny. However the process went, by approximately 370 Ma all of the exotic terranes of the NETN had accreted to Laurentia. The earlier orogenies had the greatest effects on the NETN; although the Alleghenian Orogeny involved the largest landmasses, the configuration of the collision caused the present northeastern United States to be spared the brunt of the effects.

The various terranes include several that are represented by bedrock underlying NETN parks. The most prominent is the Avalon Terrane (discussed above). Also of interest are the Gander Terrane (another relatively large block, also known as Ganderia) and the Nashoba Terrane. The Avalon Terrane is present beneath BOHA, eastern MIMA, and SAIR. ACAD overlies the Ellsworth Terrane of Ganderia. Finally, the Nashoba Terrane makes up the bulk of the bedrock of MIMA. The Gander block appears to derive from a Cambrian rift on Gondwana that grew to become an ocean basin (the Rheic Ocean), and the Nashoba Terrane is interpreted as a metamorphosed volcanic arc that formed prior to 500 Ma. These terranes and others periodically collided with each other while approaching Laurentia. One interpretation of their history is that they all began as part of one continental fragment that then broke up but later reassembled in a new configuration before the ultimate accretion into Laurentia. Other interpretations postulate independent collisions with Laurentia, or scenarios where some of the landmasses were together and the rest independent.

Interspersed with the accretion of these landmasses was the formation of volcanic arcs and marine basins in response to the tectonic processes. MABI, SAGA, and WEFA overlie bedrock that formed in these settings. The region that includes MABI and SAGA consists of two Ordovician volcanic arcs and a structural trough between them: the Sherburne Falls Arc (formed 485-470 Ma) in the west and Bronson Hill Arc (formed 455-440 Ma) in the east, separated by the Connecticut Valley-Gaspé Trough, which formed between them during the Silurian. These volcanic arcs probably formed on the margin of Laurentia and were then forced into their present locations. WEFA, to the southwest, overlies trough rocks.

The tectonic events had many other consequences, including widespread metamorphism, folding, the introduction of igneous intrusions (particularly evident at ACAD), and the movement of vast sheets of rock in thrust faults. This latter process is responsible for the complex geology of eastern New York, where large segments of continental slope rocks were pushed over the Laurentian continental shelf during the Taconic Orogeny; the thrust sheet as a whole is known as the Taconic Allochthon (a form of the term "allochthonous," referring to something that derives from somewhere other than where it is now). The ROVA parks and SARA are associated with the leading western margin of the Taconic Allochthon.

The rocks that were caught up in these tectonic events are sparsely fossiliferous. This is due in part to metamorphism, and in part to suboptimal settings for abundant life. Many of the unmetamorphosed formations are dark shales, indicating anoxic conditions, or were deposited under conditions of high sediment input. To date, a few undescribed fossils have been reported from rocks of this age at the ROVA parks and SARA, and there are rare fossils in some of the bedrock units of MABI and SAGA, although not yet found in these parks.

Pangaea broke up during the Mesozoic Era, which follows the Paleozoic Era. A period of extension that formed the Atlantic Ocean began during the Triassic, as seen through failed rift valleys and lava flows along the east coast of North America that date to that time. Approximately 11,000,000 km2 (4,200,000 miles2) of central Pangaea was covered by volcanic rocks during the eruptive events; these rocks are now known as the Central Atlantic Magmatic Province (CAMP). The system of rift basins, paralleling the Appalachian Mountains, was active for 35 million years. Two of the better-known basins are represented by bedrock under NETN parks: the Newark Basin associated with MORR, and the Hartford Basin associated with SPAR. These basins are known for their voluminous but short-lived volcanism, active over a few hundred thousand years at approximately 201 Ma, and for their cyclic lake deposits. The cyclic deposits have been correlated to climate cycles that operate today in response to changing parameters of Earth's orbit and axis. The cycles permit very fine dating resolution, as fine as annual resolution. The paleontology of the rift basins is of great interest because the rocks were deposited during a period of great change in plant and animal life, and the cyclic nature of the deposits allows study of evolutionary processes in great detail, such as of the semionotid fish that lived in the various lakes. The most famous fossils of the basins are probably the numerous dinosaur tracks. No fossils have yet been found in these rocks at MORR, but the Portland Formation at Springfield Armory's Watershops (not part of SPAR, but associated) yielded the holotype or original name-bearing specimen of the small dinosaur *Anchisaurus polyzelus*. North America was moving north during the time of deposition in these basins: deposition in the Newark and Hartford basins began when these locations were only a few degrees north of the paleoequator, and they reached approximately 20° to 25° N by the end of deposition. Climate was temperate to arid during deposition.

After the breakup of Pangaea, the eastern half of North America in general entered a relatively quiet phase of highland erosion onto coastal and interior lowlands. The most influential geological events since the breakup were the Pleistocene glaciations, occurring between 2.59 million years ago and 12,000 years ago. Several glacial advances of varying extents and durations occurred, with the most recent (late Wisconsinan advance) overprinting much of the previous activity. Ice did not advance farther south than northern New Jersey during the most recent glacial periods (the Illinoian and Wisconsinan), although it extended somewhat farther south during at least one earlier advance. The late Wisconsinan glacial advance began about 40,000 years ago, and ended about 12,000 years ago. During this time, the Laurentide Ice Sheet advanced out of Canada. When the ice sheet retreated, meltwater lakes formed in the recently deglaciated areas, temporarily trapped by glacial debris, blocks of ice, and the retreating edges of the glaciers. Large lakes filled modern river valleys and other topographic lows. These include Glacial Lake Albany in the Hudson River Valley (ROVA parks and SARA), Glacial Lake Bouvé, associated with Boston (BOHA), Glacial Lake Hitchcock in the Connecticut River Valley (MABI, SAGA, and SPAR), glacial lakes Concord and Sudbury, associated with the Concord River (MIMA), and Glacial Lake Passaic, associated with the Passaic River (MORR). Glacial lakes persisted for hundreds to thousands of years before they drained. Glacial lake deposits are known for thin annual layers called varves, which are used for establishing chronologies. Large and small glacial lakes preserve a variety of fossils, typically microfossils like pollen, spores, diatoms (algae that secrete "shells" of silica), jaws and other hard parts of insect larvae, and ostracodes (seed shrimp). Leaves and other plant fossils, bivalves, gastropods, and trace fossils from invertebrates and fish are also found. The microfossils and plant fossils are often used for paleoecological studies, tracing changing climate conditions since the retreat of the glaciers. MIMA, MORR, the ROVA parks, SAGA, and SARA all have deposits with the potential for glacial lake or wetland fossils, and ACAD and MABI have fossils from bogs or former lakes. Former swamplands and wetlands (mucklands) also have great potential for Pleistocene mammal fossils, such as sloths, mastodons, mammoths, and various ungulates. Mastodons are particularly common, and a nearly complete specimen is known from the immediate vicinity of ELRO and HOFR of the ROVA parks.

The glacial retreat had additional consequences for coastal areas, such as those represented by ACAD, BOHA, and SAIR. During glaciation, land is depressed by the great mass of ice; when the ice is removed, the land eventually rises (this phenomenon is called postglacial or isostatic rebound). In coastal areas, much land that is presently above sea level was temporarily submerged during the lag between the ice retreat and rebound. This includes parts of ACAD, BOHA, and SAIR; postglacial marine deposits are

represented by clay layers at these parks, which are fossiliferous at ACAD and BOHA. Typical fossils from these deposits are foraminifera (protists that secrete "shells", typically of calcite), bivalves, and gastropods. Postglacial deposits at BOHA should not be confused with shell layers that formed earlier, during an interglacial period. Isostatic rebound ended the brief marine incursion within a few thousand years. At the same time that isostatic rebound was occurring, sea level was rising from the return of glacial meltwater. However, it took several thousand years for the rate of sea level rise to exceed the rate of isostatic rebound. Thus, a chart of sea level for coastal New England since deglaciation would show an initial sea level much higher than present, followed by a period of lowering sea level from isostatic rebound, eventually reaching a point much below the present level, and finally a period of rising sea level until the present. During the period between isostatic rebound overtaking sea level rise, and sea level rise then overtaking rebound, wide swaths of dry land that are now submerged emerged from the water. These new coastal areas became forested and were inhabited by humans; remains of this short terrestrial period can be found in the vicinity of ACAD and BOHA.

Humans first appeared in the NETN region over 12,500 years ago. Early inhabitants interacted with the last of the Pleistocene megafauna. After the extinction or extirpation of most of the large mammals, coastal resources became an important resource for the human population; shell middens are present at ACAD and BOHA, and in the vicinity of MABI and SAIR. There are also a few cases of humans using potentially fossiliferous rocks as tools. More recently, New England was the birthplace of the study of fossil tracks in the mid 19th century, and southeastern New York was an early center of mastodon study, with the first teeth found in 1704, and the first skeletons excavated at the turn of the 19th century. While urbanization in the NETN has reduced the opportunities for finding fossils, the concentration of universities and museums has made the area a leader in the study of fossils.

Collectively, the paleontological resources of the NETN 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 National Park Service. Although at least 224 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.

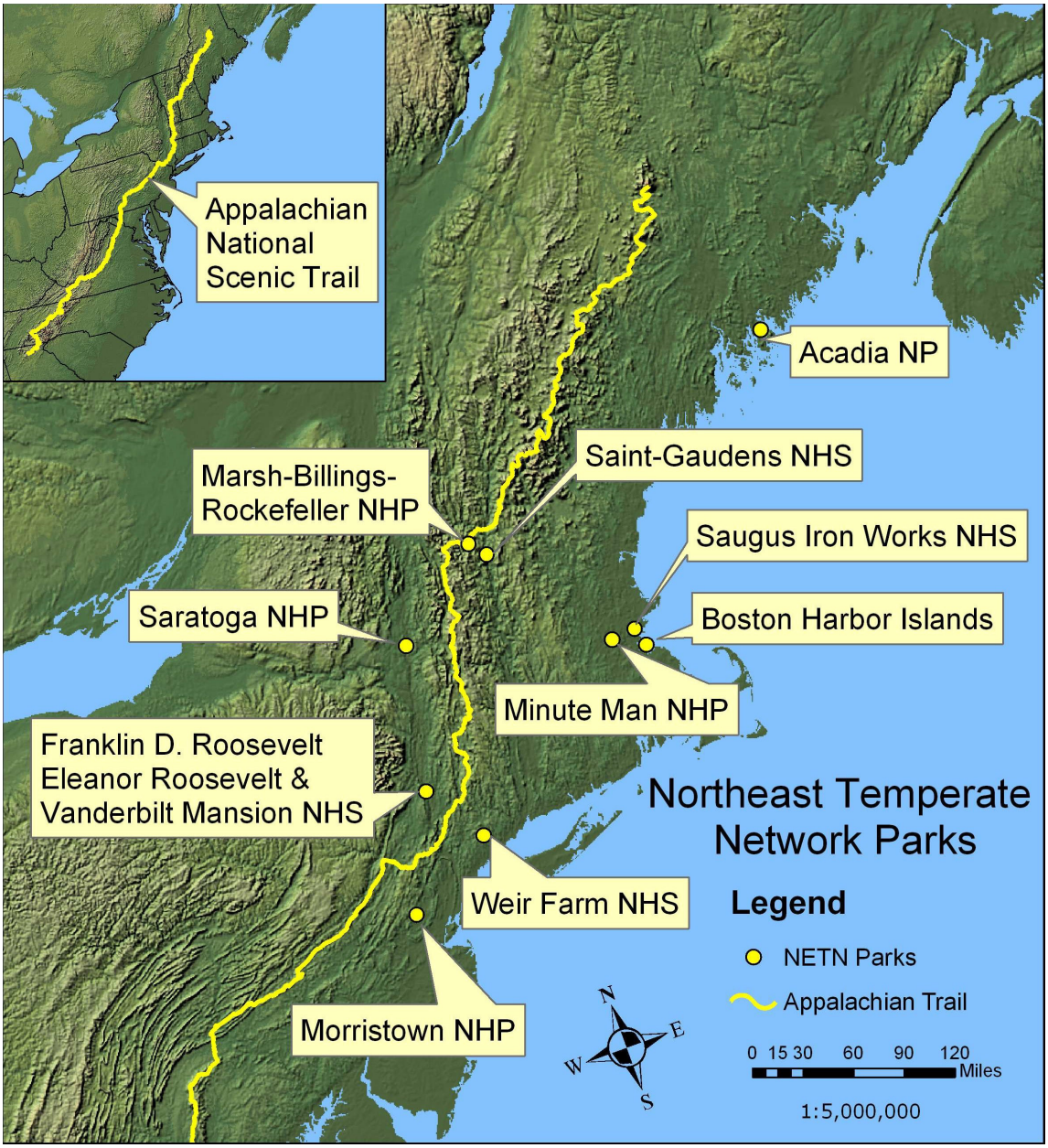


Figure 1. Map of Northeast Temperate Network parks. Courtesy NETN Staff.

Paleontological Resource Inventory Strategies and Methodology

To better document fossil occurrences and provide baseline paleontological resource data to National Park Service areas, the NPS Geologic Resources Division (GRD) and the NPS Inventory and Monitoring Program (I&M) have established three paleontological resource inventory strategies, each with its own goals and objectives. These strategies include: comprehensive park-specific paleontological resource inventories, Servicewide thematic paleontological resource inventories, and Inventory and Monitoring Network-based baseline paleontological resource inventories. Santucci and Koch (2003) outline basic paleontological resource monitoring strategies and potential threats to fossil resources.

Comprehensive Park-Specific Paleontological Resource Inventories

Comprehensive park inventories are designed to identify all known paleontological resources within a single park 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, including resource management, museum curation, law enforcement, and interpretation. Paleontology-specific training for park staff is an important component of many comprehensive paleontological inventories. Park-specific comprehensive paleontological resource inventories have been completed at Yellowstone National Park (NP) (first park to have inventory completed), Amistad National Recreation Area (NRA), Arches NP, Bighorn Canyon NRA, Death Valley NP, Grand Teton NP, Santa Monica Mountains NRA, Walnut Canyon National Monument, and Zion NP.

Servicewide Thematic Paleontological Resource Inventories

Servicewide thematic paleontological resource inventories compile data regarding specific types of paleontological resources that occur in parks throughout the NPS. 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). Cave fossils occur in two contexts: first, fossils can be preserved in the marine limestones in which caves develop; second, the remains of Pleistocene/Holocene animals and plants that lived, died or were transported into caves after death are common types of cave fossils. Servicewide thematic inventories have also been initiated for fossil fish (Hunt et al. 2006) and fossils found in cultural resource contexts (Kenworthy and Santucci 2006).

Inventory and Monitoring Network-Based Paleontological Resource Inventories

Network-based paleontological resource inventories compile baseline paleontological resource data for each of the parks within a particular network. Network-based inventories have been completed for 29 of the 32 I&M networks including this report. Research for summaries of the Central Alaska, Northern Great Plains, and South Florida/Caribbean networks are currently underway. NPS I&M Program funding is targeted to complete paleontological resource summaries for the remaining networks in FY2010. Citations for the completed reports are in the Additional References section.

I&M Network Paleontological Resource Inventory Methodology

Network-based paleontological inventories were funded directly by the individual networks from 2002 to 2006. In FY2006, the National I&M Program provided funds to complete reports for the remaining networks between FY2006-2009. These funds provide stipends or salary for contractors, interns, paleontological technicians, or NPS employees who perform data mining activities. A brief summary outlining the basic techniques used to assemble an I&M Network-based inventory follows below.

The most valuable component of any paleontological resource inventory is an intensive literature search. Various databases contain citations for geology or paleontology themed publications. The American Geological Institute's GeoRef is the primary database for geology references and contains more than three million references from the middle 1700s through today. GeoRef, available in both online or CD-ROM versions, is accessible at many major university libraries. The NPS NatureBib (which supersedes PaleoBib) is an internet-based database for scientific citations presented as bibliographic references but does not yet contain a comprehensive paleontology bibliography. The U.S. Geological Survey (USGS) Library (main branches in Reston, Virginia; Denver, Colorado; and Menlo Park, California) is a premier repository for geologic publications, and houses many of the publications obtained for the network-based paleontological resource inventories. Many USGS publications are available for free download online at the USGS Publications Warehouse (http://pubs.usgs.gov). Additionally, museum libraries such as at the Smithsonian Institution's National Museum of Natural History, and university libraries provide access to a wide range of geological and paleontological publications. Individual state geological surveys (http://www.stategeologists.org/) are also excellent sources of information, as are geologists familiar with local geology and paleontology.

The literature search also includes unpublished material (i.e. gray literature) from park files, museum archives, local newspapers, field notes, etc. These are often excellent sources of anecdotal information about park resources. 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 yield information regarding park paleontological resources. These interviews frequently result in capturing data that might otherwise be undocumented and potentially lost or unrecognized.

Bibliographic searches include a search for geologic maps associated with each park. The NPS Geologic Resources Division maintains a database of geological map coverage for many parks (current contact is Tim Connors). A digital geologic map for each park is one product of the NPS GRD Geologic Resource Inventory program. In addition, the USGS National Geologic Map Database (NGMDB; http://ngmdb.usgs.gov) lists maps for a given geographic area or place name and provides information on how to obtain maps. 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.

Fossils are most commonly found in sedimentary rocks such as sandstones, shales, and limestones. Fossils, with few exceptions, are not found within igneous rocks (volcanic or intrusive origin) or metamorphic rocks (altered by heat, pressure, and/or chemical change) due to the extreme heat and/or pressure associated with their origin and history. The nomenclature for geologic formations can be confusing, but the NGMDB includes a searchable lexicon of valid geologic formation names that can be very useful (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.

Organization of the Reports

Information from these various sources is compiled into a narrative report for each park. Each park report includes an executive summary of the park's significance and a brief description of the geologic background. Geologic formations mapped within the park that are known to preserve fossils within the park are described in the "Sources of Paleontological Resources" section. Geologic formations mapped within the park that potentially preserve fossils (based on fossil discoveries outside the park) are listed in the section "Potential Sources of Paleontological Resources." Field investigations could determine whether these "Potential Sources" do preserve fossils within the park. The park narratives also include a summary of paleontology specimens in park museum collections and, where applicable, highlight fossils that occur in cultural resource contexts (see Kenworthy and Santucci 2006).

In addition to this geologic and paleontologic content information, the authors suggest preliminary recommendations for each park regarding that park's management of the paleontological resources based on discussion with park staff and other geologists or paleontologists. A comprehensive list of publications related to paleontological research associated with the park is also included. The reports include all bibliographies that may be associated with a park's paleontological resources. However, bibliographic data are subdivided in the report into those cited in the narrative (Literature Cited) and other associated publications (Additional References). Finally, a list of data sets relative to the park's paleontological resources is developed. These data sets include museum collections where fossils from the park are reposited and locations of archives or other files and information relative to the park.

The reports undergo peer review by professional geologists, paleontologists, and staff from each park for accuracy before being submitted to the network. These reports are designed to consolidate baseline paleontological resource data for each park to support management operations and decision-making. Therefore, the reports are written in NPS language and in addition to the scientific information, the reports address issues of resource management, protection, and interpretation.

Within the "Sources of Paleontological Resources" or "Potential Sources" sections, information is synthesized regarding the scope and significance of fossils documented from geologic formations mapped within the park. Fossils are assessed and organized based upon taxonomy, stratigraphy, and paleoecology. Paleontological resources can be divided into six taxonomic groups: protists (unicellular plants and animals – typically plankton), microbes (fossil bacteria – typically found in stromatolites or as coatings on fossils), paleobotany (fossil plants), invertebrates (multicellular animals without backbones), vertebrates (animals with backbones), and trace fossils (evidence of biological activity such as tracks, traces, burrows, etc.). Fossils typically have a finite stratigraphic range and occurrence in geologic time (a geologic time scale is included as an appendix). The period between the first and final occurrences of a fossil species is referred to as the stratigraphic range zone. Thus specific groups of fossils may be identified directly with a particular stratigraphic unit or stratigraphic range. Likewise, rock units often represent specific ancient sedimentary depositional environments. Paleoecologically, fossil groups may occur primarily, or in some instances only, in specific environmental conditions (temperature, aquatic, terrestrial, etc.). Thus many fossils may be useful as indicators of past environmental conditions.

The "Sources" and "Potential Sources" sections are organized stratigraphically presenting the geologic and paleontologic information chronologically from oldest to youngest. Important fossils documented from localities outside a park are often reported in the park inventory, as these data may indicate the potential for fossils in similar stratigraphic units exposed within park boundaries.

Appalachian National Scenic Trail (APPA), one of the NPS units of the Northeast Temperate Network, was handled differently than the other units for the purposes of this report, because of its unique characteristics. Traversing parts of 14 states, six I & M networks, and dozens of fossiliferous formations, APPA required a coarser level of detail at this time. Digital state geology maps maintained by the U.S. Geological Survey (http://tin.er.usgs.gov/geology/state/) were used to establish baseline geology, and would be a useful place to start for further geological and paleontological investigations at APPA.

Given the tremendous diversity of past life, the existence of life for over a billion years, and the range of environments to which life has adapted, there is a broad spectrum of research interests in paleontology. It is not surprising that most of what is to be learned about the history of life remains to be discovered. Through research, more than 224 NPS areas have been identified as containing paleontological resources. However, the paleontological research for a particular park may vary widely from an incidental fossil discovery, to over a century of intensive paleontological investigations. Therefore, the inventory reports include information on the history of paleontological research, identification of any museums or universities serving as repositories for park fossils, and a complete bibliography.

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. The proper management of resources identified through these inventories is mandated by many NPS policies including the newly enacted Paleontological Resource Preservation Act (PRPA).

The Paleontological Resource Preservation Act (P.L. 111-11), signed into law on March 30, 2009, will serve as explicit authority for the management, protection and interpretation of paleontological resources in parks, in addition to the NPS Organic Act of 1916. The 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

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.

Paleontological resource management issues were the subject of a Report of the Secretary of the Interior in May 2000, 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. That report, an "Assessment of Fossil Management on Federal and Indian Lands," summarized a number of principles relating to paleontological resources and their management. 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. Links to the above documents are listed in the "Additional References" section.

The Geologic Resources Division and Geological Society of America are assembling a geologic resource monitoring manual that includes chapters on various geologic resources, including in situ paleontological resources (Santucci et al. 2009), and a set of monitoring vital signs that may be applicable to a variety of parks. Monitoring represents the next phase in paleontological resource management, following the initial research inventory (represented by this report) of potential fossils and any subsequent field work to identify fossils within a park.Contact the Geologic Resources Division for more information or to obtain a copy of the report.

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.

Literature Cited

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. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/8%20Hunt%202.pdf. Accessed May 2009.

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. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed July 2009.

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., 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. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/21%20Santucci%20et%20al..pdf. Accessed July 2009.

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. Online. http://nature.nps.gov/geology/paleontology/pub/cavepaleo.pdf. Accessed July 2009.

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.

Santucci, V. L. and A. L. Koch. 2003. Paleontological resource monitoring strategies for the National Park Service. Park Science **22**(1):22-25.

Additional References and Websites of Interest

Website addresses are current as of November 2009.

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. TIC# D-157. National Park Service, Fort Collins, Colorado.

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.

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.

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.

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.

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.

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.

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

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.

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

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.

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.

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.

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.

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.

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

Koch, A. L. and V. L. Santucci. 2003. Paleontological resource inventory and monitoring—**Greater Yellowstone Network**. TIC# D-1025. National Park Service, Denver, Colorado.

Koch, A. L. and V. L. Santucci. 2003. Paleontological resource inventory and monitoring—**Mediterranean Coast Network**. TIC# D-177. National Park Service, Denver, Colorado.

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.

Santucci, V. L. 1998. The Yellowstone Paleontological Survey. YCR-NR-98-1. Yellowstone Center for Resources, Yellowstone National Park, WY.

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.

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.

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.

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

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.

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. TIC# D-90. National Park Service, Fort Collins, Colorado.

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.

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.

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.

General NETN Information
NETN I&M Network: http://science.nature.nps.gov/im/units/NETN/index.cfm

Geological Survey Websites
Connecticut Geological and Natural History Survey:
http://www.ct.gov/dep/cwp/view.asp?a=2701&q=323434&depnav_gid=1641

Maine Geological Survey: http://www.maine.gov/doc/nrimc/mgs/mgs.htm

New Hampshire Geological Survey: http://des.nh.gov/organization/commissioner/gsu/index.htm

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

New York State Geological Survey: http://www.nysm.nysed.gov/nysgs/index.html or
http://nygeosurvey.geology-forum.com/

Vermont Geological Survey: http://www.anr.state.vt.us/dec/geo/vgs.htm

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

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

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

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/

Amherst College Museum of Natural History: https://www.amherst.edu/museums/naturalhistory

Connecticut State Museum of Natural History: http://www.cac.uconn.edu/mnhhome.html

Maine State Museum: http://www.maine.gov/museum/

Morris Museum: http://www.morrismuseum.org/

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

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/

Robert M. Linsley Museum (Colgate University): http://departments.colgate.edu/geology/museum/

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

Other Websites of Interest for NETN Geology

Appalachian Trail Conservancy: http://www.appalachiantrail.org/

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

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

Geological Society of Connecticut:
https://wesfiles.wesleyan.edu/home/pletourneau/Geological_Society_of_Connecticut.html

Geological Society of Maine: http://www.gsmmaine.org/

Geological Society of New Hampshire: http://www.gsnh.org/

Hudson-Mohawk Professional Geologists' Association: http://www.hmpga.org/

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/

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

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

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

North American Glacial Varve Chronology Project: http://ase.tufts.edu/geology/varves/

Office of the Massachusetts State Geologist: http://www.geo.umass.edu/stategeologist/

Vermont Geological Society: http://www.uvm.org/vtgeologicalsociety/index.html

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.

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 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.usgs.gov

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

Acadia National Park

Acadia National Park (ACAD), the first National Park east of the Mississippi River, preserves the rugged coastal landscapes and geological and cultural resources within portions of Mount Desert Island, Isle au Haut, Schoodic Peninsula, and associated islands. ACAD was proclaimed as Sieur de Monts National Monument July 8, 1916. It was then established as Lafayette National Park February 26, 1919, and renamed Acadia National Park January 19, 1929. Its boundaries have changed a number of times (January 19, 1929; May 23, 1930; May 29, 1935; August 24, 1935; June 6, 1942; December 22, 1944; July 30, 1947; September 7, 1949; August 1, 1950; July 24, 1956; October 3, 1966; March 4, 1968; March 12, 1968; October 15, 1982), with a permanent boundary established May 1986. ACAD currently encompasses 14,637.98 ha (36,171.24 acres).

Saint Croix Island International Historical Site (SACR) is not officially included in the Northeast Temperate Network, but is within the network's geographic area. It is briefly mentioned here because of its geographic proximity and geological similarity to ACAD, both having bedrock dominated by igneous rocks from the middle Paleozoic, and Quaternary glacial and marine influences (see the appendix for a geological time scale). SACR is located on the United States-Canadian border in the Saint Croix River, approximately 110 km (70 miles) northwest of the Schoodic Peninsula unit of ACAD. SACR was authorized as a national monument June 8, 1949, to commemorate the attempted French settlement of 1604, which led to the founding of New France. It was redesignated as an international historic site September 25, 1984. The total legislated area of SACR is 18.17 ha (44.90 acres), of which 11.51 ha (28.44 acres) are current NPS fee owned lands.

Geologic Background

ACAD is located mostly in southern Hancock County, south-central to southeastern Maine, with the Isle au Haut unit in the eastern part of adjoining Knox County. Most of the park's acreage is in the Mount Desert Island unit, 55 km (34 miles) east-southeast of Bangor. Mount Desert Island is a large island with several north-south glacial troughs forming lake basins or, in the case of Somes Sound, a fjord (the only true fjord on the U.S. Atlantic coast; Harris et al. 2004). These troughs dissect what had been a mountain ridge into several peaks, including several over 300 m (1,000 ft) above sea level. The tallest peak is Cadillac Mountain, at 465 m (1,530 ft) in elevation. On Mount Desert Island, Somes Sound divides park lands into two areas east and west of the sound. Several smaller islands are found just off of Mount Desert Island, including the Cranberry Isles to the south and the Porcupine Islands to the northeast. Of these, Baker Island, Bald Porcupine Island, Bar Island (two with this name), Bear Island, Long Porcupine Island, Sheep Porcupine Island, Thompson Island, and The Thrumcap are at least in part included in ACAD, and protection of parts of the Cranberry Isles is managed through ACAD as well. The Schoodic Peninsula unit is roughly 8 km (5 miles) east of Mount Desert Island, separated from it by Frenchman Bay. Part of the mainland's Schoodic Peninsula and the islands Little Moose Island, Pond Island, Rolling Island, and Schoodic Island are within ACAD boundaries here. Finally, the Isle au Haut unit includes approximately the southwestern half of Isle au Haut, as well as the island's Eastern Head point and a smaller island, Western Ear. Isle au Haut is located southeast of Penobscot Bay, a large embayment formed by the partially drowned valley of the Penobscot River. It is near several other large islands, including Vinalhaven Island and North Haven Island to the west, Deer Isle to the north, and Marshall Island, Swans Island, and Long Island to the northeast. The Isle au Haut unit is roughly 30 km (19 miles) southwest of Mount Desert Island.

The geology of ACAD and the surrounding region has long been studied, particularly on Mount Desert Island, and there are a number of publications that touch on ACAD geological units and features. Most publications have been about Mount Desert Island's igneous geology, but there are a number of more general works as well (Shaler 1889; Chadwick 1939, 1944; C. Chapman 1970; Gilman et al. 1988; O'Connor and White 1988; Caldwell 1998; Harris et al. 2004). A number of publications also include references to or description of fossils from Mount Desert Island and ACAD (Shaler 1889; H. Chapman

1892; W. Davis 1894; Blaney and Loomis 1916; Bascum 1919; Brown and Branson 1932; Knox 1956; Leonard and Cameron 1979; Tolonen et al. 1980; Norton and Kahl 1987; Gilman et al. 1988; Lowell 1989, 1990; Russell et al. 1993; Barnhardt and Kelley 1995; Norton et al. 1997; Brandes et al. 2000; Schauffler and Jacobson 2002; Schauffler et al. 2007; J. Kelley et al. 2009; Perry et al. 2009). Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held for ACAD during June 2008, which resulted in a geologic scoping summary (Graham 2008); this is an internal NPS document.

Most of New England is made up of exotic accreted terranes, which are blocks of crust that originated somewhere other than their present location and are demonstrably different from surrounding rocks. The timing of assembly and the origins of the various terranes are heavily debated (Skehan 2001; Wintsch et al. 1993, 2007). Many older references describe ACAD as on the Avalon Terrane (Gilman et al. 1988; Caldwell 1998; Harris et al. 2004), but it is now thought to have been part of the Ellsworth Terrane (Seaman et al. 1999; Schulz et al. 2008), with the Avalon Terrane adjacent to the southeast (Reusch 2001) (note that this can become confusing as different authors may use different concepts of the Avalon Terrane). The Ellsworth Terrane was part of a larger block called Gander or Ganderia, and appears to have formed during the Cambrian as part of an oceanic rift in the early stages of growth, like the modern Red Sea. This ocean rift is interpreted as having progressed to split Gander from the Southern Hemisphere supercontinent Gondwana, becoming an ocean basin (the Rheic Ocean) (Schulz et al. 2008). Of course, as with any information about the assembly of eastern North America, this interpretation is subject to change. SACR is within the St. Croix Terrane (Ludman and Berry 2003) or the Mascarene Terrane (Miller et al. 2007).

For many years, the prevailing interpretation of how the east coast of North America assembled attributed the collision of the Avalon Terrane and other associated terranes to the Acadian Orogeny (a mountain-building event) of the Devonian (Caldwell 1998; Levin 1999; Harris et al. 2004). More recently, it has been proposed that the Avalon and Gander terranes collided with North America during the late Ordovician and early Silurian, as part of the Salinic Orogeny (Murphy and Keppie 2005; Murphy et al. 2007), or that the Gander collision was part of the Salinic Orogeny and the Avalon collision was part of the later Acadian Orogeny (van Staal et al. 2004; van Staal and Whalen 2006). In both recent models, the large igneous intrusions of ACAD and other areas of coastal Maine are associated with subduction (where a crustal plate is overridden by another plate) and melting that occurred during the Acadian Orogeny.

Large-scale igneous intrusions occurred along what is now coastal Maine during a period of time centered in the Late Silurian. At ACAD, they are represented by the Cadillac Mountain Igneous Complex, dating between roughly 425 and 417 Ma (million years ago) (Wiebe et al. 1997a). Rocks of similar age and composition are present on the Schoodic Peninsula (Gilman et al. 1988; Koteas and Seaman 2006) and Isle au Haut (Gilman et al. 1988; Wiebe and Chapman 1993). The intruding igneous rocks pushed into a shallow level of the crust, perhaps 5 to 7 km (3 to 4 miles) below the surface (Wiebe et al. 1997b), crystallizing among volcanic rocks being erupted at the same time (Wiebe et al. 1997a, 1997b).

The later Alleghenian Orogeny, during which eastern North America collided with West Africa in the final stages of the formation of the supercontinent Pangaea, had little effect on the area (Harris et al. 2004). Pangaea broke up during the Mesozoic Era, which follows the Paleozoic Era. A period of extension that formed the Atlantic Ocean began during the Triassic (Caldwell 1998; Levin 1999), as seen through failed rift valleys and lava flows along the east coast of North America that date to that time (Levin 1999; see the Morristown National Historical Park and Springfield Armory National Historic Site summaries in this document for more information on this period of time). This Triassic-Jurassic extension was followed by uplift and erosion that extended through the Cenozoic, bringing the igneous bodies to the surface (Harris et al. 2004). Maine has been relatively quiet, geologically speaking, since the Triassic-Jurassic rifting, although earthquakes occur from time to time. A series of small to medium quakes struck between the fall of 2006 and the spring of 2007, mostly between September and November 2006 (Ebel et al. 2008), with the most powerful measured at 4.0 Mw (Kim and Gold 2007) or 4.2 Mw (Ebel et al. 2008).

The most influential geological events in coastal Maine since the rifting of Africa to date were the Pleistocene glaciations. While multiple glacial events occurred during the Pleistocene, only evidence for the most recent (the late Wisconsinan glaciation) is preserved in Maine. This glacial advance began about 40,000 years ago (Caldwell 1998). During this time, the Laurentide Ice Sheet advanced out of Canada and covered the state (P. Davis et al. 2003). At least 600 m (1,970 ft) of ice covered Mount Desert Island at the height of glaciation (Lowell 1980). The ice reached its maximum extent between 22,000 and 20,000 radiocarbon years before present (Dorion et al. 2001), extending as far as Georges Bank, now over 100 km (60 miles) east of the Massachusetts shore (Harris et al. 2004) (note that radiocarbon dates are not the same as calendar dates, and that radiocarbon years require calibration to yield calendar years. Uncalibrated radiocarbon dates in publications are often denoted with "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. Therefore, dates that are not labeled with "calendar years" or something similar should be assumed to be uncalibrated radiocarbon dates). Beginning its retreat soon after, the ice sheets left Penobscot Bay between 14,500 and 14,000 years ago (Syverson et al. 2009), and left Mount Desert Island around 14,000 years ago (Schauffler et al. 2007), pulling back to the approximate location of the modern Maine coast between 13,800 and 13,500 years ago (Caldwell 1998). Deglaciation at Mount Desert Island may have been due to ice calving at marine embayments (Lowell 1980). The Wisconsinan glaciation ended approximately 12,000 years ago (Caldwell 1998).

Local sea level has varied greatly since deglaciation. The exact timing and relative sea levels attained differ by location and from source to source, but the basic chronology is that during and shortly after the retreat of the glaciers, much of coastal Maine was submerged by marine waters, due to the temporary depression of the land surface from the great weight of the ice. A blanket of sediment formed from glacial clay and marine material was deposited over this depressed coastal area (the Presumpscot Formation; Caldwell 1998). Much of ACAD was under water (Dorion et al. 2001), with sea level reaching 135 m (445 ft) above the present level (Rubin and Morgan 2002). After the weight of the ice was removed, the land began to rise; this phenomenon is known as isostatic rebound. At the same time that isostatic rebound was occurring, sea level was rising from the return of glacial meltwater. However, it took several thousand years for the rate of sea level rise to exceed the rate of isostatic rebound. Thus, a chart of sea level for coastal Maine since deglaciation would show an initial sea level much higher than present, followed by a period of lowering sea level from isostatic rebound, eventually reaching a point much below the present level, and finally a period of rising sea level until the present. Of course, within this chart the curve would not be smooth, but would have changes in rate in response to various factors. A recent chart of the northern Gulf of Maine sea level is presented in Belknap et al. (2005), which depicts sea level falling steeply after glaciation until reaching a lowstand of between –50 m (–165 ft) and –60 m (–200 ft) at about 11,000 radiocarbon years before present. After this, sea level rose sharply for about a thousand years, and then more slowly until the present, with two extended periods of little change (Belknap et al. 2005). At Mount Desert Island, the early rate plateau persisted until about 7,000 years ago, when sea level rose slowly from –25 m (–80 ft) to –15 m (–50 ft). This period has been called a "slowstand", and deposits formed during the period are fossiliferous (J. Kelley et al. 2009). Drowned coastal deposits in general are fossiliferous and contain methane, which they are outgassing. This phenomenon may be related to distinctive pockmarks on the seafloor. Somes Sound, a former lake, is one area with pockmarks (J. Kelley et al. 2003).

Humans arrived in the Penobscot River area during the late Pleistocene (A. Kelley and Sanger 2006), over 10,000 years ago. The oldest extant coastal sites are about 5,200 years old, although older sites have probably been submerged by rising sea level (W. Anderson et al. 1984). For example, stone tools possibly from the Archaic cultural period have been recovered off of Bass Harbor, Mount Desert Island (J. Kelley et al. 2009). People have lived on Mount Desert Island for several thousand years, with the first being the Red Paint People, noted for their use of ochre pigments for funerary purposes. These people made deep shell middens on the island (Harris et al. 2004).

From oldest to youngest, the bedrock geology of the Mount Desert Island unit of ACAD and its neighboring islands consists of the Ellsworth Schist (Cambrian), Bar Harbor Formation (Silurian),

Cranberry Island Volcanics (Silurian), and several igneous units dating to the Silurian, the most prominent of which are unnamed gabbro and diorite, the Southwest Harbor Granite, the Cadillac Mountain Granite (with associated shatter zone of broken host rock), and the Somesville Granite; most of these are considered part of the Cadillac Mountain Igneous Complex (Gilman et al. 1988; ages after more recent dating). The Schoodic Peninsula unit is underlain by Silurian-Devonian granite (Osberg et al. 1985; Gilman et al. 1988). Finally, the Isle au Haut unit is underlain by the Castine Formation (Cambrian) in the west and Silurian-Devonian gabbro, diorite, and granite in the east (Osberg et al. 1985; Gilman et al. 1988). SACR is underlain by the Red Beach Granite, of Middle or Late Devonian age (Ludman and Berry 2003).

Several of these units are sedimentary in origin, but fossils have never been described from them (Churchill-Dickson 2007). While it would be inappropriate to include them as potential sources of fossil resources, they are here covered briefly in the event that fossils are found from one or more of them. These units include the Ellsworth Schist, Castine Volcanics, Bar Harbor Formation, and Cranberry Island Volcanics.

The Ellsworth Schist is a heterogeneous marine unit (Stewart et al. 1996). Before metamorphism, it was composed of deposits of mud and volcanic debris on a seafloor (Gilman et al. 1988), with some sandstone (now quartzite), limestone or dolomite (now marble), and iron and manganese precipitates (Schulz et al. 2008). It is primarily composed of dark green or gray schist in the northwestern area of Mount Desert Island, and is also present on Thompson Island (Gilman et al. 1988). The Ellsworth Schist is a thick unit, up to 4.7 km (2.9 miles) thick, and has been dated to 508.6 ± 0.8 Ma (Schulz et al. 2008).

The Castine Volcanics are stratigraphically above the Ellsworth Schist, but appears to be made of the same type of rocks, only from closer to the source. Like the Ellsworth Schist, the Castine Volcanics are thick (up to 2 km or 1.2 miles) and include volcanic flows, rocks formed from volcanic debris, carbonates, and precipitates, deposited in a marine setting. The base of the unit is conglomeratic (Schulz et al. 2008). The Castine Volcanics were thought to date to the Devonian and to correlate to the Cranberry Island Volcanics (Brookins et al. 1973; Brookins 1976), but are now known to be Cambrian in age, slightly younger than the Ellsworth Schist (503.5 ± 2.5 Ma per Schulz et al. [2008]). What were described as Devonian ostracodes were reported from limestone beds assigned to the Castine Volcanics on Compass Island in Penobscot Bay (Brookins et al. 1973; Metzger et al. 1982), but these specimens or the limestone must have been reevaluated. Outcrops of the Castine Volcanics can be found on Isle au Haut (Osberg et al. 1985).

The Bar Harbor Formation is composed of tan, gray, and lavender siltstone and sandstone beds that formed in a marine setting, with some volcanic material including ash beds (Gilman et al. 1988; Harris et al. 2004). It is best exposed in discontinuous areas along the northeast coast of Mount Desert Island (Gilman et al. 1988); in fact, it is named for outcrops at Bar Harbor (Graham 2008). This formation has been metamorphosed, but not heavily; Shaler (1889) noted that it did not appear to be metamorphosed enough to destroy fossils. The unit can be 610 m (2,000 ft) thick, with a basal conglomerate (Metzger 1975). Its age is uncertain. It was long thought to be Devonian in age, and younger than the Cranberry Island Volcanics, but these ideas have been rejected (Mose and Metzger 1977). It is now regarded as Silurian in age (Caldwell 1998), older than the 424 ± 1 Ma Cranberry Island Volcanics (Seaman et al. 1999) and the intruding 419 ± 2 Ma Cadillac Mountain Granite (Wiebe et al. 1997a).

The Cranberry Island Volcanics (or Series) are present on the Cranberry Isles and in southwestern Mount Desert Island. These rocks include volcanic flows and ash layers, and some associated metamorphosed marine siltstones and slates (Gilman et al. 1988; Harris et al. 2004). The rocks were sharply folded and compressed shortly after deposition (Harris et al. 2004). The Cranberry Island Volcanics have been dated to 424 ± 1 Ma (Seaman et al. 1999). They are part of a series of units called the Coastal Maine Magmatic Province, dated to the late Silurian and early Devonian, with many units including both basaltic and quartz-rich (felsic) igneous rocks (Seaman et al. 1999). At one time the Cranberry Island Volcanics were thought to represent a different depositional setting of the Bar Harbor Formation, but this has been

rejected (Metzger et al. 1982). The volcanics may instead be the erupted equivalent of the greater Cadillac Mountain Igneous Complex (Wiebe et al. 1997b; Seaman et al. 1999)

The surface geology of the Mount Desert Island Unit is dominated by bedrock outcrops, Pleistocene glacial till (glacial debris), and slightly younger fine-grained marine sediments. Also present are moraines (accumulations of glacial debris), glacial delta deposits, glacial outwash, and coarser marine sediments from the Pleistocene, and beach, salt marsh, freshwater wetland, and talus deposits from the Holocene (Gilman et al. 1988). The only unit among these to have a formal name is the Pleistocene-age Presumpscot Formation (Bloom 1963; Thompson and Borns 1985; identified on Mount Desert Island most recently by Nielson [2006]).

ACAD may have a rich post-glacial fossil record, but relatively little work has been done to date to explore potential occurrences; most occurrences of fossils mentioned in the literature are as part of other projects. The glaciomarine clay sometimes identified as the Presumpscot Formation, and younger marsh, wetland, and lake deposits, can be regarded as fossiliferous on Mount Desert Island and within ACAD. Additionally, Sand Beach, which is made of sand-sized fragments of benthic invertebrates, probably includes older Holocene material as well as contemporary specimens.

Sources of Paleontological Resources

The fossils of ACAD present opportunities for education, interpretation, and continued or future scientific research in the park.

Presumpscot Formation (glaciomarine clay) (upper Pleistocene)

As discussed earlier, most of coastal Maine was briefly submerged after the last glacial retreat, with the glaciomarine Presumpscot Formation representing this period. ACAD is no exception to this, with much of its acreage under water at the time (Dorion et al. 2001). The Presumpscot Formation (or Presumpscot Clay; also called the Leda Clay) was deposited between 15,000 and 11,000 years ago (Richards and Belknap 2003). Present within ACAD, this formation is the only named Quaternary unit of the coastal region. It formed from silt and clay deposited in seawater during and after the glacial retreat, while isostatic loading locally depressed the land 100 to 120 m (330 to 395 ft) below sea level (Nielson 2006). Post-glacial rebound exposed the present nearshore to 60 m (195 ft) below present, and later global sea-level rise flooded the shelf to its present configuration (Belknap et al. 1987; Barnhardt et al. 1997).

The Presumpscot Clay has yielded a diverse, largely marine fossil assemblage. Plant material includes pollen, spores (Knox 1956), logs (Thompson et al. 2008), and other plant macrofossils (R. Anderson et al. 1982). Invertebrates include foraminifera (protists that form "shells"), sponge spicules (Knox 1956), bryozoans ("moss animals"), bivalves, gastropods, the shell-dwelling polychaete worm (bristleworm) *Spirorbis* (Brown and Branson 1932), beetles, ants (Kilian and Nelson 2008), barnacles, decapod crustaceans (crabs, shrimp, lobsters, and allies), ostracodes (seed shrimp), and ophiuroids (brittle stars) (Brown and Branson 1932). There have also been some vertebrate finds, including fish (Brown and Branson 1932) and a few rare large mammals, such as walruses, whales (Caldwell 1998), and at least one mammoth (Hoyle et al. 2004). Walrus remains have been reported from localities including Andrews Island, 31 km (19 miles) west of the Isle au Haut unit, Addison Point, 37 km (23 miles) northeast of the Schoodic Peninsula unit, and Gardiner, 92 km (57 miles) west-northwest of Isle au Haut (Hay 1923; all of these are not necessarily from the Presumpscot Formation). The mammoth bones were found at Scarborough, 140 km (87 miles) southwest of Isle au Haut (Hoyle et al. 2004).

Fossils have been found from several locations in the Presumpscot Formation of Mount Desert Island, and some of them may be within ACAD boundaries, as the locality information in some publications is not detailed enough to be certain. Even if none of the known localities are within the park, it is likely that such fossils are present somewhere in the park. Fossils were first reported from the Presumpscot Formation of the island during the late 19th century. Shaler (1889) reported fossiliferous "Leda Clay" on Mount Desert Island up to 30 m (100 ft) above sea level. Specific fossils were not reported, but he noted

that they were the same type as those found to the south in eastern Massachusetts, in beds of similar age. Such beds, which are known as the Boston Blue Clay in the Boston area, have produced foraminifera, diatoms (algae with silica "shells"), pollen (Judson 1949), mollusks, barnacles, and ostracodes (Kaye 1976) (see the summaries for Boston Harbor Islands National Recreation Area and Saugus Iron Works National Historic Site for more information on the Boston Blue Clay). One specific locality cited by Shaler is Seal Harbor, partially within ACAD boundaries. He noted the presence of a fossiliferous layer 3 m (10 ft) above sea level, including decomposing organic matter, and reported similar fossiliferous clays throughout the coves of Mount Desert Island. Brown and Branson (1932) reported further fossils from Seal Harbor, including foraminifera, bryozoans, bivalves, gastropods, *Spirorbis*, barnacles, decapods, ostracodes, ophiuroids, and fish. These fossils were found on the southern shore, between 28 and 30 m (91 and 100 ft) above sea level, in sandy lenses 3 to 5 cm (1 to 2 in) thick in the clay.

Fossils have been described from the Presumpscot Clay in other areas of Mount Desert Island as well. H. Chapman (1892) reported the discovery of brachiopods, bivalves, and ophiuroids from clay recovered from the "Old Farm" well at Bar Harbor. Chapman regarded these as the first fossils from Mount Desert Island except for unspecified "lowly organized forms" from Seal Harbor. Chapman's locality could be within ACAD boundaries. Blaney and Loomis (1916) and Knox (1956) published on fossils from the clay at Goose Cove, outside of ACAD boundaries. Blaney and Loomis (1916) found brachiopods, bivalves, and gastropods, while Knox (1956) reported on microfossils, including pollen grains, spores, foraminifera, and sponge spicules, which were recovered from clay taken 3 m (10 ft) above high tide near the head of the cove. The Goose Cove fossils are approximately 12,250 years old (Gilman et al. 1988). Blaney and Loomis (1916) also found brachiopods, bivalves, and gastropods at Frenchman's Bay; these fossils could have been found within the present ACAD boundaries. Pete Berquist (former ACAD geologist, pers. comm., January 2010) reported clay exposures on the northeast bank of Otter Creek as a possible microfossil locality. General reports of fossils from the island include W. Davis (1894), who noted the presence of marine fossils in stratified clay layers up to 60 m (200 ft) above sea level on the island, and Bascom (1919), who reported marine fossils in stratified clay 90 to 105 m (300 to 340 ft) above sea level.

Quaternary rocks and sediments (excluding the Presumpscot Formation) (Pleistocene-Holocene)

Quaternary deposits within ACAD units are poorly developed. For example, most glacial debris from Mount Desert Island was pushed off of the island by the ice, and there has been little sedimentary accumulation since then (Harris et al. 2004). Additionally, the lack of large rivers means that fluvial sediments are rare and eroded material is not redistributed (Gilman et al. 1988). There are significant accumulations of organic-rich sediments in freshwater and saltwater wetlands on Mount Desert Island, though (Gilman et al. 1988). Some glacial debris is present as well (Hansen 1980; Caldwell 1998), including moraines left when a glacial front oscillated in location (Chadwick 1945). There are also several trough lakes formed in former glacial valleys, including Eagle Lake, Echo Lake, Jordan Pond, Long Pond, and Seal Cove Pond (Harris et al. 2004), any of which could have fossil records extending to at least the period of deglaciation. Beach and sand bar deposits are also present on and around Mount Desert Island (Harris et al. 2004), and at least one within ACAD (Sand Beach) has excellent potential to be fossiliferous (see below). It should also be noted that glaciers may transport rocks plucked from preexisting fossiliferous formations. Transported erratics from fossiliferous units farther north in Maine are occasionally found in coastal regions (Churchill-Dickson 2007).

Lake, marsh, and wetland deposits are known to have pollen records extending back to at least the Pleistocene-Holocene transition within ACAD, but only the most recent period of time is well known. Given the rich fossil records of similar deposits elsewhere in Maine, it is probable that research focus and not absence of material is the reason why the ACAD record is not more fully known. The main focus of research has been on anthropogenic environmental issues, particularly over the last few hundred years. Examples of such studies include: a peat record covering the past 500 years studied from ACAD's Long Pond, Big Heath, and Sargent Mountain Pond (Norton and Kahl 1987); a peat core from Big Heath Bog and a sediment core from Sargent Mountain Pond, where the period studied went back to 1750 AD

(Norton et al. 1997); material including pollen, spruce needles, leaf fragments, woody fragments, seeds, and charred organics used for dating in six cores from ACAD's Hadlock Brook and Cadillac Brook watersheds, with a record of about 1,500 years (Schauffler et al. 2007); and a note in an abstract about chemical weathering of a sediment record going back 16,500 years from Sargent Mountain Pond (Perry et al. 2009). Lowell (1989, 1990), researching the deglaciation of Mount Desert Island, reported on freshwater diatoms from a core taken from The Bowl, and found that gyttja (organic muck) at the base of his core dated to 11,355 ± 125 radiocarbon years before present.

The most detailed publications concerning Holocene fossils from ACAD are Tolonen et al. (1980) and Schauffler and Jacobson (2002). Tolonen et al. (1980), studying peat accumulation rates, took five peatland cores of various lengths from Big Heath. They found the oldest date in the longest core to be over 7,400 years before present (6,565 ± 90 radiocarbon years before present), and also presented a pollen analysis for the core. Schauffler and Jacobson (2002) studied pollen records from Isle au Haut, Mount Desert Island, and Schoodic Peninsula. The Mount Desert Island pollen came from a spruce stand in Blackwoods, which is within ACAD, and the South Hollow site on Isle au Haut is within the central part of ACAD's Isle au Haut unit by the provided coordinates. The fossils were recovered from wet forested hollows. The Blackwoods core had a fossil record extending to 11,480-11,000 calendar years before present (uncalibrated age 9,970 ± 60 radiocarbon years before present), with wood, charred material, seeds, and bark as well as pollen. The South Hollow core, which is the older of the two Isle au Haut cores, dated as far back as 5,275-4,850 calendar years before present (uncalibrated age 4,410 ± 60 radiocarbon years before present), and included bark, twigs, and charred material besides pollen. The North Hollow core had similar material, but did not go back as far. The Schoodic Peninsula core dated as far back as 7,995-7,805 calendar years before present (uncalibrated age 7,140 ± 60 radiocarbon years before present), and included bark, seeds, plant fragments, and insect parts with its pollen (Schauffler and Jacobson 2002).

Sand Beach, which is part of the Mount Desert Island unit, and a beach on nearby Little Cranberry Island are rare examples of high-latitude carbonate beaches. Their sediment is made up of sand-sized fragments of benthic organisms, including foraminifera, red algae, bryozoans, bivalves, gastropods, barnacles, and echinoids (sea urchins) and other echinoderms, with barnacles, bivalves, and echinoids the most common constituents (Leonard and Cameron 1979; Barnhardt and Kelley 1995). These fragments are considered recent (Leonard and Cameron 1979), but some are doubtless older. Offshore deposits elsewhere around Mount Desert Island have seagrass, bivalves, and peaty material from submerged lagoons and tidal flats (J. Kelley et al. 2009), which have the potential to wash onshore. This material, which also includes artifacts, was deposited during the slowstand that ended around 7,000 years ago; slowstand deposits are probably the most favorable setting for finding submerged coastal deposits on the Maine shelf (J. Kelley et al. 2009). In Penobscot Bay, Holocene sediments include organics, wood, and bivalves (Belknap et al. 2002).

There are also several informal references to Quaternary fossils at ACAD. These include personal communications regarding biological material such as bivalves and pollen preserved in postglacial marine and lake sediment, dating back approximately 10,000 years (P. Super, ACAD, pers comm. to M. Bacon, Fossil Butte National Monument, September 1998), and regarding barnacles and bivalves in a former sea cave (J. Kelley, University of Maine geologist, pers. comm. to V. Santucci, 2001). Shell beds that are potentially fossiliferous may be present on Baker Island and some of the other smaller islands of ACAD (P. Berquist, pers. comm., January 2010). Additionally, the geologic scoping summary implies the presence of fairly old beach shells (dated by radiocarbon) and paleontological material in cores (Graham 2008).

Numerous Quaternary-age (mostly Holocene) sites with material suitable for paleoecological work or radiocarbon dating are known within approximately 100 km (60 miles) of ACAD (Stuvier and Borns 1975 [including the Presumpscot Formation]; Russell et al. 1993; Gehrels et al. 1996; Belknap and Kelley 2006; Clark et al. 2007). Fossils recovered from the Holocene deposits include foraminifera (Gehrels 1999), the stonewort *Chara* (R. Anderson et al. 1982), seaweed (Stuvier and Borns 1975), gyttja, peat, sphagnum moss, roots (Roos-Barraclough et al. 2006), pollen (R. Anderson et al. 1982), plant fragments, tree stumps (Gehrels et al. 1996), wood (Johnson et al. 2007), tundra plants, fungi (R. Anderson et al. 1982), bivalves

and other shell fragments (Johnson et al. 2007), and fish bones (R. Anderson et al. 1982). One site with a particularly diverse assemblage is Gould Pond, 84 km (52 miles) northwest of Mount Desert Island. This site has both Presumpscot Formation clay and younger sediment. The younger sediment includes *Chara*, pollen, tundra plants, fungi, and fish (R. Anderson et al. 1982).

Park Collections

Seeds, bones, and shells, between 3,000 and 800 years old and from archeological sites, are in ACAD collections (R. Cole-Will, ACAD cultural resources program manager, pers. comm., January 2010). Ann Dieffenbacher-Krall collected approximately 300 seeds in 1997 from sediment samples, which she reported as paleontological (B. Childrey, ACAD, pers. comm. to V. Santucci, December 2002), but as Rebecca Cole-Will reported that there were no fossil materials in ACAD collections (pers. comm. January 2010), these specimens must have been reevaluated, or are elsewhere.

Postglacial material from ACAD has been studied by researchers from the University of Maine and the University of Massachusetts (P. Super, pers comm. to M. Bacon, September 1998). For example, Schauffler and Jacobson (2002), who described pollen from ACAD's Isle au Haut and Mount Desert Island units, were affiliated with the University of Maine. Additionally, the fossils reported by H. Chapman (1892) were sent to the Academy of Natural Sciences in Philadelphia, Pennsylvania.

Cultural Resource Contexts

There is evidence of human activity on Mount Desert Island for thousands of years. The earliest evidence for human occupation in Frenchman Bay consists of Middle Archaic artifacts (approximately 7,000 – 6,000 years before present) recovered by scallop draggers on now submerged landforms off Mount Desert Island (R. Cole-Will, ACAD, pers. comm., April 2010). Conditions favorable for shellfish began during the mid-Holocene, and shell middens became common around 3,200 years ago (Schauffler and Jacobson 2002). Note, though, that coastal sites are threatened by rising sea level and erosion, and older sites, which are closer to the coast, have been disproportionably affected (Sanger 1981; W. Anderson et al. 1984). Bones, shells, and seeds have been recovered from archeological sites within ACAD; they are thought to be between 3,000 and 800 years old (R. Cole-Will, pers. comm., January 2010). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Food bone remains and tools made from bones are widely preserved in shell midden contexts on the Maine coast, including several sites within ACAD or the greater Frenchman Bay area (Sanger and Johnson 1980; Sanger 1988, 1989; Spiess and Lewis 2001; Will 2002). Faunal remains are representative of a wide-variety of food resources harvested by Native people and include shellfish, fish, birds, and mammals. Carbonized seeds and macro plant fossils are less common, but do preserve (Sidell-Asch 1999). Clay and silt from the fossiliferous Presumpscot Formation was used in pottery, and potentially fossiliferous chert, jasper, and quartzite are among the types of stones used for tools (Amanda et al. 2009).

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division coordinated a geologic resource inventory scoping session for ACAD during June 2008 (Graham 2008). No specific paleontological resource recommendations were noted in that summary.
- Documented paleontological resources at ACAD consist of marine fossils from glaciomarine clay layers, younger marine invertebrate material on beaches, and a variety of terrestrial fossils (particularly pollen) from Holocene sediments. Future field inventories could establish where fossils are currently present in the glaciomarine clay.

- ACAD has deposits that are geologically very young, which can make it difficult to determine what material is a "fossil" and what would be considered "modern." The National Park Service defines a fossil as any remains of life preserved in a geologic context. This definition does not include an arbitrary date where older specimens are considered fossils, and younger specimens are not. The "geologic context" phrase is intended to imply some level of antiquity. Generally, specimens dating back to the late Pleistocene are considered fossils. Late Holocene (last few hundred or thousand years, "Recent") specimens are usually considered modern and not fossils. Pleistocene remains may differ from younger remains by having dark staining and being heavily worn and bored, but this does not always hold true. Surface and subsurface specimens collected at ACAD span this range between Pleistocene and Holocene. Regardless of what label is assigned to them, these specimens are important natural resources and valuable pieces of the history of life on earth.
- Park staff should be encouraged to observe exposed sedimentary material for fossil material while conducting their usual duties. Staff should photodocument and potentially 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. 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).
- Future archeological excavations or infrastructure developments should consider scheduling site monitoring by a trained paleontologist in order to document and protect fossil resources.
- Rising sea level and associated erosion may impact paleoecological sites along the coast. Sanger (1981) and W. Anderson et al. (1984) described erosion of cultural sites.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

Literature Cited

Amanda, D., E. Wood, S. Dowaliby, A. S. Lakota, N. D. Hamilton, and S. G. Pollock. 2009. Analysis of pottery and lithic artifacts, from the Nevin and Richards sites, Blue Hill Bay Maine. Abstracts with Programs - Geological Society of America **41**(3):95.

Anderson, R. S., G. L. Jacobson Jr., and R. B. Davis. 1982. Late- and postglacial environmental change in central Maine: a record of marine, lacustrine and terrestrial fossils from Gould Pond. Program and Abstracts - American Quaternary Association **7**:59.

Anderson, W. A., J. T. Kelley, W. B. Thompson, H. W. Borns Jr., D. Sanger, D. C. Smith, D. A. Tyler, R. S. Anderson, A. E. Bridges, K. J. Crossen, J. W. Ladd, B. G. Andersen, and F. T. Lee. 1984. Crustal warping in coastal Maine. Geology **12**(11):677-680.

Barnhardt, W. A. and J. T. Kelley. 1995. Carbonate accumulation on the inner continental shelf of Maine: a modern consequence of late Quaternary glaciation and sea-level change. Journal of Sedimentary Research, Section A: Sedimentary Petrology and Processes **65**(1):195-207.

Barnhardt, W. A., W. R. Gehrels, D. F. Belknap, and J. T. Kelley. 1995. Late Quaternary relative sea-level change in the western Gulf of Maine: evidence for a migrating glacial forebulge. Geology **23**(4):317-320.

Bascom, F. 1919. The physiography of Mount Desert. The Bulletin of the Geographical Society of Philadelphia 17(4):117-130. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/bulletingeograp01unkngoog]

Belknap, D. F. and J. T. Kelley. 2006. Postglacial stratigraphy and evolution of Maine lakes. Abstracts with Programs - Geological Society of America **38**(2):18.

Belknap, D. F., B. G. Andersen, R. S. Anderson, W. A. Anderson, H. W. Borns Jr., G. Jacobson Jr., J. T. Kelley, R. C. Shipp, D. C. Smith, R. Stuckenrath Jr., W. B. Thompson, and D. A. Tyler. 1987. Late Quaternary sea-level changes in Maine. Pages 71-85 *in* Nummedal, D., O. H. Pilkey Jr. and J. D. Howard, editors. Sea-level fluctuation and coastal evolution. Society of Economic Paleontologists and Mineralogists, Tulsa, OK. Special Publication 41.

Belknap, D. F., J. T. Kelley, and A. M. Gontz. 2002. Evolution of the glaciated shelf and coastline of the northern Gulf of Maine, USA. Journal of Coastal Research Special Issue **36**:37-55.

Belknap, D. F., A. M. Gontz, and J. T. Kelley. 2005. Paleodeltas and preservation potential on a paraglacial coast: evolution of eastern Penobscot Bay, Maine. Pages 335-360 *in* FitzGerald, D. M. and J. Knight, editors. High resolution morphodynamics and sedimentary evolution of estuaries. Springer, Dordrecht, the Netherlands. Coastal Systems and Continental Margins 8.

Blaney, D. and F. B. Loomis. 1916. A Pleistocene locality on Mount Desert Island, Maine. American Journal of Science **42**(251):399-401.

Bloom, A. L. 1963. Late-Pleistocene fluctuations of sealevel and postglacial crustal rebound in coastal Maine. American Journal of Science **261**(9):862-879.

Brandes, A. L., D. F. Belknap, and J. T. Kelley. 2000. Stratigraphy and dynamics of a cool-water carbonate beach system, Maine. Abstracts with Programs - Geological Society of America **32**(1):7.

Brookins, D. G. 1976. Geochronologic contributions to stratigraphic interpretation and correlation in the Penobscot Bay area, eastern Maine. Pages 129-145 *in* Page, L. R., editor. Contributions to the stratigraphy of New England. Geological Society of America, Boulder, CO. Memoir 148.

Brookins, D. G., J. M. Berdan, and D. B. Stewart. 1973. Isotopic and paleontologic evidence for correlating three volcanic sequences in the Maine Coastal Volcanic Belt. Geological Society of America Bulletin **84**(5):1619-1628.

Brown, C. W. and C. C. Branson. 1932. High-level Pleistocene marine clays of Mount Desert Island, Maine, and their fauna. Geological Society of America Bulletin **43**(1):282-283.

Caldwell, D. W. 1998. Roadside geology of Maine. Mountain Press Publishing Company, Missoula, MT.

Chadwick, G. H. 1939. Geology of Mount Desert Island, Maine. American Journal of Science **237**(5):355-363.

Chadwick, G. H. 1944. The geology of Mount Desert Island (Acadia National Park). Transactions of the New York Academy of Sciences **6**(6):171-178.

Chadwick, G. H. 1945. Moraine on Mount Desert Island (Maine). Geological Society of America Bulletin **56**(12, Part 2):1152.

Chapman, H. C. 1892. Note on the geology of Mount Desert Island. Proceedings of the Academy of Natural Sciences of Philadelphia **44**:350.

Chapman, C. A. 1970. The geology of Acadia National Park. Chatham Press, Chatham, MA.

Churchill-Dickson, L. 2007. Maine's fossil record: the Paleozoic. Maine Geological Survey, Augusta, ME.

Clark, C. K., N. W. Krumdieck, E. F. Littlefield, and R. E. Nelson. 2007. Pre- and post-European forest composition and bog flora changes documented by pollen from Maine Sphagnum cores. Abstracts with Programs - Geological Society of America **39**(6):401.

Davis, P. T., P. R. Bierman, J. Brigham-Grette, D. M. Fitzgerald, B. K. Fowler, M. J. Retelle, J. C. Ridge, W. B. Thompson, and T. K. Weddle. 2003. Quaternary and geomorphic processes and landforms along a traverse across northern New England. Pages 365-398 *in* Easterbrook, D. J., editor. Quaternary geology of the United States. INQUA 2003 field guide volume. Desert Research Institute, Reno, NV.

Davis, W. M. 1894. An outline of the geology of Mount Desert. Pages 43-71 *in* Rand, E. L. and J. H. Redfield. Flora of Mount Desert Island, Maine. John Wilson and Son, Cambridge, MA. [full text available on Google Books]

Dorion, C. C., G. A. Balco, M. R. Kaplan, K. J. Kreutz, J. D. Wright, and H. W. Borns Jr. 2001. Stratigraphy, paleoceanography, chronology, and environment during deglaciation of eastern Maine. Pages 215-242 *in* Weddle, T. K. and M. J. Retelle, editors. Deglacial history and relative sea-level changes, northern New England and adjacent Canada. Geological Society of America, Boulder, CO. Special Paper 351.

Ebel, J. E., A. M. Moulis, D. Smith, and M. Hagerty. 2008. The 2006-2007 earthquake sequence at Bar Harbor, Maine. Seismological Research Letters **79**(3):457-468.

Gehrels, W. R. 1999. Middle and late Holocene sea-level changes in eastern Maine reconstructed from foraminiferal saltmarsh stratigraphy and AMS ^{14}C dates on basal peat. Quaternary Research **52**(3):350-359.

Gehrels, W. R., D. F. Belknap, and J. T. Kelley. 1996. Integrated high-precision analyses of Holocene relative sea-level changes: lessons from the coast of Maine. Geological Society of America Bulletin **108**(9):1073-1088.

Gilman, R. A., C. A. Chapman, T. V. Lowell, and H. W. Borns Jr. 1988. The geology of Mount Desert Island: a visitor's guide to the geology of Acadia National Park. Maine Geological Survey, Augusta, ME. Bulletin 38. Online. http://www.maine.gov/doc/nrimc/mgs/explore/bedrock/acadia/contents.htm. Accessed January 2010.

Graham, J. 2008. Geologic resource evaluation scoping summary: Acadia National Park, Maine. National Park Service, Geologic Resources Division, Denver, CO. Online. http://www.nature.nps.gov/geology/inventory/publications/s_summaries/ACAD_scoping_summary_2006-0922.pdf. Accessed January 2010.

Hansen, B. P. 1980. Ground water availability in Acadia National Park and vicinity, Hancock and Knox counties, Maine. U.S. Geological Survey, Reston, VA. Open-File Report 80-1050.

Harris, A. G., E. Tuttle, and S. D. Tuttle. 2004. Geology of national parks (6th edition). Kendall/Hunt Publishing Company, Dubuque, IA.

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°. Carnegie Institution of

Washington Publication 322. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/pleistoceneofnor00hayouoft]

Hoyle, B. G., D. C. Fisher, H. W. Borns Jr., L. L. Churchill-Dickson, C. C. Dorion, and T. K. Weddle. 2004. Late Pleistocene mammoth remains from coastal Maine, USA. Quaternary Research **61**(3):277-288.

Johnson, B. J., K. A. Moore, C. Lehmann, C. Bohlen, and T. A. Brown. 2007. Middle to late Holocene fluctuations of C (sub 3) and C (sub 4) vegetation in a northern New England salt marsh: Sprague Marsh, Phippsburg, Maine. Organic Geochemistry **38**(3):394-403.

Judson, S. S. Jr. 1949. The Pleistocene stratigraphy of Boston, Massachusetts and its relation to the Boylston Street Fishweir. Pages 7-48 *in* Johnson, F., editor. The Boylston Street Fishweir II. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology **4**(1).

Kaye, C. A. 1976. Outline of the Pleistocene geology of the Boston Basin. Pages 46-63 *in* Cameron, B., editor. Geology of southeastern New England: a guidebook for field trips to the Boston area and vicinity. Science Press, Princeton, NJ. Annual Meeting - New England Intercollegiate Geological Conference 68.

Kelley, A. R. and D. Sanger. 2006. Archaeological geology of the central Penobscot River Valley, Maine, USA. Abstracts with Programs - Geological Society of America **38**(7):452.

Kelley, J. T., D. F. Belknap, and A. M. Gontz. 2003. A review of shallow-water pockmark distribution and origins in the northwestern Gulf of Maine. Abstracts with Programs - Geological Society of America **35**(3):7.

Kelley, J. T., S. H. Claesson, D. F. Belknap, W. Barnhardt, and A. L. Baker. 2009. A drowned, formerly inhabited bay/lake shoreline off Mount Desert Island, Maine. Abstracts with Programs - Geological Society of America **41**(3):10.

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* Lucas, S. G., 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, NM. Bulletin 34. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed December 2009.

Kilian, T. M. and R. E. Nelson. 2008. A late Pleistocene coleopteran fauna from Presumpscot Formation sediments in Portland, Maine. Abstracts with Programs - Geological Society of America **40**(2):60.

Kim, W. and M. E. Gold. 2007. The 2006 Acadia National Park, Maine earthquake sequence. Eos **88**(supplement to 52):F1784. Abstract S31A-0206.

Knox, A. S. 1956. Pollen from Leda clay of Maine. Science **123**(3208):1118-1119.

Koteas, C. and S. J. Seaman. 2006. Construction of the Devonian bimodal Gouldsboro Pluton via multiple intrusion, coastal Maine, USA. Eos **87**(supplement to 52):F2253. Abstract V23D-0668.

Leonard, J. E. and B. Cameron. 1979. Origin of a high latitude carbonate beach: Mt. Desert Island, Maine. Northeastern Geology **1**:133-143.

Levin, H. L. 1999. The Earth through time (6th edition). Saunders College Publishing, Fort Worth, TX.

Lowell, T. V. 1980. Late Wisconsin ice extent in the Gulf of Maine: evidence from Mount Desert Island, Maine. Abstracts with Programs - Geological Society of America **12**(2):71.

Lowell, T. V. 1989. Late Wisconsin glacial geology of the eastern portion of Mount Desert Island. Pages 103-118 *in* Tucker, R. D. and R. G. Marvinney, editors. Quaternary geology. Volume 6 *of* Studies in Maine geology: papers to commemorate the 150th anniversary of C. T. Jackson's reports on the geology of Maine. Maine Geological Survey, Augusta, ME.

Lowell, T. V. 1990. Deglaciation of Mount Desert Island: observations and glaciological implications. Pages 80-113 *in* Ludman, A., editor. Geology of the coastal lithotectonic block and neighboring terranes, eastern Maine and southern New Brunswick. New England Intercollegiate Geologic Conference, Amherst, MA. Annual Meeting - New England Intercollegiate Geological Conference 83.

Ludman, A. and H. N. Berry IV. 2003. Bedrock geology of the Calais 1:100,000 quadrangle, Maine. Maine Geological Survey, Augusta, ME. Open-File 03-97. Scale 1:100,000. Online. http://www.maine.gov/doc/nrimc/mgs/pubs/online/bedrock/bd-calais100.pdf. Accessed January 2010.

Metzger, W. J. 1975. Stratigraphy and correlation of the Bar Harbor Series, Frenchman Bay, Maine. Abstracts with Programs - Geological Society of America **7**(1):95-96.

Metzger, W. J., D. G. Mose, and M. S. Nagel. 1982. Rb-Sr whole-rock ages of igneous rocks in the vicinity of Mt. Desert Island, coastal Maine. Northeastern Geology **4**(1):33-38.

Miller, B. V., S. M. Barr, and R. S. Black. 2007. Neoproterozoic and Cambrian U-Pb (zircon) ages from Grand Manan Island, New Brunswick: implications for stratigraphy and northern Appalachian terrane correlations. Canadian Journal of Earth Sciences **44**(7):911-923.

Mose, D. G. and W. J. Metzger. 1977. Rb-Sr whole-rock ages of volcanic rocks on Mt. Desert and Flint islands, coastal Maine. Abstracts with Programs - Geological Society of America **9**(3):303.

Murphy, J. B. and J. D. Keppie. 2005. The Acadian Orogeny in the Northern Appalachians. International Geology Review **47**(7):663-687.

Murphy, J. B., J. D. Keppie, and R. D. Nance. 2007. What is the Acadian Orogeny? Abstracts with Programs - Geological Society of America **39**(1):69.

Nielsen, M. G. 2006. Hydrogeomorphic classification of wetlands on Mt. Desert Island, Maine, including hydrologic susceptibility factors for wetlands in Acadia National Park. U.S. Geological Survey, Reston, VA. Scientific Investigations Report 2006-5162. Online. http://pubs.usgs.gov/sir/2006/5162/. Accessed January 2010.

Norton, S. A. and J. S. Kahl. 1987. A comparison of lake sediments and ombrotrophic peat deposits as long-term monitors of atmospheric pollution. Pages 40-57 *in* Boyle, T. P., editor. New approaches to monitoring aquatic ecosystems. ASTM International, West Conshohocken, PA. Special Technical Publication 940.

Norton, S. A., G. C. Evans, and J. S. Kahl. 1997. Comparison of Hg and Pb fluxes to hummocks and hollows of ombrotrophic Big Heath Bog and to nearby Sargent Mt. Pond, Maine, USA. Water, Air and Soil Pollution **100**(3-4):271-286.

O'Connor, J. V. and W. R. White. 1988. Geological foundations on Mount Desert Island, Maine. Northeastern Geology **10**(1):1-7.

Osberg, P. H., A. M. Hussey II, and G. M. Boone. 1985. Bedrock geologic map of Maine. Maine Geological Survey, Augusta, ME. Scale 1:500,000.

Perry, R. H., S. A. Norton, and P. O. Koons. 2009. A 16.5 ka post-glacial lake sediment record of apatite weathering and depletion from Sargent Mountain Pond, Maine (USA): implications for carbon flux and nutrient budgets on recently deglaciated landscapes. Abstracts with Programs - Geological Society of America **41**(3):5.

Reusch, D. N. 2001. Geology of the Newbury Neck 1:24,000 quadrangle, coastal Maine. Atlantic Geology **37**(1):123.

Richards, M. D. and D. F. Belknap. 2003.Paleoecology of the glaciomarine Presumpscot Formation (latest Pleistocene) of south-central Maine. Abstracts with Programs - Geological Society of America **35**(3):73.

Roos-Barraclough, F., N. Givelet, A. K. Cheburkin, W. Shotyk, and S. A. Norton. 2006. Use of Br and Se in peat to reconstruct the natural and anthropogenic fluxes of atmospheric Hg: a 10,000 year record from Caribou Bog, Maine. Environmental Science & Technology **40**(10):3188-3194.

Rubin, P. A. and B. Morgan. 2002. Relict sea caves record temporary coastal stillstands. Annual Convention Program - National Speleological Society **2002**:A26-A27.

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**:647-644.

Sanger, D. 1981. Coastal subsidence and archaeological sites in the Gulf of Maine. Abstracts with Programs - Geological Society of America **13**(3):174.

Sanger, D. 1988. Maritime adaptations in the Gulf of Maine. Archaeology of Eastern North America **16**:81-100.

Sanger, D. 1989. Insights into Native American life at Fernald Point. *in* McMullen, A. and D. Kopec, editors. An island in time. Robert Abbe Museum, Bar Harbor, ME. Bulletin 12.

Sanger, D. and B. Johnson. 1980. Archaeological Investigations at Fernald Point, Maine. Report prepared for the National Park Service.

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

Schauffler, M. and G. L. Jackson Jr. 2002. Persistence of coastal spruce refugia during the Holocene in northern New England, USA, detected by stand-scale pollen stratigraphies. Journal of Ecology **90**:235-250.

Schauffler, M., S. J. Nelson, J. S. Kahl, G. L. Jacobson, T. A. Haines, W. A. Patterson, and K. B. Johnson. 2007. Paleoecological assessment of watershed history in PRIMENet watersheds at Acadia National Park, USA. Environmental Monitoring and Assessment **126**(1-3):39-53.

Schulz, K. J., D. B. Stewart, R. D. Tucker, J. C. Pollock, and R. A. Ayuso. 2008. The Ellsworth Terrane, coastal Maine: geochronology, geochemistry, and Nd-Pb isotopic composition: implications for the rifting of Ganderia. Geological Society of America Bulletin **120**(9-10):1134-1158.

Seaman, S. J., E. E. Scherer, R. A. Wobus, J. H. Zimmer, and J. G. Sales. 1999. Late Silurian volcanism in coastal Maine: the Cranberry Island Series. Geological Society of America Bulletin **111**(5):686-708.

Shaler, N. S. 1889. The geology of the Island of Mount Desert, Maine. United States Geological Survey Annual Report **8**(2):987-1061. Online. http://pubs.er.usgs.gov/usgspubs/ar/ar8_2. Accessed January 2010.

Sidell, N. A. 1999. Prehistoric plant use in Maine: Paleoindian to contact period. Pages 191-223 *in* Hart, J. P., editor. Current northeast paleoethnobotany. New York State Museum, Albany, NY. Bulletin 494.

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

Spiess, A. and R. Lewis. 2001. The Turner Farm fauna: five thousand years of hunting and fishing in Penobscot Bay, Maine. Occasional Publications in Maine Archaeology 11.

Stewart, D. B., M. J. K. Flohr, and R. D. Tucker. 1996. Geochemistry, age, and tectonic setting of the Ellsworth Schist, mid-coastal Maine. Abstracts with Programs - Geological Society of America **28**(3):101-102.

Stuvier, M. and H. W. Borns Jr. 1975. Late Quaternary marine invasion in Maine: its chronology and associated crustal movement. Geological Society of America Bulletin **86**(4):99-104.

Syverson, K. M., A. H. Thompson, and T. K. Weddle. 2009. Convergent ice-flow indicators in the Penobscot River valley, Bangor, Maine: evidence for a calving embayment. Abstracts with Programs - Geological Society of America **41**(3):36.

Thompson, W. B. and H. W. Borns Jr. 1985. Surficial geologic map of Maine. Maine Geological Survey, Augusta, ME. Scale 1:500,000.

Thompson, W. B., C. B. Griggs, N. G. Miller, and T. K. Weddle. 2008. Associated terrestrial and marine fossils in the late-glacial Presumpscot Formation, southern coastal Maine, and the marine reservoir effect on radiocarbon ages. Abstracts with Programs - Geological Society of America **40**(2):60.

Tolonen, K., R. B. Davis, and L. S. Widoff. 1988. Peat accumulation rates in selected Maine peat deposits. Maine Geological Survey, Augusta, ME. Bulletin 33.

van Staal, C. R. and J. B. Whalen. 2006. Magmatism during the Salinic, Acadian, and Neoacadian orogenies. Abstracts with Programs - Geological Society of America **38**(2):31.

van Staal, C. R., V. McNicoll, P. Valverde-Vaquero, S. M. Barr, L. R. Fyffe, and D. N. Reusch. 2004. Ganderia, Avalonia, and the Salinic and Acadian orogenies. Abstracts with Programs - Geological Society of America **36**(2):128-129.

Wiebe, R. A. and M. Chapman. 1993. Layered gabbro-diorite intrusions of coastal Maine: basaltic infusions into floored silicic magma chambers. Pages A.1-A.24 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(1).

Wiebe, R. A., J. B. Holden, M. L. Coombs, R. A. Wobus, K. J. Schuh, and B. P. Plummer. 1997a. The Cadillac Mountain intrusive complex, Maine: the role of shallow-level magma chamber processes in the generation of A-type granites. Pages 397-418 *in* Sinha, A. K., J. B. Whalen, and J. P. Hogan, editors.

The nature of magmatism in the Appalachian Orogen. Geological Society of America, Boulder, CO. Memoir 191.

Wiebe, R. A., D. Smith, M. Sturm, E. M. King, and M. S. Seckler. 1997b. Enclaves in the Cadillac Mountain Granite (coastal Maine): samples of hybrid magma from the base of the chamber. Journal of Petrology **38**(3):393-423.

Will, R. T. 2002. Bone artifacts: continuity in technology and form in pre-European archaeological sites along the Maine coast. Northeast Anthropology **64**:5-16.

Wintsch, R. P., J. F. Sutter, M. J. Kunk, J. N. Aleinikoff, and J. L. Boyd. 1993. Alleghanian assembly of Proterozoic and Paleozoic lithotectonic terranes in south central New England: new constraints from geochronology and petrology. Pages H.1-H.30 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Wintsch, R. P., J. N. Aleinikoff, G. J. Walsh, W. A. Bothner, A. M. Hussey II, and C. M. Fanning. 2007. SHRIMP U-Pb evidence for a Late Silurian age of metasedimentary rocks in the Merrimack and Putnam-Nashoba Terranes, eastern New England. American Journal of Science **307**(1):119-167.

Additional References

Anderson, R. S. and H. W. Borns Jr. 1983. Evidence for late Holocene sea-level rise in New England: a summary of available data derived from salt marshes and other organic materials. Maine Geological Survey, Augusta, ME. Open-File Report 83-8.

Bourque, B. J., K. Morris, and A. Spiess. 1978. Determining the season of death of mammal teeth from archeological sites: a new sectioning technique. Science **199**(4328):530-531.

Johnson, D. W. 1925. The New England-Acadian shoreline. J. Wiley & Sons, New York, NY.

Kaplan, M. R. 1999. Retreat of a tidewater margin of the Laurentide ice sheet in eastern coastal Maine between ca. 14 000 and 13 000 ^{14}C yr B.P. Geological Society of America Bulletin **111**(4):620-632.

Kelley, A. R. and D. Sanger. 2003. Postglacial development of the Penobscot River valley: implications for geoarchaeology. Pages 119-133 *in* Cremeens, D. L. and J. P. Hart, editors. Geoarchaeology of landscapes in the glaciated Northeast. New York State Museum and Science Service, Albany, NY. Bulletin 497.

Kelley, A. R., C. C. Dorion, G. Balco, A. Dieffenbacher-Krall, P. Garrett, D. Locke, and A. Tolman. 2000. Late Pleistocene/Holocene geological evolution of the central Penobscot River valley: surficial geology, geoarchaeology, and water supply. Pages 168-186 *in* Yates, M. G., D. R. Lux, and J. T. Kelley, editors. Guidebook for field trips in coastal and east-central Maine. New England Intercollegiate Geologic Conference, Amherst, MA. Annual Meeting - New England Intercollegiate Geological Conference 92.

Kelley, J. T., D. F. Belknap, D. M. FitzGerald, and J. C. Boothroyd. 2001. Quaternary sea-level change and coastal evolution in eastern Maine. Pages A1-A31 *in* West, D. P. Jr. and R. H. Bailey, editors. Guidebook for geological field trips in New England. Geological Society of America, Boulder, CO.

Magennis, A. L. and L. T. Barbian. 1996. Diet, health, and subsistence at the Late Archaic Turner Farm Site, Maine. Northeastern Anthropology **52**:95-119. Online.

http://isites.harvard.edu/fs/docs/icb.topic248375.files/Magennis%20and%20Barbian%201996.pdf. Accessed January 2010.

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

Metzger, W. J. 1979. Stratigraphy and geology of the Bar Harbor Formation, Frenchman Bay, Maine. Maine Geology. Bulletin **1**:1-17.

Oldale, R. N., J. R. Grimes, and F. C. Whitmore Jr. 1988. Late-Wisconsinan elephant teeth from the western Gulf of Maine. Abstracts with Programs - Geological Society of America **20**(1):59.

Principato, S. M. and J. T. Markus. 2009. Holocene environmental conditions interpreted from coastal mudflats and peat in Washington County, Maine. Abstracts with Programs - Geological Society of America **41**(3):84.

Rubin, P. A. 1991. Emerged sea caves and coastal features as evidence of glacio-isostatic rebound, Mount Desert Island, Maine. Pages 75-83 *in* Kastning, E. H. and K. M. Kastning, editors. Appalachian karst: proceedings of the Appalachian karst symposium. National Speleological Society, Huntsville, AL.

Sanger, D., A. R. Kelley, and H. Almquist. 2003. Geoarchaeological and cultural interpretations in the lower Penobscot Valley, Maine. Pages 135-150 *in* Cremeens, D. L. and J. P. Hart, editors. Geoarchaeology of landscapes in the glaciated Northeast. New York State Museum and Science Service, Albany, NY. Bulletin 497.

Seaman, S. J., R. A. Wobus, R. A. Wiebe, N. Lubick, and S. A. Bowring. 1995. Volcanic expression of bimodal magmatism: the Cranberry Island-Cadillac Mountain complex, coastal Maine. Journal of Geology **103**(3):301-311.

Data Sets

Acadia National Park Collections
1916–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by BOHA staff; status: Active.

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

Acadia National Park Digital Geologic Map
2008-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online.
http://science.nature.nps.gov/nrdata/datastore.cfm?ID=45869.

Academy of Natural Sciences
1916-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by ANSP staff; status: Active.

Maine Digital Geologic Map
2005-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by Maine Office of GIS staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=ME.

Museum of Science (Boston) (formerly Boston Society of Natural History)

1916-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by MOS staff; status: Active.

University of Maine
1916-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by MU staff; status: Active.

University of Massachusetts Amherst
1916-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by UMA staff; status: Active.

Appalachian National Scenic Trail

The Appalachian National Scenic Trail (APPA) was first conceived of in 1921 and was completed as a continuous trail in 1937. It was established as the first National Scenic Trail on October 2, 1968. The trail traverses the ridgecrests and valleys of the Appalachian Mountains from Mount Katahdin, Maine to Springer Mountain, Georgia, passing through 14 states, six other NPS units, six I & M networks, and a variety of physiographic and geologic settings. APPA is 3,500 km (2,175 miles) long, and there are usually at least 150 m (500 ft) of NPS land on either side of the center line, but some sections are substantially wider, at a km- or mile-scale. APPA encompasses 91,863.86 ha (227,000.55 acres), of which 68,583.53 ha (169,473.59 acres) are under federal administration.

Geologic Background

APPA is located along several mountain groups of the Appalachian Mountains, a mountain range that roughly parallels the Atlantic coast of North America for much of the continent's length. Starting from the northern end, APPA passes through Maine, New Hampshire, Vermont, Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, Maryland, West Virginia, Virginia, Tennessee, North Carolina, and Georgia. For inventory and monitoring purposes, the networks involved from north to south are the Northeast Temperate Network (NETN), the Eastern Rivers and Mountains Network (ERMN), the Mid-Atlantic Network (MIDN), the National Capital Region Network (NCRN), the Appalachian Highlands Network (APHN), and the Cumberland Piedmont Network (CUPN). APPA also crosses a number of state and federal parks, monuments, forests, and recreational areas. NPS units along the trail include, in the order encountered from north to south: Delaware Water Gap National Recreation Area (DEWA) in the ERMN; Chesapeake and Ohio Canal National Historical Park (CHOH) and Harpers Ferry National Historical Park (HAFE) in the NCRN; Shenandoah National Park (SHEN) in the MIDN; and the Blue Ridge Parkway (BLRI) and Great Smoky Mountains National Park (GRSM) in the APHN. Paleontological resource inventories have been written for all of these parks and networks (Kenworthy and Santucci 2004; Kenworthy et al. 2006; Koch and Santucci 2004; Santucci et al. 2008; Hunt-Foster et al. 2009). The information in the reports has been used to supplement this report. The CHOH and DEWA summaries (Kenworthy and Santucci 2004; Koch and Santucci 2004) are particularly useful because of the large number of fossiliferous formations they have in common with APPA.

The physiography of APPA can be divided into three general sections: the Northern Appalachians of the New England states; the Valley and Ridge on the west side of the spine of the Appalachians, which the trail passes through from southern New York to southern Virginia; and the Blue Ridge Mountains on the east side of the spine, which the trail passes through from southern Virginia to Georgia. These provinces are flanked on the west by the Appalachian Plateau and on the east by the Piedmont. The Northern Appalachians and the Blue Ridge Mountains are largely made up of crystalline rocks (igneous and metamorphic rocks), and are sparsely fossiliferous. The Valley and Ridge rocks, however, are largely sedimentary. These rocks formed in shallow marine to coastal terrestrial settings during the Paleozoic (see the appendix for a geological time scale). These settings were inhabited by diverse assemblages of shelled benthic and burrowing marine invertebrates, and later some of the first forests, with early terrestrial plants, arthropods, and tetrapods. The geology of the Appalachian Trail is diverse, but Chew (1993) has provided a summary; as with the previously mentioned network-based paleontological resource inventory summaries, it is an invaluable resource. Geologic formations were determined with the use of the U.S. Geological Survey's online digital state geologic map service (http://tin.er.usgs.gov/geology/state/); these maps are based on previously published state geologic maps. The digital geologic maps on the USGS website are, by necessity, rather coarse in resolution (typically 1:250,000). The maps also lump together geologic units in regions where the geology is particularly complex. Nevertheless, the maps provide a very useful first-order approximation of the geology along the trail.

Geologic Background: Northern Appalachians

The Northern Appalachians province, including the New England portion of APPA (Maine, New Hampshire, Vermont, Massachusetts, and Connecticut) and part of extreme eastern New York, consists of an area of the eastern margin of the North American craton (continental core; the technical term for the proto-North American core is Laurentia) sutured with an area assembled from a number of smaller continental fragments, microcontinents, volcanic island arcs, and trapped sedimentary basins during the Proterozoic and Paleozoic. This history gives the province complex structural geology, extensive metamorphism, and widespread igneous intrusions. Most of the park summaries in this document include descriptions of at least one terrane or related geologic event. Relatively few fossiliferous formations are present in the Northern Appalachian province.

Most of New England is made up of exotic accreted terranes, which are blocks of crust that originated somewhere other than their present location and are demonstrably different from surrounding rocks. The timing of assembly and the origins of the various terranes are heavily debated (Skehan 2001; Wintsch et al. 1993, 2007). For many years, the basic interpretation of the assembly of the east coast of North America was as a three-stage process. It begins with a passive plate boundary, similar to the modern configuration, where the continental crust leads into an ocean basin that is part of the same tectonic plate. In the first event, during the Ordovician, the Iapetus Ocean east of North America began subducting under it, carrying along with it an island arc that was added to the continent. The associated mountain-building event is known as the Taconic Orogeny. Then, during the Devonian, the Iapetus Ocean finished subducting, and a substantial continental fragment called Avalon or Avalonia collided with North America; this is known as the Acadian Orogeny. Finally, during the Pennsylvanian, the continent Gondwana collided with North America, with the landmass that now forms Africa in contact with the east coast; this is known as the Alleghenian Orogeny, and was the culmination of a process that ended in the formation of the supercontinent Pangaea (Levin 1999). As research continues, this basic three-orogeny sequence has been refined to include additional events and small landmasses. For example, it is now known that there were numerous terranes, and that some may have collided with North America during the late Ordovician and early Silurian, as part of the Salinic Orogeny (Murphy and Keppie 2005; Murphy et al. 2007), or over both the Salinic Orogeny and the Acadian Orogeny (van Staal et al. 2004; van Staal and Whalen 2006).

In the Northern Appalachians, the earlier orogenies had the greatest effects, with the Alleghenian Orogeny not as prominent. The Taconic Orogeny in particular had extensive effects, creating large thrust sheets of rock that were shoved many kilometers (or miles) across the continental shelf. An example of such thrusting is the Taconic Mountains of eastern New York (Levin 1999), from which the orogeny got its name.

Pangaea broke up during the Mesozoic Era, which follows the Paleozoic Era. A period of extension that formed the Atlantic Ocean began during the Triassic, as seen through failed rift valleys and lava flows along the east coast of North America that date to that time (Levin 1999; see the Morristown National Historical Park [MORR] and Springfield Armory National Historic Site [SPAR] summaries in this document for more information on this period of time).

After the breakup of Pangaea, the Northern Appalachians, and the eastern half of North America in general, entered a relatively quiet phase of highland erosion. The most influential geological events since the breakup in the Northern Appalachians were the Pleistocene glaciations, occurring between 2.59 million years ago and 12,000 years ago. Several glacial advances of varying extents and durations occurred, with the most recent (late Wisconsinan advance) overprinting much of the previous activity. With regards to APPA, the glaciations can be considered largely a Northern Appalachian event. Ice did not advance farther south than northern New Jersey during the most recent glacial periods (the Illinoian and Wisconsinan), although it extended somewhat farther south during at least one earlier advance (Stanford 1993). The late Wisconsinan glacial advance began about 40,000 years ago, and ended about 12,000 years ago (Caldwell 1998). During this time, the Laurentide Ice Sheet advanced out of Canada (Davis et al. 2003). When the ice sheet retreated, meltwater lakes formed in the recently deglaciated areas,

temporarily trapped by glacial debris, blocks of ice, and the retreating edges of the glaciers. Large lakes filled modern river valleys, including several crossed by the trail. These include Glacial Lake Albany in the Hudson River Valley and Glacial Lake Hitchcock in the Connecticut River Valley. Glacial lakes persisted for hundreds to thousands of years before they drained (Benner et al. 2009).

Geologic Background: Valley and Ridge

The Valley and Ridge province accounts for most of the trail's land between southern New York and the stretch of trail near the Virginia and West Virginia border. It is made up of Paleozoic sedimentary rocks that were folded into their current configuration during the Alleghenian Orogeny. The Appalachian Plateau province flanking it to the west is composed of similar but non-folded rocks. The sedimentary rocks derived from the mountain highlands formed during the orogenies before the Alleghenian Orogeny, and were deposited in massive wedges that covered parts of multiple states, such as the Queenstown clastic wedge that formed during the late Ordovician after the Taconic Orogeny, and the Catskill clastic wedge or delta that formed in the aftermath of the Acadian Orogeny. Sediments were shed into the shallow epicontinental sea covering much of North America; between the Cambrian and the Permian, there were several prolonged periods when shallow seas submerged large parts of the continent, providing extensive habitat for shallow marine organisms. During the Paleozoic, land plants and animals evolved and spread, leading to the first forests (and subsequently to the great Carboniferous-age coal fields of the Appalachian Plateau and lands to the west) (Levin 1999). Formations in the Valley and Ridge province deposited between the Devonian and Pennsylvanian preserve remains of some of these first forests, and early terrestrial arthropods and tetrapods as well. Following the assembly of Pangaea, the Valley and Ridge province has been geologically quiet, being west of the Triassic-Jurassic rift valleys and generally south of the Pleistocene glaciations.

Geologic Background: Blue Ridge Mountains

The Blue Ridge Mountains province is another region of heavily metamorphosed rocks, with some igneous intrusions. Unlike the Northern Appalachians province, also made up in large part of metamorphic and igneous rocks, the Blue Ridge Mountains province was part of the North American continent during the Paleozoic orogenic events, and was heavily affected by the Alleghenian Orogeny. It accounts for that part of APPA from southwestern Virginia to its end in northern Georgia, and borders the Valley and Ridge to the west. The rocks of the Blue Ridge include sedimentary, igneous, and metamorphic rocks. These rocks bore the brunt of repeated collisions, were formed as a direct result of them, or both (Levin 1999). The Blue Ridge province is sparsely fossiliferous, like the Northern Appalachian province. That portion which APPA crosses is noted for the ancient Ocoee Supergroup (Precambrian) and Chilhowee Group (Cambrian), composed of a variety of sedimentary and metamorphosed sedimentary rocks with few fossils.

Organization of APPA Paleontology Summary

The structure of this summary is somewhat different from the other park summaries in this document, due to the substantial length and linear nature of APPA. The other summaries include a list of park geologic formations arranged by age, but the numerous formations crossed by APPA makes that arrangement impractical. Instead, geologic formations are addressed by state. States are listed from north to south, and fossiliferous formations found in multiple states will be discussed in the first state in which they are present. Note that there are occasionally differences between states for terminology and formation age. There are also many nomenclatural differences in the literature, with several units used as groups or formations, and different rosters of formations included in groups. Because the Georgia section of APPA is entirely underlain by unfossiliferous crystalline bedrock (Precambrian metamorphic rocks; Lawton et al. 1976), it is omitted as a separate state. In general, crystalline rocks lack fossils; the exceptions are certain types of volcanic rocks, and some low- to medium-grade metamorphic rocks derived from sedimentary rocks, where the alterations were not strong enough to render fossils unrecognizable. There are a few cases of the latter in the vicinity of APPA, including a locality where the rocks are regarded as the most metamorphosed in the world that still retain recognizable fossils (see "Maine" under "Potential Sources of Paleontological Resources" below). Known fossiliferous localities

on the trail will be discussed first, in the next section. Documented paleontological resources at APPA to date consist of Paleozoic marine fossils (mostly trace fossils from marine invertebrates), scattered across several states. Given the fossiliferous nature of many of the formations crossed by the trail (see the "Potential Sources" section), there is excellent potential for new and continued discoveries along APPA.

Sources of Paleontological Resources

The fossils of APPA present opportunities for education, interpretation, and continued or future scientific research on the trail. There are probably other fossil occurrences on the trail, but they may have escaped detection because they are small, and, in the case of some trace fossils, not immediately recognizable as fossils.

Pennsylvania

Trace fossils (*Arthrophycus*) are present in rocks on The Pinnacle on APPA (Wilshusen 1983), which are probably part of the Ordovician-age Shawangunk Formation (Berg et al. 1980). Trace fossils were the only fossils reported by Wilshusen (1983) in the rocks of APPA along the Blue and Kittatinny mountains. Fossils of *Lepidodendron* can be found on loose shale slabs in mine waste near Dehart Reservoir, just north of APPA. These fossils come from the Pennsylvanian-age upper Pottsville Group (Wilshusen 1983). It is not surprising that plant fossils are present in this area; the region where Dauphin and Lebanon counties meet in south-central Pennsylvania is part of the state's anthracite coal fields (Wilshusen 1983).

In addition, APPA formerly passed near Swatara Gap (Chew 1993), a famous Ordovician fossil site that has now been closed because over-enthusiastic collecting was in danger of undermining Interstate Route 81 (Reese et al. 2004). The Swatara Gap locality is discussed in more detail under "Pennsylvania: Ordovician formations" in the following section, with the Martinsburg Formation.

Tennessee

Skolithos trace fossils are found in unnamed Cambrian-age quartzite at Pond Mountain on APPA near Laurel Fork Grove in Tennessee (Chew 1993). These rocks are probably part of the Chilhowee Group (Hardeman 1966).

Virginia

Skolithos trace fossils and shells are found in quartzite and sandstone at the Garden Mountain area of APPA in Virginia. These are probably Silurian rocks, which are mostly made up of the Tuscarora Sandstone in this area (Chew 1993).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following rock units within APPA. However, they are known to preserve fossils elsewhere, and future field investigations on the trail may recover fossils from one or more of them.

Maine

The bedrock of APPA in Maine includes the Silurian-age Rangeley Formation and The Forks Formation, the Silurian-Devonian-age Madrid Formation, Devonian igneous rocks, and the Devonian-age Carrabassett Formation, Hildreths Formation, and Littleton Formation (Osberg et al. 1985). The Littleton Formation, Madrid Formation, and Rangeley Formation are also present along the trail in New Hampshire (Lyons et al. 1997). Of these rock units, fossils are known from The Forks Formation and the Littleton Formation. The Forks Formation has yielded crinoids and fragments of other fossils, including corals and brachiopods (Marvinney 1988). Fossils in the Littleton Formation are better known. Organisms recovered from the Littleton Formation include brachiopods, bivalves, gastropods, *Tentaculites* (a possible mollusk with a conical ribbed shell), and crinoids ("sea lilies") (Billings and Cleaves 1934). Some of these fossils were recovered near Mount Moosilauke, just south of APPA in the western part of White Mountains National Forest, in western New Hampshire. The Littleton Formation

fossils from Mount Moosilauke are notable because the rocks in which they were found are the highest metamorphic grade in the world that has yielded identifiable fossils (Boucot and Rumble 1978, 1980).

New Hampshire

The bedrock of APPA in New Hampshire includes the Ordovician-age Partridge Formation, the Silurian-age Clough Quartzite (or Formation), Fitch Formation, Madrid Formation, Perry Mountain Formation, Rangeley Formation, the Devonian-age Littleton Formation, and igneous rocks of Ordovician, Devonian, and Jurassic ages (Lyons et al. 1997). As noted above, the Littleton Formation, Madrid Formation, and Rangeley Formation are also present along the trail in Maine. The formations that are currently known to be fossiliferous are the Clough Quartzite, the Fitch Formation, and the Littleton Formation (described under Maine). The Clough Quartzite has yielded fossils of rugose and tabulate corals, brachiopods, gastropods, trilobites, and pelmatozoans (stalked echinoderms, such as crinoids) (Boucot and Thompson 1958, 1963). One locality, at Croydon Mountain, is approximately 27 km (17 miles) south of the trail in western New Hampshire (Boucot and Thompson 1963). Some of the fossils are from heavily-metamorphosed rocks (Boucot and Thompson 1958), similar to those in the Littleton Formation. The Fitch Formation has fossils of stromatoporoids (a type of colonial sponge), corals, bryozoans, brachiopods, bivalves, gastropods, trilobites, crinoids (Billings and Cleaves 1934), and conodonts (eel-like chordates) (Harris et al. 1983; Elbert et al. 1988).

Vermont

The bedrock of APPA in Vermont includes the Precambrian-age Mount Holly complex and Stamford Gneiss, the Cambrian-age Dalton Formation, Ottauquechee Formation, Pinney Formation, and Tyson Formation, the Cambrian-Ordovician-age Stowe Formation, the Ordovician-age Missisquoi Formation and Orfordville Formation, the Silurian-Devonian-age Northfield Formation, and the Devonian-age Gile Mountain Formation and Waits River Formation (Doll et al. 1961). The Dalton Formation is also found along the trail in Massachusetts and Connecticut (Zen et al. 1983; Rodgers 1985). Of the formations, the Gile Mountain Formation and Waits River Formation are known to be fossiliferous. The Gile Mountain Formation is sparsely fossiliferous. Its fossil assemblage includes *Prototaxites* (a giant fungus) (Hueber et al. 1990), corals, trilobites, and crinoids (Doll 1984). The Waits River Formation is also sparsely fossiliferous. This unit has yielded microfossils (Dennis 1956), plant fragments pertaining to trimerophytes (a group of early vascular plants) and unidentified plants, crinoid and other echinoderm fragments (Hueber et al. 1990), and a cephalopod (Doll 1984). For more details on the Gile Mountain Formation and Waits River Formation, see the Marsh-Billings-Rockefeller National Historical Park (MABI) summary in this document.

Massachusetts

The bedrock of APPA in Massachusetts includes the Precambrian-age Lee Gneiss, Stamford Gneiss, Tyringham Gneiss, Washington Gneiss, and other unnamed metamorphic and igneous rocks, the Precambrian-Cambrian-age Dalton Formation and Greylock Schist, the Precambrian-Ordovician-age Canaan Mountain Formation, the Cambrian-age Cheshire Quartzite and Stockbridge Formation (or Marble), the Ordovician-age Walloomsac Formation (or Schist), and Ordovician-age granite (Zen et al. 1983). The Dalton Formation is also found on the trail in Vermont and Connecticut (Doll et al. 1961; Rodgers 1985), and the Stockbridge Formation and Walloomsac Formation are also present in Connecticut and New York (Fisher et al. 1970; Rodgers 1985). The Stockbridge Formation and Walloomsac Formation are fossiliferous. Stromatolites (layered sedimentary structures formed by microbial mats trapping sediment) and evidence of bioturbation are reported in the Stockbridge Formation (Glumac and Mutti 2007). Corals are known from limestone at the base of the Walloomsac Formation, previously thought to be part of the underlying Stockbridge Formation (Zen 1966). Graptolites (colonial animals, often planktonic) and conodonts are also known from the Walloomsac Formation (Ratcliffe et al. 1999).

Connecticut

The bedrock of APPA in Connecticut includes Precambrian metamorphic rocks, the Cambrian-age Dalton Formation, Everett Schist, Manhattan Schist (or Formation), and Stockbridge Marble, and the

Ordovician-age Walloomsac Schist (Rodgers 1985). The Dalton Formation is also found on the trail in Vermont and Massachusetts (Doll et al. 1961; Zen et al. 1983), the Stockbridge Marble and Walloomsac Schist are also present in Massachusetts and New York (Fisher et al. 1970; Zen et al. 1983), and the Everett Schist and Manhattan Schist are also present in New York (Fisher et al. 1970). Of the formations, the Manhattan Schist, Stockbridge Formation (described under Massachusetts), and Walloomsac Formation (described under Massachusetts) are fossiliferous. The Manhattan Schist may have produced pelmatozoan fragments (Ratcliffe and Knowles 1969), although the authors were uncertain of the identity of the fossiliferous rock unit, identifying it as the "Manhattan Schist."

New York

The bedrock of APPA in New York includes Precambrian metamorphic and igneous rocks, the Cambrian-age Everett Schist and Poughquag Quartzite, the Cambrian-age Wappinger Group (including the Briarcliff Dolostone, Pine Plains Formation, Stissing Formation or Dolostone, and undivided rocks), the Cambrian-Ordovician-age Stockbridge Formation, the Ordovician-age Austin Glen Formation, Manhattan Formation, and Walloomsac Formation, and the Devonian-age Hamilton Group (Fisher et al. 1970). The Stockbridge Formation and Walloomsac Formation are also found on the trail in Massachusetts and Connecticut (Zen et al. 1983; Rodgers 1985), the Everett Schist and Manhattan Formation are also present in Connecticut (Rodgers 1985), and the Hamilton Group is also present in Pennsylvania (Berg et al. 1980). Of the formations, the Austin Glen Formation, Briarcliff Dolostone, Hamilton Group, Manhattan Formation (described under Connecticut), Pine Plains Formation, Poughquag Quartzite, Stissing Formation, Stockbridge Formation (described under Massachusetts) and Walloomsac Formation (described under Massachusetts) are known to be fossiliferous.

Fossils that can be reliably ascribed to the Austin Glen Formation include graptolites (Fisher and Warthin 1976; Rowley et al. 1979) and worm burrows that have been altered to pyrite ("fool's gold") (Bock et al. 1998). For more details on the Austin Glen Formation, see the summaries in this document for the Roosevelt-Vanderbilt parks (ROVA) and Saratoga National Historical Park (SARA). The Briarcliff Dolostone has yielded brachiopods and trilobites (Knopf 1962). The Hamilton Group is extensively fossiliferous, with a fossil assemblage including the oldest fossil forest in the world (Bartholomew and Brett 2003), *Lepidodendron* ("scale trees"), plant fragments, sponges (*Chaetetes*, long thought to be a coral), corals, conulatans (extinct distant relatives of coral that formed conical structures from rods), bryozoans, brachiopods, bivalves, cephalopods, gastropods, hyoliths (extinct enigmatic invertebrates with conical shells, perhaps mollusks), *Tentaculites*, *Coleolus* (a type of worm tube that resembles a scaphopod or "tusk shell" mollusk), *Spirorbis* (a polychaete or "bristle worm" with a coiled shell), ostracodes ("seed shrimp"), phyllocarid crustaceans (shrimp-like), trilobites, crinoids (Cleland 1903), conodonts (Bonelli et al. 2006), and invertebrate trace fossils (Cleland 1903). Some fossils from these rocks are preserved as pyrite (Dick and Brett 1982). Additional details on the Hamilton Group from NPS units that contact APPA can be found in the Delaware Water Gap National Recreation Area (DEWA) summary in the ERMN paleontological resources inventory (Koch and Santucci 2004), and the Chesapeake and Ohio Canal National Historic Park (CHOH) summary in the NCRN paleontological resources inventory (Kenworthy and Santucci 2004). Fossils from the Pine Plains Formation include algal structures such as thrombolites (similar to stromatolites but clotted instead of layered) (Gural et al. 2005) and reefs formed out of stromatolites, brachiopods, and trilobites (Knopf 1962; Ervilus and Friedman 1991). Original fossil material has usually been dissolved, so specimens are preserved as molds or casts (Ervilus and Friedman 1991). Fossils from the Poughquag Quartzite include brachiopods and trilobites (Knopf 1962). Finally, the fossil assemblage of the Stissing Formation includes brachiopods, hyoliths, trilobites, and ostracodes (Knopf 1962)

New Jersey

The bedrock of APPA in New Jersey includes Precambrian metamorphic and igneous rocks, the Cambrian-age Leithsville Formation, the Cambrian-Ordovician-age Allentown Dolomite (or Formation or Limestone), the Ordovician-age High Point and Ramseyburg members of the Martinsburg Formation, Ordovician- and Silurian-age igneous rocks, and the Silurian-age Bloomsburg Red Beds (or Formation) and Shawangunk Formation (Drake et al. 1996). The Bloomsburg Red Beds and Shawangunk Formation

are also present along the trail in Pennsylvania, as are other rocks of the Martinsburg Formation (Berg et al. 1980); the full Martinsburg Formation will be discussed under Pennsylvania. The formations that are currently known to be fossiliferous are the Allentown Dolomite, Bloomsburg Red Beds, Leithsville Formation, High Point and Ramseyburg members of the Martinsburg Formation, and the Shawangunk Formation.

The Allentown Dolomite has stromatolites and a variety of other algal fossils and traces, particularly in its Limeport Member (Howell 1950; Sohl 1993), foraminifera (protists that form shells, typically of carbonate) (Willard 1961), brachiopods, and trilobites (Howell 1950). The Bloomsburg Red Beds have diverse fossils, including microfossils (Beck and Strother 2002), spores, thalloid (undifferentiated body structures of certain organisms such as fungi and seaweed) and other compressions (Tomescu et al. 2009), *Prototaxites*, *Nematothallus* (possibly an early plant), coal (Strother 1988), foraminifera, tabulate corals, bryozoans (Hoskins 1961), brachiopods (Hoskins 1960), bivalves, gastropods, *Cornulites* (an extinct enigmatic shelled encrusting animal), *Tentaculites* (Hoskins 1961), an ancestral horseshoe crab (Metz 2006), eurypterids ("sea scorpions"), ostracodes, crinoids, scales and plates of early jawless fish (Hoskins 1961), and trace fossils (Garlock and Isaacson 1977) including *Skolithos* (Metz 2006). The formation includes both marine and nonmarine strata (Hoskins 1961). Additional details on the Bloomsburg Red Beds can be found in the DEWA summary in the ERMN paleontological resources inventory (Koch and Santucci 2004), and the CHOH summary in the NCRN paleontological resources inventory (Kenworthy and Santucci 2004).

The Leithsville Formation has stromatolites (Brewer 1993), possible foraminifera (Willard 1961), archaeocyaths (a type of early reef-formers, possibly sponges but resembling horn corals in shape), brachiopods, hyoliths, and trilobites (McMenamin et al. 1994). The High Point Member of the Martinsburg Formation has graptolites (Drake 1991). The Ramseyburg Member has brachiopods, *Cornulites*, trilobites, asteroids (sea stars), crinoids, and graptolites (Parris and Cruikshank 1992). Finally, the Shawangunk Formation has yielded pod structures that could be organic or inorganic (Feldman et al. 2009), brachiopods, eurypterids (Epstein 1993), trace fossils (including *Arthrophycus* and *Skolithos*; Metz 1998), and fish (Epstein 1993). Dipleurozoans, a type of extinct soft-bodied enigmatic organism, have been reported from the Shawangunk Formation, as *Rutgersella* (Fox 1968). However, *Rutgersella* has also been identified as a pseudofossil (Cloud 1973). Like the Bloomsburg Red Beds, there are more details on the Shawangunk Formation in the DEWA summary in the ERMN paleontological resources inventory (Koch and Santucci 2004).

Pennsylvania

The bedrock of APPA in Pennsylvania includes the most rock units of any state (Berg et al. 1980). Precambrian units include unnamed metamorphic rocks. Cambrian-age units include the Antietam Formation, Elbrook Formation, Harpers Formation, undivided Loudoun and Weverton formations, Shadygrove Formation, Tomstown Formation (or Dolomite), Waynesboro Formation, and Zullinger Formation. Ordovician-age units include undivided Bald Eagle and Juniata formations, Chambersburg Formation, Hamburg sequence, Martinsburg Formation, Pinesburg Station Formation, Rockdale Run Formation, Saint Paul Group, and Stonehenge Formation. Silurian-age units include the Bloomsburg Formation, undivided Bloomsburg and Mifflintown formations, Clinton Group, Shawangunk Formation, Tuscarora Formation, and Wills Creek Formation. Silurian-Devonian-age units include undivided Keyser and Tonoloway formations, and an undivided sequence including the Onondaga, Ridgeley, Rondout, Decker, Bossardville, and Poxono Island Limestone. Devonian-age units include the Catskill Formation (including the Clarks Ferry, Duncannon, Irish Valley, and Sherman Creek members), Hamilton Group, undivided Onondaga and Old Port formations, and Trimmers Rock Formation. Devonian-Mississippian-age units include the Spechty Kopf Formation. Mississippian-age units include the Mauch Chunk Formation (or Group) and Pocono Formation. Finally, Pennsylvanian-age units include the Llewellyn Formation and Pottsville Formation (or Group); the Pennsylvanian Subperiod of the Carboniferous Period is named for the state because extensive exposures of rocks of this age are present, particularly coal. The Hamilton Group is also present along the trail in New York (Fisher et al. 1970), the Bloomsburg and Shawangunk formations are also present in New Jersey (Drake et al. 1996), the Harpers, Loudoun,

and Weverton formations are also present in Maryland and West Virginia (Cardwell et al. 1968; Cleaves et al. 1968), and the Elbrook and Waynesboro formations are also present in Virginia (Virginia Division of Mineral Resources 1993). Given the lengthy list of rock units, the fossiliferous formations will be considered by geologic period. Fossils are not known from the Precambrian metamorphic rocks.

Pennsylvania: Cambrian rock units

Of the Cambrian rock units, the Antietam Formation, Elbrook Formation, Harpers Formation, Shadygrove Formation, Tomstown Formation, Waynesboro Formation, and Zullinger Formation are all known to be fossiliferous. Additional details on all of these formations, except for the Shadygrove and Zullinger formations, can be found in the CHOH summary in the NCRN paleontological resources inventory (Kenworthy and Santucci 2004). Most of these formations are sparsely fossiliferous. The fossil assemblage of the Antietam Formation includes hyoliths, ostracodes, trilobites (Brezinski 1992), and trace fossils such as *Skolithos* (Skoog et al. 1994). The Elbrook Formation has microbial reefs, trilobites, and conodonts (Brezinski et al. 2002). So far, only the trace fossil *Skolithos* has been found in the Harpers Formation (Brezinksi 1992). The Shadygrove Formation has algal structures and trilobites (Root 1968). The Tomstown Formation has algal structures, the problematic possible mollusk *Salterella* (Reinhardt and Wall 1975), possible trilobite fragments (Brezinksi 1992), and trace fossils (Kenworthy and Santucci 2004). The Waynesboro Formation has yielded stromatolites (Brezinski 1992), brachiopods, hyoliths, and trilobites (Ryder et al. 1992). Finally, the Zullinger Formation has algal structures and trilobites (Root 1968). The Antietam, Harpers, Tomstown, and Weverton formations are northern members of the Chilhowee Group; other formations of this group are discussed in the "Virginia: Cambrian formations" section below.

Pennsylvania: Ordovician rock units

Of the Ordovician rock units, the Bald Eagle Formation, Chambersburg Formation, Juniata Formation, Martinsburg Formation, Pinesburg Station Formation, Rockdale Run Formation, Saint Paul Group, and Stonehenge Formation are known to be fossiliferous. Additional details on all of these formations, except for the Bald Eagle and Juniata formations, can be found in the CHOH summary in the NCRN paleontological resources inventory (Kenworthy and Santucci 2004), and the DEWA summary in the ERMN paleontological resources inventory also covers the Martinsburg Formation (Koch and Santucci 2004). The Bald Eagle Formation is sparsely fossiliferous (Bretsky 1969) and its fossils not diagnostic (Epstein and Epstein 1972). The Chambersburg Formation fossil assemblage includes the alga (or coral) *Mastopora* (Osgood and Fisher 1960), brachiopods, bryozoans, trilobites (Kenworthy and Santucci 2004), carpoids (enigmatic extinct echinoderms) (Derstler 1975), and conodonts (Boger and Bergström 1976). The Juniata Formation has yielded a problematic cast of a plant and trace fossils, including a possible millipede burrow (Retallack 2001).

The Martinsburg Formation fossil assemblage includes carbonaceous debris (Feldman et al. 2006), acritarchs (a nebulous group of microfossils that are classified together on the basis that they cannot be identified as anything else) (Beck and Strother 2000), thalloid compressions (Tomescu et al. 2009), sponges (Gerhart 1983), corals (Feldman et al. 2006), conulatans (Wei-Haas et al. 2007), bryozoans, brachiopods, bivalves, cephalopods, gastropods (Gerhart 1983), eurypterids (Lehmann 1988), ostracodes, trilobites, crinoids, stelleroids (sea stars and brittle stars) (Gerhart 1983), carpoids (Derstler 1975), graptolites (Gerhart 1983), conodonts (Woodcock et al. 2000), and burrows (Lehmann 1988). A particularly well-known fossil site in the Martinsburg Formation is the Swatara Gap locality, mentioned earlier. This site yielded algae, sponges, conulatans, bryozoans, brachiopods, *Cornulites*, mollusks (including bivalves, cephalopods, gastropods, hyoliths, and monoplacophorans [something like a cross between a bivalve and a gastropod]), echinoderm-like stylophorans, echinoderms (including asteroids [sea stars], carpoids, crinoids, and ophiuroids [brittle stars]), eurypterids and other merostomatans, ostracodes, trilobites, graptolites, and burrows (Gerhart 1983; Lehman and Pope 1989). Fossils at Swatara Gap were often found as molds filled with iron oxide (H. Cramer 1957). The rock unit is sometimes identified as the correlative Reedsville Formation (Lehman and Pope 1989). The High Point and Ramseyburg members of the Martinsburg Formation are discussed above, under New Jersey.

The Pinesburg Station Formation and Rockdale Run Formation are parts of the Beekmantown Group (or Formation), which will also be discussed under Virginia. The Pinesburg Station Formation fossil assemblage includes stromatolites and conodonts, while the Rockdale Run Formation has sponges, corals, brachiopods, gastropods, cephalopods, and conodonts (Kenworthy and Santucci 2004). The Saint Paul Group has stromatolites (Mitchell 1980), other algal structures, tabulate corals, bryozoans, brachiopods, cephalopods, gastropods, ostracodes, trilobites, and conodonts (Kenworthy and Santucci 2004). Finally, the Stonehenge Formation has yielded microbial reefs (Brezinski et al. 2002), stromatolites, corals, brachiopods, cephalopods, gastropods (Kenworthy and Santucci 2004), rostroconchs (extinct mollusks similar to bivalves and scaphopods), *Tentaculites*, trilobites, pelmatozoans (Donaldson 1962), conodonts (Brezinksi et al. 2002), invertebrate burrows, and fecal pellets (Manns and Goodwin 1972).

Pennsylvania: Silurian rock units

Of the Silurian rock units, the Bloomsburg Formation (described under New Jersey), Clinton Group, Mifflintown Formation, Shawangunk Formation (described under New Jersey), Tuscarora Formation, and Wills Creek Formation are known to be fossiliferous. Additional details on the Bloomsburg and Shawangunk formations can be found in the CHOH summary in the NCRN paleontological resources inventory (Kenworthy and Santucci 2004) and the DEWA summary in the ERMN paleontological resources inventory (Koch and Santucci 2004), and the CHOH summary also covers the Tuscarora and Wills Creek formations. The Clinton Group is very fossiliferous. In Pennsylvania, fossiliferous subunits along the trail include the Rose Hill and Keefer formations (Wilshusen 1983). Its fossil assemblage includes stromatolites (Kleffner 1991), marine and nonmarine microfossils (Beck and Strother 2002), acritarchs, chitinozoans (flask-shaped marine microfossils) (F. Cramer 1969), thalloid compressions (Tomescu et al. 2009), stromatoporoids, corals, bryozoans, brachiopods, bivalves, cephalopods, gastropods (Gillette 1947), *Tentaculites* (Berdan and Zenger 1965), scolecodonts (jaws of polychaete worms) (F. Cramer 1969), eurypterids (Boucot et al. 1994), ostracodes, trilobites, crinoids, cystoids (a group of extinct stalked echinoderms superficially similar to crinoids) (Gillette 1947), conodonts (Kleffner 1991), and arthropod tracks (Tomescu et al. 2009) and other trace fossils (Gillette 1947). The Mifflintown Formation has yielded marine and nonmarine microfossils (Beck and Strother 2002), tabulate and rugose corals (Inners 1988), bryozoans, brachiopods, bivalves, cephalopods, gastropods (Sumrall et al. 2009), *Tentaculites* (Hoskins 1961) ostracodes, crinoids, edrioasteroids (disk-shaped extinct echinoderms) (Sumrall et al. 2009), and scales from jawless fish (Hoskins 1961).

The fossils of the Tuscarora Formation include acritarchs, chitinozoans, other phytoplankton (F. Cramer 1969), thalloid compressions (Tomescu et al. 2009), spores (Boucot et al. 1994), brachiopods (Amsden 1951), scolecodonts (F. Cramer 1969), eurypterids (Boucot et al. 1994), echinoderms including pelmatozoans (Hinds and Ward 1974), and trace fossils (Diecchio and Hall 1963), including *Skolithos* (Boucot et al. 1994). Finally, the Wills Creek Formation has algal structures (Strother and Beck 1993), palynomorphs (organic microfossils) (Strother and Beck 1993; Beck and Strother 2000), bryozoans (Kenworthy and Santucci 2004), brachiopods, bivalves (Kjellesvig-Waering and Leutze 1966), gastropods (Kenworthy and Santucci 2004), eurypterids, ostracodes (Kjellesvig-Waering and Leutze 1966), trilobites, conodonts (Kenworthy and Santucci 2004), and jawless fish (Leutze 1960).

Pennsylvania: Silurian-Devonian rock units

One of the drawbacks of using statewide maps is that the stratigraphic resolution can be coarse. On the Pennsylvania state map, there are two Silurian-Devonian map units of interest that are made up of multiple formations. These are the undivided Keyser and Tonoloway formations, and an undivided sequence including the Onondaga, Ridgeley, Rondout, Decker, Bossardville, and Poxono Island Limestone formations. These are all fossiliferous formations, but they are not all necessarily found within APPA. Additional details on the Keyser, Ridgeley, and Tonoloway formations can be found in the CHOH summary in the NCRN paleontological resources inventory (Kenworthy and Santucci 2004), and additional details on the Bossardville, Decker, Ridgeley, and Rondout formations can be found in the DEWA summary in the ERMN paleontological resources inventory (Koch and Santucci 2004).

Fossils from an undivided Tonoloway-Keyser sequence consist mostly of marine invertebrates. While not hosting quite as diverse a fossil assemblage as the overlying Keyser Formation, the Tonoloway Formation does have diverse algal structures (Blackerby and Smosna 1985), marine and nonmarine microfossils (Beck and Strother 2002), stromatoporoids, brachiopods, gastropods, *Tentaculites*, eurypterids (Kenworthy and Santucci 2004), ostracodes (Warshauer and Smosna 1978), conodonts (Denkler et al. 1983), and fish (Leutze 1960). The Keyser Formation (or Limestone) has yielded stromatoporoids, rugose and tabulate corals (Gianniny 1999), bryozoans, brachiopods, bivalves, cephalopods, gastropods, *Tentaculites*, *Spirorbis*, ostracodes (C. Miller 1982), trilobites (Devries and Isaacson 1977), crinoid and rhombiferan cystoid echinoderms (C. Miller 1982), graptolites (Stock and Holmes 1986), and conodonts (Helfrich 1978). Additionally, at least one sinkhole in the Keyser Formation trapped Pleistocene vertebrates (Fonda 1982), and fossiliferous stone from the formation has been used as building material (Kenworthy and Santucci 2004).

The Onondaga-Ridgeley-Rondout-Decker-Bossardville-Poxono Island Limestone series also has a fossil assemblage dominated by marine fossils. The Onondaga Formation has a diverse assemblage including plants, sponges, corals, conulatans, bryozoans, brachiopods, bivalves, cephalopods, gastropods, hyoliths, tentaculites, *Coleolus*, *Enchostoma* (a problematic tubular fossil, possibly from worms), ostracodes, phyllocarid crustaceans, trilobites, crinoids, conodonts, fish, and trace fossils (Willard 1936). The Ridgeley Formation has yielded brachiopods, gastropods (Hoffman 1984), and trace fossils (Metz 2002). The Rondout Formation has organic debris (Fetterhoff and Waines 1987), stromatoporoids, corals, bryozoans, bivalves, bivalves, gastropods, ostracodes, trilobites (Hoar and Bowen 1967; Parris and Albright 1979a), crinoids, conodonts (Johannessen et al. 1997), and trace fossils (Hoar and Bowen 1967). Fossils from the Decker Formation include corals, bryozoans, brachiopods, cephalopods, gastropods, "worms," ostracodes, trilobites, crinoids (Parris and Albright 1979a), and trace fossils (Metz 2003). The Bossardville Formation has yielded ostracodes (Koch and Santucci 2004). Finally, the Poxono Island Limestone has trilobites, ostracodes, and trace fossils (DeWindt 1973).

Pennsylvania: Devonian rock units

Of the Devonian rock units, the Catskill Formation, Hamilton Group (described under New York), undivided Onondaga Formation (described above) and Old Port Formation, and Trimmers Rock Formation are known to be fossiliferous. The DEWA summary in the ERMN paleontological resources inventory (Koch and Santucci 2004) has additional details on the Hamilton Group and Trimmers Rock Formation, and the CHOH summary in the NCRN paleontological resources inventory (Kenworthy and Santucci 2004) also discusses the Hamilton Group.

The Catskill Formation can be divided into the Clarks Ferry, Duncannon, Irish Valley, and Sherman Creek members within APPA, but they will be considered as one for the purposes of this report. The fossils of the Duncannon Member are particularly well-known, and include the earliest known North American tetrapod fossils. These fossils were found at a site known as Red Hill near Hyner, Pennsylvania (Retallack et al. 2009), over 113 km (70 miles) northwest of the nearest section of APPA. Fossils of the Catskill Formation include spores, root traces, a variety of plants such as lycopsids, ferns, progymnosperms, and gymnosperms, millipedes, scorpions, spider-like trigonotarbid arachnids, placoderms (early jawed fish), xenacanth and ctenacanth sharks, acanthodians ("spiny sharks"), early ray-finned fish, lungfish and other lobe-finned fish, at least four early tetrapods (Retallack et al. 2009) including *Densignathus* (Daeschler 2000) and *Hynerpeton* (Daeschler and Shubin 1994), and animal trace fossils (Retallack et al. 2009). The Old Port Formation was instated to encompass several formations that may not be mappable, including the Coeymans, Corriganville, Helderberg, Mandata, New Scotland, Oriskany, Ridgeley, and Shriver formations (Faill et al. 1989). Given the current lack of resolution on what the Old Port Formation would encompass within APPA, it is omitted here, although the Ridgeley Formation is discussed above, and several of the other associated formations are discussed in the DEWA summary in the ERMN paleontological resources inventory (Koch and Santucci 2004) and the CHOH summary in the NCRN paleontological resources inventory (Kenworthy and Santucci 2004). Finally, the Trimmers Rock Formation has palynomorphs (Norton and Allen 1970), root casts and stump casts (Driese et al. 1997), other plants, corals, bryozoans, brachiopods, bivalves (Parris and Albright 1979b),

cephalopods (Inners 1981), gastropods, "worms," trilobites and other arthropods, crinoids (Parris and Albright 1979b), invertebrate trace fossils (Inners 1981), and fish (Parris and Albright 1979b).

Pennsylvania: Devonian-Mississippian rock units

There is one Devonian-Mississippian formation that is crossed by APPA in Pennsylvania: the fossiliferous Spechty Kopf Formation. Its fossils include sparse plant material (Trexler et al. 1962).

Pennsylvania: Mississippian rock units

Of the Mississippian rock units crossed by APPA in Pennsylvania, both the Mauch Chunk Formation and the Pocono Formation are fossiliferous. The Mauch Chunk Formation is sometimes divided into members, or formations if it is considered a group. A notable vertebrate site occurs in this unit near Greer, West Virginia, 185 km (115 miles) west of the nearest part of APPA; remains of sharks, acanthodians, lungfish, the temnospondyl amphibian *Greerepeton*, the anthracosaur amphibian *Proterogyrinus*, and a large *Eryops*-like amphibian have been found here (Elliott and Taber 1981a; Smithson 1982). The Mauch Chunk Formation has both diverse marine and nonmarine fossils. Its fossils include root traces (Jennings 1985), plants (Read 1955), foraminifera, corals, conulatans, bryozoans, brachiopods, bivalves, cephalopods, gastropods (Simonsen 1988), rostroconchs (Hoare and Peck 2005), ostracodes, trilobites, blastoids ("sea buds"), crinoids, echinoids ("sea urchins"), conodonts (Simonsen 1988), invertebrate trace fossils (Jennings 1985; Lucas et al. 2006), sharks, acanthodians, lungfish, amphibians (Elliott and Taber 1981a), and tetrapod tracks (Lucas et al. 2006; Brazo et al. 2007). The Pocono Formation has yielded coal (Dunlap 1996), plants (Arnold 1933; Read 1955), bryozoans, brachiopods, bivalves, cephalopods, gastropods, *Spirorbis* (Girty 1928), trigonotarbid arachnids (Dunlap 1996), shrimp-like crustaceans (Schram 1988), and crinoids (Girty 1928).

Pennsylvania: Pennsylvanian rock units

The last set of potentially fossiliferous rock units crossed by the trail in Pennsylvania includes the Pennsylvanian-age Llewellyn Formation and Pottsville Formation. The Llewellyn Formation fossil assemblage includes coal, diverse plant fossils including lycopods, giant club mosses, horsetails, ferns, and gymnosperms (Oleksyshyn 1979, 1982; Klose 1982), *Spirorbis* (Klose 1982), and insect body fossils and tracks (Smith et al. 2009). The Pottsville Formation has yielded coal (Wilshusen 1983), spores (Eble 1979), plants including horsetails and seed ferns (Jennings 1985), foraminifera, fusulinid foraminifera (particularly large foraminifera that went extinct at the end of the Permian), corals, conulatans, bryozoans, brachiopods, bivalves, cephalopods, gastropods, scaphopods, *Spirorbis*, trilobites (Morningstar 1922), conchostracans ("clam shrimp") (Williams 1979), crinoids, echinoids, and rare fish teeth and plates (Morningstar 1922).

Maryland and West Virginia

Maryland and West Virginia are considered together because they have very similar bedrock units. The bedrock units crossed by APPA in Maryland include Precambrian gneiss, the Precambrian-Cambrian-age Catoctin Metabasalt (or Formation) and Weverton Formation, and the Cambrian-age Harpers Formation and Loudoun Formation (Cleaves et al. 1968). The bedrock crossed by the trail in West Virginia also includes the Harpers Formation, Loudoun Formation, and Weverton Formation, and may include the Catoctin Formation (APPA follows close to the state border with Virginia, and the Catoctin Formation is present on the West Virginia side of the border). The only units of interest for West Virginia that are not present in Maryland are the Ordovician-age Juniata Formation and Oswego Formation, which, like the Catoctin Formation, are present on the West Virginia-Virginia border segment of APPA (Cardwell et al. 1968). Additionally, most of these formations are also crossed by the trail in Pennsylvania, including the Harpers Formation, Juniata Formation, Loudoun Formation, and Weverton Formation. Of the formations, the Harpers Formation (described under Pennsylvania), Juniata Formation (described under Pennsylvania), and Oswego Formation are known to be fossiliferous. Like the Juniata Formation and the equivalent Bald Eagle Formation, fossils are uncommon in the Oswego Formation (Bretsky 1969). There are compressions of terrestrial fossils, and marine fossils are present near the base of the unit (Tomescu et al. 2003). There are also thalloid compressions in the Oswego Formation's transition with the Reedsville Formation (Tomescu et al. 2009).

Virginia

As with Pennsylvania, there are numerous bedrock units crossed by APPA in Virginia (Virginia Division of Mineral Resources 1993). Precambrian-age units include the Konnarock Formation, Mount Rogers Formation, and Swift Run Formation, and unnamed igneous and metamorphic rocks. Precambrian or younger units include unnamed metamorphic rocks of undetermined Precambrian or Paleozoic age. Cambrian-age units include the Catoctin Formation, Chilhowee Group (including at least the Erwin Formation or Quartzite, Hampton Formation, Shady Dolomite or Formation, and Unicoi Formation), Conococheague Formation or Limestone, Elbrook Formation, Honaker Formation, Nolichucky Formation, Rome Formation, and Waynesboro Formation. Cambrian-Ordovician-age units include the Knox Group and undivided Cambrian-Ordovician formations. Ordovician-age units include the Beekmantown Group (or Formation), a complex undivided sequence, and a unit mapped as the "Juniata, Reedsville, Trenton, and Eggleston formations". Silurian-Devonian units include undivided Silurian and Silurian-Devonian units. Devonian-age units include the Brallier Formation, Chemung Formation or Foreknobs Formation, Huntersville Chert, Millboro Shale, Needmore Formation, and Rocky Gap Sandstone. Finally, Mississippian-age units include the Maccrady Formation and Price Formation. The Elbrook and Waynesboro formations are also present on the trail in Pennsylvania (Berg et al. 1980), the Hampton, Erwin, Rome, and Unicoi formations are also present in Tennessee (Hardeman 1966), and the Shady Dolomite is also present in Tennessee and North Carolina (Hardeman 1966; North Carolina Geological Survey 1985). As with Pennsylvania, the fossiliferous formations will be considered by geologic period, and the Precambrian formations are not known to be fossiliferous.

Virginia: Cambrian rock units

Of the Cambrian formations, the fossiliferous rock units are the Chilhowee Group (including the Erwin, Hampton, Shady, and Unicoi formations), Conococheague Formation, Elbrook Formation (described under Pennsylvania), Honaker Formation, Nolichucky Formation, Rome Formation, and Waynesboro Formation (described under Pennsylvania). Several of the NPS units that APPA passes through include one or more of these formations: additional details on the Conococheague Formation can be found in the CHOH summary in the NCRN paleontological resources inventory (Kenworthy and Santucci 2004), the Erwin and Hampton formations are described in more detail in the Shenandoah National Park (SHEN) summary in the MIDN paleontological resources inventory (Kenworthy et al. 2006), and the rocks of the Chilhowee Group are described in more detail in the Blue Ridge Parkway (BLRI) and Great Smoky Mountains National Park (GRSM) summaries in the APHN paleontological resources inventory (Santucci et al. 2008; although note that the Chilhowee Group of GRSM has different formations than present in the Virginia section of APPA).

Most of the Cambrian units are not extensively fossiliferous. The Chilhowee Group in general yields such fossils as brachiopods, hyoliths, ostracodes, trilobites, and trace fossils (including *Skolithos*) (King 1964; Neuman and Nelson 1965). Of the included rock units specifically discussed on the Virginia state map, most are limited to trace fossils. The Erwin Formation has the trace fossil *Skolithos* (Simpson and Eriksson 1990), and the Hampton Formation has hyoliths (Simpson and Eriksson 1989) and trace fossils (Simpson and Eriksson 1990). The best-known fossils from the Shady Dolomite are its archaeocyathid patch reefs, although at least one authority has interpreted a reef as thick weathered burrows (Balsam 1974). Its fossil assemblage includes stromatolites, thrombolites, and other algal structures (Read and Pfeil 1983), the problematic *Labyrinthus* (not the same as the gastropod genus) (Kobluk 1982), possible foraminifera, sponges (Kobluk 1985), archaeocyaths, brachiopods, helcionellids (early mollusks, perhaps gastropods), hyoliths, *Salterella*, *Coleoloides*, trilobites (Willoughby 1976), possible burrows, and pellets (Thompson 1971). Some fossil sites in West Virginia are near the trail (Byrd et al. 1973). Finally, the Unicoi Formation has trace fossils, including *Skolithos* (Simpson and Eriksson 1989). The Chilhowee Group formations found in Tennessee and North Carolina have similarly sparse assemblages. The Nichols Shale, Nebo Sandstone, and Hesse Sandstone encountered in eastern Tennessee have *Skolithos* (King 1964) and other trace fossils (Santucci et al. 2008). The Helenmode Formation has trilobites and unspecified other fossils (Santucci et al. 2008). The Murray Shale has brachiopods, ostracodes, and trilobites (Neuman and Nelson 1965).

The Conococheague Formation has yielded microbial reefs (Brezinski et al. 2002), stromatolites (Busch and Fedosh 1978), thrombolites, algae, possible foraminifera and foraminifera-like organisms, brachiopods, gastropods, trilobites (Demicco et al. 1982), conodonts (Orndorff 1988), and trace fossils (Busch and Fedosh 1978), with possible patch reefs (Demicco et al. 1982). The Honaker Formation has algal structures (Ottinger 1999) and trilobites (Derby 1965). The fossil assemblage of the Nolichucky Formation includes stromatolites (Markello and Read 1978), acritarchs, other palynomorphs (Strother 2008), lime-secreting algae (Markello and Read 1978), the problematic *Kinsabia*, sponges, brachiopods (Derby 1965), hyoliths (Malinky 1988), problematic pelagiellid and tergomyan mollusks (gastropod-like) among other mollusks, scenellids (problematic extinct possible mollusks), trilobites, echinoderm fragments (Gibson and Dunagan 2008), and graptolites (Derby 1965). Finally, the Rome Formation has brachiopods, hyoliths, *Salterella*, and trilobites (Osborne and Yochelson 1994).

Virginia: Cambrian-Ordovician rock units

Of the Cambrian-Ordovician-age rock units, the Knox Group is known to be fossiliferous, and the undivided Cambrian-Ordovician formations can be assumed to be fossiliferous as well. As discussed elsewhere in this summary, a typical Cambrian-Ordovician assemblage would probably include a variety of shelly marine invertebrates, or colonial forms with hard substrates, such as sponges, corals, brachiopods, bivalves, gastropods, cephalopods, ostracodes, trilobites, and crinoids, as well as trace fossils, with bryozoans appearing in the Ordovician. The Knox Group is fossiliferous, although it is usually considered in terms of individual formations. These may include the Conococheague and Beekmantown formations, which are described above and below, respectively. One publication that addresses the Knox Group as a whole reports sponges, brachiopods, and gastropods (King 1964).

Virginia: Ordovician rock units

The Ordovician-age rock units that are known to be fossiliferous include the Beekmantown Group, the Eggleston Formation, the Juniata Formation (described under Pennsylvania), the Reedsville Formation, and the Trenton Limestone (or Group). As discussed above, the complex undivided sequence is probably fossiliferous somewhere, with an assemblage of marine invertebrates with hard parts. The Beekmantown Group is generally unfossiliferous, with cephalopods, gastropods, and conodonts reported from Virginia (Suter and Tillman 1973). A richer assemblage is known in New York, including thrombolites, chitinozoans, brachiopods, cephalopods, gastropods, monoplacophorans, ostracodes, trilobites, echinoderms, and conodonts (Landing and Westrop 2006). Individual formations assigned to the Beekmantown Group include the Pinesburg Station Formation, Rockdale Run Formation, and Stonehenge Formation; these were described under Pennsylvania. The Eggleston Formation has yielded bryozoans, brachiopods, gastropods, and crinoids (Haynes 1992). The Reedsville Formation correlates to the Martinsburg Formation (Lehmann 1988). It has yielded bryozoans, brachiopods, bivalves, gastropods, trilobites, crinoids (Bretsky 1969), rhombiferan cystoids, graptolites (Lehmann 2002), and conodonts (Hall and Diecchio 1988), and thalloid compressions are known from the Reedsville-Oswego Formation transition (Tomsecu et al. 2009). Finally, the Trenton Limestone is extensively fossiliferous, with New York fossils particularly well known. The Trenton Limestone fossil assemblage includes a variety of algae (red, blue, and blue-green) and algal structures, sponges, corals, conulatans, brachiopods, mollusks (including bivalves, cephalopods, gastropods, and monoplacophorans), serpulid worms (annelids), arthropods (including ostracodes, trilobites, and others), echinoderms (including asteroids, carpoids, crinoids, cyclocystoids, and cystoids), graptolites, conodonts, and invertebrate trace fossils including burrows and fecal pellets (Titus and Cameron 1976; Titus 1982a, 1982b, 1986).

Virginia: Silurian and Devonian rock units

APPA crosses undivided Silurian-Devonian and Devonian sedimentary units. These are likely fossiliferous. Referring to larger-scale geologic maps of the area would yield additional information about the specific formations mapped in the area. In general, the categories of fossils present in middle Paleozoic units are similar to those of early Paleozoic units, except early land plants, fish, and tetrapods appeared and began to spread during this time. Also, as the Paleozoic progressed, enigmatic organisms became less abundant and decreased in diversity.

Of the Devonian-age rock units, the Brallier Formation, Chemung/Foreknobs Formation, Huntersville Chert, Millboro Shale, Needmore Formation, and Rocky Gap Sandstone are known to be fossiliferous. Additional details on the Brallier Formation, Foreknobs Formation, and Needmore Formation can be found in the CHOH summary in the NCRN paleontological resources inventory (Kenworthy and Santucci 2004). The Brallier Formation has yielded palynomorphs (Norton and Allen 1970), carbonized plant fragments (W. Miller et al. 1982), conulatans (Rossbach 2000), brachiopods, bivalves (Avary and Dennison 1980), cephalopods (Kenworthy and Santucci 2004), possible asteroids, and trace fossils (McDowell et al. 2007). Invertebrate fossils are uncommon in this unit (Avary and Dennison 1980; McDowell et al. 2007). The Chemung Formation was originally named in New York, and may not be appropriate to use in this area (McDowell and Schultz 1990). In Maryland, West Virginia, and Virginia, it has been divided into the Scherr Formation (mapped with the Brallier Formation), and the Foreknobs Formation (Kenworthy and Santucci 2004). Fossils reported from the Chemung Formation of the central APPA region include palynomorphs (Norton and Allen 1970), sponges (Rice 1958), and crinoids (Nair et al. 1992). The Foreknobs Formation has coalified and pyritized wood (McDowell and Britton 2006), plant debris, brachiopods, bivalves, gastropods, crinoids (Dennison 1970; Fleming and Filer 2006), edrioasteroids (Elliott and Taber 1981b), and trace fossils (McDowell et al. 2007). The Blizzard, Mallow, and Red Lick members of the Foreknobs Formation are noted for their fossils (McDowell et al. 2007). The Huntersville Chert has corals, bryozoans, brachiopods, bivalves, ostracodes, and crinoids (Ciaramella 1959). The Millboro Shale is sparsely fossiliferous (McDowell and Schultz 1990), although at least one location has abundant unidentified tiny fossils (Avary and Dennison 1980). Plants including progymnosperms are present in the formation (Stein 1982; Stein et al. 1983; Wight and Beck 1984), as well as invertebrates (McDowell et al. 2007), including bivalves (W. Miller et al. 1982). The fossil assemblage of the Needmore Formation includes rugose corals (Oliver 1989), brachiopods, cephalopods, scaphopods, ostracodes, trilobites (DeWitt and Colton 1964), and conodonts (Harris et al. 1994). Finally, the Rocky Gap Sandstone has molds of brachiopods and crinoids (McDowell and Schultz 1990).

Virginia: Mississippian rock units

Of the two Mississippian-age formations that APPA crosses in Virginia, both the Maccrady Formation and Price Formation are fossiliferous. The Maccrady Formation has brachiopods (Powell 2008) and conodonts (Stamm 1997). The Price Formation has produced lycopod root casts, coal (Jennings 1975), spores, seeds (Knaus et al. 2000), plant tissues including stems and leaves (Gensel 1988a), plant compressions and impressions (Gensel 1988b), bryozoans, brachiopods, bivalves, cephalopods, gastropods (Bjerstedt 1988), arachnids, eurypterids, syncarid crustaceans, crinoids (Tczap and Tillman 1982), and trace fossils including *Skolithos* (Bjerstedt 1988). Invertebrate fossils are mostly molds (Carter and Kammer 1990).

Tennessee and North Carolina

As was done with Maryland and West Virginia, Tennessee and North Carolina will be discussed together because their bedrock geology overlaps substantially. This is due in large part to the path of APPA: much of APPA between Virginia and Georgia follows the Tennessee-North Carolina border. The bedrock crossed by APPA in Tennessee includes unnamed Precambrian igneous and metamorphic units, formations of the Precambrian-age Ocoee Supergroup, and the Cambrian-age Chilhowee Group (Erwin, Hampton, Shady, and Unicoi formations) and Rome Formation (Hardeman 1966). The North Carolina bedrock is essentially the same, except there are some additional Precambrian units (the Brasstown Formation, Coweeta Group, Nantahala Formation, and Tusquitee Quartzite), and the Rome Formation is not present (North Carolina Geological Survey 1985).

The Ocoee Supergroup requires some explanation, as it is a complex unit. It includes three groups (the Great Smoky Group, Snowbird Group, and Walden Creek Group) and two other formations (the Cades Sandstone and Rich Butt Sandstone). In the area crossed by APPA, the Great Smoky Group includes the Anakeesta Formation, Copperhill Formation, Dean Formation, Elkmont Sandstone, Thunderhead Sandstone, and Wehutty Formation. Similarly, the Snowbird Group includes the Longarm Quartzite, Metcalf Phyllite, Pigeon Siltstone, Roaring Fork Sandstone, and Wading Branch Formation. Finally, the Walden Creek Group includes the Licklog Formation, Sandsuck Formation, Shields Formation, and

Wilhite Formation (Hardeman 1966; North Carolina Geological Survey 1985). The Ocoee Supergroup is traditionally thought of as Precambrian in age, but there has been some controversy involving Silurian or younger fossils described from the Sandsuck and Wilhite formations, as will be described below. The Chilhowee Group and Rome Formation are also found in Virginia (Virginia Division of Mineral Resources 1993).

Of the Precambrian formations, the Longarm Quartzite, Sandsuck Formation, Shields Formation, and Wilhite Formation are reported as fossiliferous or potentially fossiliferous. However, some of the reported fossils of the Sandsuck and Wilhite formations are Paleozoic in age, implying that either the stratigraphic framework has been interpreted incorrectly and at least some part of the Ocoee Supergroup is much younger than usually thought, or that Paleozoic rocks have been mapped as Ocoee Supergroup. For example, it has been suggested that "Sandsuck Formation" rocks with Paleozoic conodonts are faulted younger rocks (Repetski et al. 2006). The Longarm Quartzite may have burrows (Chapman 1975). Acritarchs have been reported from the Sandsuck, Shields, and Wilhite formations (Knoll and Keller 1979). Rocks mapped as the Sandsuck Formation in the western Blue Ridge Foothills have yielded Paleozoic conodonts (Repetski et al. 2006). An extensive assemblage, Silurian or younger in age, has been found from eleven localities in the Wilhite Formation, including algae, calcispheres (limy spherical microfossils), foraminifera, bryozoans, mollusks, ostracodes, trilobites, and pelmatozoans (Unrug and Unrug 1990; Unrug et al. 2000).

Of the Cambrian formations, the Erwin Formation, Hampton Formation, Rome Formation, Shady Dolomite, and Unicoi Formation are known to be fossiliferous. All are present in Virginia as well, and are described under the Cambrian section for that state.

Quaternary rocks and sediments (Pleistocene-Holocene)

The surficial cover of APPA is potentially fossiliferous, although not as ideal as other settings, because the trail's route takes it primarily through areas of erosion, not deposition. The most likely areas for fossils are those places where the trail crosses or passes near water, such as rivers and in recently-deglaciated areas where lakes and former lakes are abundant, primarily north of New Jersey. Quaternary fossils from the regions surrounding the trail usually belong to one of two broad categories: paleoecological materials, principally Holocene in age, such as pollen, spores, and other microfossils, which are used to reconstruct past climate; and Pleistocene vertebrates, particularly extinct megafauna such as sloths, mastodons, mammoths, horses, and a variety of extinct artiodactyls.

While it is possible to find pollen or charcoal of several thousand years' age or more in sufficiently old soil, most finds have been made in lakes or former lakes. Numerous paleoecological studies have been done in the deglaciated lands within 100 km (60 miles) of APPA, and the summaries in this report concerning non-coastal parks and monuments of the NETN cite many specific examples. The summaries of interest are those for Marsh-Billings-Rockefeller National Historic Park (MABI), Minute Man National Historic Park (MIMA), Morristown National Historic Park (MORR), the Roosevelt-Vanderbilt national historic sites (ROVA), Saint-Gaudens National Historic Site (SAGA), Saratoga National Historic Park (SARA), Springfield Armory National Historic Site (SPAR), and Weir Farm National Historic Site (WEFA). While pollen is the most widely used type of fossil, diatoms (algae with silica "shells") (for example Dixit et al. 1993) and the hard parts of various insect larvae, particularly midges (for example Uutala 1990 or Erickson et al. 2008), are also frequently used. Another subcategory of interest are the deposits of the great glacial meltwater lakes. Their deposits, such as those from Glacial Lake Hitchcock of the Connecticut River Valley, include remains of spores, plants (Knecht et al. 2009), snails (Ridge et al. 2009), crustaceans (Knecht et al. 2009), midges, ostracodes, and fish, and trace fossils from invertebrates and fish (Benner et al. 2009).

The Pleistocene vertebrate assemblage of the eastern United States is known from numerous sites as well, although the distribution is partially the reverse of paleoecological materials: there are few Pleistocene vertebrate sites in New England, where glacial events covered the land part of the time and reworked surficial deposits formed during interglacial periods, but there are numerous Holocene-age

paleoecological sites, as there are many lakes and former lakes because of the glaciers. The 1923 survey by Hay of North American Pleistocene vertebrates east of the Mississippi is particularly useful, albeit dated (Hay 1923). Dozens of localities are detailed in this work for sloths, giant beavers, mastodons, mammoths, horses, tapirs, peccaries, camel, deer, elk, caribou, musk ox, and bison. Most finds of interest for this report are concentrated in two areas: a zone including southern New York, New Jersey, and northern and eastern Pennsylvania, in the vicinity of the furthest advance of the last glaciation; and a zone that follows the West Virginia-Virginia and Tennessee-North Carolina borders (Hay 1923). Coincidentally, the part of APPA from New York to the Tennessee-North Carolina border is also the most likely area for finding Paleozoic fossils. By far the most common Pleistocene mammal in the vicinity of the trail is the American mastodon, with dozens of occurrences in the mucklands of southeastern New York alone (Hartnagel and Bishop 1921; Hay 1923).

An interesting connection of a bedrock unit present on the trail and Quaternary organisms was found near Hollidaysburg, Pennsylvanian, over 90 km (56 miles) northwest of the nearest part of APPA. At this site, a filled sinkhole in the Keyser Formation, a diverse assemblage of trapped Pleistocene vertebrates has been found, including frogs, toads, turtles, snakes, insectivores, bats, lagomorphs, rodents, carnivorans, proboscideans, and ungulates. Among the animals found there which are now extinct or extirpated from the area are a type of ground squirrel, martens, coyotes, mastodons, tapirs, peccaries, the stag elk *Cervalces*, and elk (Fonda 1982).

One example of a site that includes paleoecological fossils and vertebrates is the Hyde Park mastodon site, 28 km (17 miles) northwest of the nearest APPA segment adjacent to Home of Franklin D. Roosevelt National Historic Site (HOFR) and Eleanor Roosevelt National Historic Site (ELRO) (see the summary in this report for the Roosevelt-Vanderbilt national historic sites for more information). While most famous for its nearly complete mastodon, the site has many other types of fossils, including diatoms (Allmon et al. 2001; Sokal and Hall 2003), peat, pollen, plant macrofossils (leaves, needles, twigs, seeds, fruits, cones, and megaspores from aquatic, wetland, and other plants), bivalves, gastropods, ostracodes (N. Miller and Nester 2006), and several types of beetles (Nelson et al. 2002).

Park Collections

There are no reported fossils in APPA collections.

Cultural Resource Contexts

People have inhabited lands near APPA for over ten thousand years. Fossiliferous rocks of the same formations present on the trail have been used for various purposes by humans over this time, from the prehistoric (such as the use of the fossiliferous Allentown Dolomite chert for stone tools; Sohl 1993) to the present (fossiliferous Keyser Formation rocks have been used for building, such as within CHOH; Kenworthy and Santucci 2004). 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

- No formal NPS inventories have been undertaken for APPA; this document represents the first step toward supporting field inventories in the park.
- A full paleontological resource survey of the trail would be a massive undertaking. Higher-resolution geologic maps would provide the basis for such an effort. Areas of particularly high visitation should be prioritized given the associated resource management concerns.
- Museums, state geological surveys, universities and other institutions could serve as local contacts and sources of expertise as needed. Contact the NPS Geologic Resources Division for assistance.

- Given the variety of landowners and partners along the trail, interagency collaboration will be crucial for any paleontological resource inventory effort.
- Trail staff should be encouraged to observe exposed sedimentary material for fossil material while conducting their usual duties. Staff should photodocument and potentially 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. Corridor stewards, ridgerunners, caretakers, and other trail management groups might also be able to provide additional information about fossil occurrences. 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).
- Future archeological excavations or infrastructure developments should consider scheduling site monitoring by a trained paleontologist in order to document and protect fossil resources.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

Literature Cited

Allmon, W. D., P. L. Nester, J. Sherpa, J. J. Chiment, A. J. Erwin, N. Russell, and C. B. Griggs. 2001. Preliminary paleoenvironmental, paleoecological, and taphonomic comparison of two new Mastodon skeletons from the late Pleistocene of New York State. Abstracts with Programs - Geological Society of America **33**(1):84.

Amsden, T. W. 1951. Paleontology. Pages 98-123 *in* Cloos, E., editor. The physical features of Washington County. Maryland Geological Survey, Baltimore, MD. County Report 14.

Arnold, C. A. 1933. A lycopodiaceous strobilus from the Pocono sandstone of Pennsylvania. American Journal of Botany **20**(2):114-117.

Avary, K. L. and J. M. Dennison. 1980. Back Creek Siltstone member of Devonian Brallier Formation in Virginia and West Virginia. Southeastern Geology **21**(2):121-153.

Balsam, W. L. 1974. Reinterpretation of an archaeocyathid reef: Shady Formation, southwestern Virginia. Southeastern Geology **16**(2):121-129.

Bartholomew, A. J. and C. E. Brett. 2003. The Middle Devonian (Givetian) Gilboa Forest: sequence stratigraphic determination of the world's oldest fossil forest deposit, Schoharie Co., New York State. Abstracts with Programs - Geological Society of America **35**(3):83-84.

Beck, J. H. and P. K. Strother. 2000. Palynomorphs as environmental indicators in lower Paleozoic strata. Abstracts with Programs - Geological Society of America **32**(1):4.

Beck, J. H. and P. K. Strother. 2002. Pre-Devonian palynology in the Appalachian Basin: a new look at lithofacies. Abstracts with Programs - Geological Society of America **34**(1):71.

Benner, J. S., J. C. Ridge, and R. J. Knecht. 2009. Timing of post-glacial reinhabitation and ecological development of two New England, USA, drainages based on trace fossil evidence. Palaeogeography, Palaeoclimatology, Palaeoecology **272**(3-4):212-231.

Berdan, J. M. and D. H. Zenger. 1965. Presence of the ostracode *Drepanellina clarki* in the type Clinton (Middle Silurian) in New York State. Pages C96-C100 *in* Geological Survey Research 1965. U.S. Geological Survey, Reston, VA. Professional Paper 525-C.

Berg, T. M., W. E. Edmunds, A. R. Geyer, A. D. Glover, D. M. Hoskins, D. B. MacLachlan, S. I. Root, W. D. Sevon, and A. A. Socolow. 1980. Geologic map of Pennsylvania. Pennsylvania Geological Survey, Harrisburg, PA. Map 1. Scale 1:250,000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_34341.htm. Accessed January 2010.

Billings, M. P. and A. B. Cleaves. 1934. Paleontology of the Littleton area, New Hampshire. American Journal of Science **28**(168):412-438.

Bjerstedt, T. W. 1988. Trace fossils from the Early Mississippian Price Delta, Southeast West Virginia. Journal of Paleontology **62**(4):506-519.

Blackerby, J. N. and R. Smosna. 1985. Ecological diversity of stromatolites in the Silurian Tonoloway Limestone. Abstracts with Programs - Geological Society of America **17**(1):5.

Bock, B., S. M. McLennan, and G. N. Hanson. 1998. Geochemistry and provenance of the Middle Ordovician Austin Glen Member (Normanskill Formation) and the Taconian Orogeny in New England. Sedimentology **45**(4):635-655.

Boger, J. L. and S. M. Bergström. 1976. Conodont biostratigraphy of the upper Beekmantown Group and the St. Paul Group (early and middle Ordovician) of Maryland and West Virginia. Abstracts with Programs - Geological Society of America **8**(4):465.

Bonelli, J. R., C. E. Brett, A. I. Miller, and J. B. Bennington. 2006. Testing for faunal stability across a regional biotic transition: quantifying stasis and variation among recurring coral-rich biofacies in the Middle Devonian Appalachian Basin. Paleobiology **32**(1):20-37.

Boucot, A. J. and D. Rumble III. 1978. Devonian brachiopods from the sillimanite zone, Mount Moosilauke, New Hampshire. Science **201**(4353):348-349.

Boucot, A. J. and D. Rumble III. 1980. Regionally metamorphosed (high sillimanite zone, granulite facies) Early Devonian brachiopods from the Littleton Formation of New Hampshire. Journal of Paleontology **54**(1):188-195.

Boucot, A. J. and J. B. Thompson Jr. 1958. Late Lower Silurian fossils from sillimanite zone near Claremont, New Hampshire. Science **128**(3320):362-363.

Boucot, A. J. and J. B. Thompson Jr. 1963. Metamorphosed Silurian brachiopods from New Hampshire. Geological Society of America Bulletin **74**(11):1313-1333.

Boucot, A. J., J. Gray, and D. M. Hoskins. 1994. New hughmilleriid (Eurypterida) occurrence from the Tuscarora Formation, central Pennsylvania, and its environmental interpretation. Pages 21-23 *in* Landing, E., editor. Studies in stratigraphy and paleontology in honor of Donald W. Fisher. New York State Museum, Albany, NY. Bulletin 481.

Brazo, M. B., M. J. Benton, and E. B. Daeschler. 2007. Tetrapod tracks from the Mauch Chunk Formation (Middle to Upper Mississippian) of Pennsylvania, U.S.A. Proceedings of the Academy of Natural Sciences of Philadelphia 156:199-209. [full text available on Google Books]

Bretsky, P. W. 1969. Central Appalachian Late Ordovician communities. Geological Society of America Bulletin **80**(2):193-212.

Brewer, M. C. 1993. The Lower and Middle Camerian Leithsville Formation within the Wallkill River valley, Sussex County, New Jersey: its stratigraphy and archaeological relevance. Abstracts with Programs - Geological Society of America **25**(2):7.

Brezinski, D. K. 1992. Lithostratigraphy of the western Blue Ridge cover rocks in Maryland. Maryland Geological Survey, Baltimore, MD. Report of Investigations 55.

Brezinski, D. K., J. E. Repetski, and J. F. Taylor. 2002. Middle Cambrian to Upper Ordovician stratigraphy and paleontology along the Chesapeake & Ohio Canal National Historical Park, western Maryland. Abstracts with Programs - Geological Society of America **34**(6):423.

Busch, R. M. and M. S. Fedosh. 1978. *Welleraspis* (Trilobita) in the Conococheaque Formation of southeast Pennsylvania. Pennsylvania Geology **9**(6):13-14.

Byrd, W. J., E. L. Weinberg, and E. L. Yochelson. 1973. *Salterella* in the lower Cambrian Shady Dolomite of southwestern Virginia. American Journal of Science **273**-A:252-260.

Caldwell, D. W. 1998. Roadside geology of Maine. Mountain Press Publishing Company, Missoula, MT.

Cardwell, D. H., R. B. Erwin, and H. P. Woodward. 1968. Geologic map of West Virginia. West Virginia Geological and Economic Survey. Morgantown, WV. Scale 1:250,000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_13205.htm. Accessed January 2010.

Carter, J. L. and T. W. Kammer. 1990. Late Devonian and Early Carboniferous brachiopods (Brachiopoda, Articulata) from the Price Formation of West Virginia and adjacent areas of Pennsylvania and Maryland. Annals of Carnegie Museum **59**(2):77-103.

Chapman, J. J. 1975. Possible fossil burrows from the Precambrian of North Carolina. Abstracts with Programs - Geological Society of America **7**(4):477.

Chew, V. C. 1988. Underfoot: a geologic guide to the Appalachian Trail. Appalachian Trail Conservancy, Harpers Ferry, WV.

Ciaramella, P. S. Jr. 1959. The age and the fauna of the Huntersville Formation. Virginia Journal of Science **10**(4):294-295.

Cleaves, E. T., J. Edwards Jr., and J. D. Glaser. 1968. Geologic map of Maryland. Maryland Geological Survey, Baltimore, MD. Scale 1:250,000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_16548.htm. Accessed January 2010.

Cleland, H. F. 1903. A study of the fauna of the Hamilton Formation on the Cayuga Lake section in central New York. U.S. Geological Survey, Reston, VA. Bulletin 206.

Cloud, P. 1973. Pseudofossils: a plea for caution. Geology **1**(3):123-127.

Cramer, F. H. 1969. Possible implications for Silurian paleogeography from phytoplankton assemblages of the Rose Hill and Tuscarora of Pennsylvania. Journal of Paleontology **43**(2):485-491.

Cramer, H. R. 1957. Ordovician starfish from the Martinsburg shale, Swatara Gap, Pennsylvania. Journal of Paleontology **31**(5):903-907.

Daeschler, E. B. 2000. Early tetrapod jaws from the Late Devonian of Pennsylvania, USA. Journal of Paleontology **74**(2):301-308.

Daeschler, T. and N. Shubin. 1994. A Late Devonian tetrapod from Pennsylvania. Journal of Vertebrate Paleontology **14**(supplement to 3):A22.

Davis, P. T., P. R. Bierman, J. Brigham-Grette, D. M. Fitzgerald, B. K. Fowler, M. J. Retelle, J. C. Ridge, W. B. Thompson, and T. K. Weddle. 2003. Quaternary and geomorphic processes and landforms along a traverse across northern New England. Pages 365-398 *in* Easterbrook, D. J., editor. Quaternary geology of the United States. INQUA 2003 field guide volume. Desert Research Institute, Reno, NV.

Demicco, R. V., L. A. Hardie, and J. S. Haley. 1982. Algal mounds of Upper Cambrian carbonates of Appalachians, western Maryland: examples of early patch and marginal reefs. AAPG Bulletin **66**(5):563.

Denkler, K. E., A. G. Harris, and R. T. Lierman. 1983. Conodont biofacies of a Late Silurian carbonate mudflat. Abstracts with Programs - Geological Society of America **15**(4):220.

Dennis, J. G. 1956. The geology of the Lyndonville area, Vermont. Vermont Geological Survey, Montpelier, VT. Bulletin 8.

Dennison, J. M. 1970. Stratigraphic divisions of Upper Devonian Greenland Gap Group ("Chemung Formation") along Allegheny Front in West Virginia, Maryland, and Highland County, Virginia. Southeastern Geology **12**(1):53-82.

Derby, J. R. 1965. Paleontology of the Nolichucky Formation and adjacent formations in Virginia and Tennessee. Page 42 *in* Abstracts for 1964. Geological Society of America, Boulder, CO. Special Paper 82.

Derstler, K. L. 1975. Carpoid echinoderms from Pennsylvania. Abstracts with Programs - Geological Society of America **7**(1):48.

Devries, T. J. and P. E. Isaacson. 1977. Fossil assemblages and a transgressive carbonate sequence in the uppermost Keyser Formation (Early Devonian), Maryland. Abstracts with Programs - Geological Society of America **9**(3):255.

DeWindt, J. T. 1973. Occurrence of *Rusophycus* in the Poxono Island Formation (upper Silurian) of eastern Pennsylvania. Journal of Paleontology **47**(5):999-1000.

DeWitt, W. Jr. and G. W. Colton. 1964. Bedrock geology of the Evitts Creek and Pattersons Creek quadrangles, Maryland, Pennsylvania, and West Virginia. U.S. Geological Survey, Reston, VA. Bulletin 1173. Online. http://pubs.er.usgs.gov/usgspubs/b/b1173. Accessed January 2010.

Dick, V. B. and C. E. Brett. 1982. Taphonomy and depositional environment of Middle Devonian (Hamilton Group) pyritic fossil horizons in western New York. Abstracts with Programs - Geological Society of America **14**(1-2):15.

Diecchio, R. J. and J. C. Hall. 1983. Upper Ordovician to Middle Silurian trace fossil assemblages from Virginia and West Virginia. Abstracts with Programs - Geological Society of America **15**(6):558.

Dixit, S. S., B. F. Cumming, H. J. B. Birks, J. P. Smol, J. C. Kingston, A. J. Uutala, D. F. Charles, and K. E. Camburn. 1993. Diatom assemblages from Adirondack lakes (New York, USA) and the development of inference models for retrospective environmental assessment. Journal of Paleolimnology **8**(1):27-47.

Doll, C. G., W. M. Cady, J. B. Thompson, and M. P. Billings. 1961. Centennial geologic map of Vermont. Vermont Geological Survey, Miscellaneous Map MISCMAP-01. scale 1:250000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_16345.htm. Accessed January 2010.

Doll, C. G. 1984. Fossils from the metamorphic rocks of the Silurian-Devonian Magog Belt in northern Vermont. Vermont Geology 3.

Donaldson, A. C. 1962. A patelliform gastropod, *Palaelophacmaea criola*: a new genus and species from the Lower Ordovician of central Pennsylvania. Proceedings of the West Virginia Academy of Science **34**:143-149.

Drake, A. A. Jr. 1991. The High Point Member (Upper Ordovician) of the Martinsburg Formation in northern New Jersey and southeastern New York. Pages B1-B29 *in* Drake, A. A. Jr., editor. Contributions to New Jersey geology: U.S. Geological Survey, Reston, VA. Bulletin 1952-B. Online. http://pubs.er.usgs.gov/usgspubs/b/b1952. Accessed January 2010.

Drake, A. A., R. A. Volkert, D. H. Monteverde, G. C. Herman, H. F. Houghton, R. A. Parker, and R. F. Dalton. 1996. Bedrock geologic map of northern New Jersey. U.S. Geological Survey, Reston, VA. Miscellaneous Investigations Map 2540-A. Scale 1:100,000.

Driese, S. G., C. I. Mora, and J. M. Elick. 1997. Morphology and taphonomy of root and stump casts of the earliest trees (Middle to Late Devonian), Pennsylvania and New York, U.S.A. Palaios **12**(6):524-537.

Dunlop, J. A. 1996. A redescription of the trigonotarbid arachnid *Pocononia whitei* (Ewing 1930). Palaeontologische Zeitschrift **70**(1-2):145-151.

Eble, C. F. 1986. Palynology of coal beds along a portion of Route 48 in West Virginia. Proceedings of the West Virginia Academy of Science **58**(1):26-27.

Elbert, D. C., A. G. Harris, and K. E. Denkler. 1988. Earliest Devonian conodonts from marbles of the Fitch Formation, Bernardston Nappe, north-central Massachusetts. American Journal of Science **288**(7):684-700.

Elliott, D. K. and A. C. Taber. 1981a. Mississippian vertebrates from Greer, West Virginia. Proceedings of the West Virginia Academy of Science **53**(1):14.

Elliott, D. K. and A. C. Taber. 1981b. *Cooperidiscus alleganius* (Clarke) (Edrioasteroidea) from the Upper Devonian of West Virginia. Proceedings of the West Virginia Academy of Science **53**(1):14.

Epstein, J. B. 1993. Stratigraphy of Silurian rocks in Shawangunk Mountain, southeastern New York, including a historical review of nomenclature. U.S. Geological Survey, Reston, Va. Bulletin 1839-L. Online. http://pubs.er.usgs.gov/usgspubs/b/b1839L. Accessed January 2010.

Epstein, J. B. and A. G. Epstein. 1972. The Shawangunk Formation (Upper Ordovician (?) to Middle Silurian) in eastern Pennsylvania. U.S. Geological Survey, Reston, VA. Professional Paper 744. Online. http://pubs.er.usgs.gov/usgspubs/pp/pp744. Accessed January 2010.

Erickson, J. M., K. D. Zubin-Stathopoulos, M. J. Simmons. 2008. Paleotemperatures through the Younger Dryas interval at Glovers Pond, northern NJ, derived from fossil Chironomidae. Abstracts with Programs - Geological Society of America **40**(6):164.

Ervilus, P. A. and G. M. Friedman. 1991. Notes on Cambro-Ordovician dolostones (the Pine Plains Formation) in southern New York. Northeastern Geology **13**(3):165-176.

Faill, R.T., A. D. Glover, and J. H. Way. 1989. Geology and mineral resources of the Blandburg, Tipton, Altoona, and Bellwood quadrangles, Blair, Cambria, Clearfield and Centre Counties, Pennsylvania. Pennsylvania Geological Survey, Harrisburg, PA. Topographic and Geologic Atlas, 4th series, 86. Scale 1:24,000 and 1:48,000.

Feldman, H. R., A. J. Boucot, J. A. Smoliga, and M. A. Wilson. 2006. A brachiopod faunule from the Ordovician Martinsburg Shale, Shawangunk Mountains, New York. Abstracts with Programs - Geological Society of America **38**(7):436.

Feldman, H. R., J. A. Smoliga, M. A. Wilson, M. Schemm-Gregory, and J. Starr. 2009. Mysterious "pods" in the Middle Silurian Shawangunk Formation, mid-Hudson Valley, New York. Abstracts with Programs - Geological Society of America **41**(3):88.

Fetterhoff, B. V. and R. H. Waines. 1987. Stratigraphic significance of a halysitid tabulate coral in the Whiteport Member of the Rondout Formation (latest Silurian), town of Esopus, Ulster County, southeastern New York. Abstracts with Programs - Geological Society of America **19**(1):14.

Fisher, D. W. and A. S. Warthin Jr. 1976. Stratigraphic and structural geology in western Dutchess County, New York. Trip B-6 *in* Johnsen, J. H., editor. Guidebook to field excursions at the 48th annual meeting of the New York State Geological Association. New York State Geological Association, Staten Island, NY.

Fisher, D. W., Y. W. Isachsen, and L. V. Rickard. 1970. Geologic map of New York: Lower Hudson sheet. New York State Museum and Science Service, Albany, NY. Map and Chart Series 15. Scale 1:250,000.

Fleming, J. and J. Filer. 2006. Examination of inferred late Frasnian and early Famennian fauna at Elkins, West Virginia. Abstracts with Programs - Geological Society of America **38**(7):501.

Fonda, S. S. 1982. Late Pleistocene vertebrates from a filled fissure-cave in central Pennsylvania. Abstracts with Programs - Geological Society of America **14**(1-2):18.

Fox, S. K. Jr. 1968. Dipleurozoa from Lower Silurian of North America. Science **162**(3849):119-120.

Garlock, T. L. and P. E. Isaacson. 1977. An occurrence of *Cruziana* population in the Moyer Ridge Member of the Bloomsburg Formation (late Silurian): Snyder County, Pennsylvania. Journal of Paleontology **51**(2):282-287.

Gensel, P. G. 1988a. Megaspores and small spores, probably allied to *Lepidodendropsis*, from the Lower Carboniferous of Virginia, U.S.A. Palynology **12**:239.

Gensel, P. G. 1988b. On *Neuropteris* Brongniart and *Cardiopteridium* Nathorst from the Early Carboniferous Price Formation, southwestern Virginia, U.S.A. Review of Palaeobotany and Palynology **54**(1-2):105-119.

Gerhart, J. 1983. Trilobites highlight a collection of fossils from Swatara Gap. Pennsylvania Geology **14**(4):2-6.

Gianniny, G. L 1999. Highstand stromatoporoid-favositid buildups in the Silurian-Devonian Keyser Limestone, Pennsylvania. Abstracts with Programs - Geological Society of America **31**(2):A-17.

Gibson, M. A. and S. P. Dunagan. 2008. Preliminary assessment of echinoderm-trilobite shell beds in the Nolichucky Formation (Cambrian) of eastern Tennessee. Abstracts with Programs - Geological Society of America **40**(4):67.

Gillette, T. 1947. The Clinton of western and central New York. New York State Museum, Albany, NY. Bulletin 341.

Girty, G. H. 1928. The Pocono fauna of the Broad Top coal field, Pennsylvania. U.S. Geological Survey, Reston, VA. Professional Paper 150-E.

Glumac, B. and L. E. Mutti. 2007. Late Cambrian (Steptoean) sedimentation and responses to sea-level change along the northeastern Laurentian margin: insights from carbon isotope stratigraphy. Geological Society of America Bulletin **119**(5-6):623-636.

Gural, P. A., H. K. Brueckner, and P. W. G. Brock. 2005. K-feldspar rich clastics in Cambro-Ordovician carbonate facies of the Pine Plains Formation, Dutchess County, S.E. New York. Abstracts with Programs - Geological Society of America **37**(7):297.

Hall, J. C. and R. J. Diecchio. 1998. Conodont biostratigraphy and the timing of sea-level events in the Middle-Upper Ordovician Reedsville Formation of West Virginia. Abstracts with Programs - Geological Society of America **30**(4):16.

Hardeman, W. D. 1966. Geologic map of Tennessee. State of Tennessee Department of Conservation, Division of Geology, Nashville, TN. Scale 1:250,000.

Harris, A. G., N. L. Hatch Jr., and J. T. Dutro Jr. 1983. Late Silurian conodonts update the metamorphosed Fitch Formation, Littleton area, New Hampshire. American Journal of Science **283**(7):722-738.

Harris, A. G., N. R. Stamm, D. J. Weary, J. E. Repetski, R. G. Stamm, and R. A. Parker. 1994. Conodont Color Alteration Index (CAI) map and conodont-based age determinations for the Winchester 30'x60' quadrangle and adjacent area, Virginia, West Virginia, and Maryland. U.S. Geological Survey, Reston, VA. Miscellaneous Field Studies Map MF-2239. Scale 1:100,000.

Hartnagel, C. A. and S. C. Bishop. 1921. The mastodons, mammoths and other Pleistocene mammals of New York State. New York State Museum and Science Service, 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°. Carnegie Institution of Washington Publication 322. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/pleistoceneofnor00hayouoft]

Haynes, J. T. 1992. Reinterpretation of Rocklandian (Upper Ordovician) K-Bentonite stratigraphy in southwest Virginia, southeast West Virginia, and northeast Tennessee. Virginia Division of Mineral Resources, Richmond, VA. Publication 126.

Helfrich, C. T. 1978. A conodont fauna from the Keyser Limestone of Virginia and West Virginia. Journal of Paleontology **52**(5):1133-1142.

Hinds, R. W. and A. N. Ward Jr. 1974. Lower Tuscarora (Silurian) marine faunal assemblage from central Pennsylvania. Abstracts with Programs - Geological Society of America **6**(1):38.

Hoar, F. G. and Z. P. Bowen. 1967. Brachiopoda and stratigraphy of the Rondout Formation in the Rosendale Quadrangle, southeastern New York. Journal of Paleontology **41**(1):1-36.

Hoare, R. D. and R. L. Peck. 2005. A new rostroconch (Mollusca) from the Mississippian of West Virginia. Journal of Paleontology **79**(5):1019-1020.

Hoffman, R. B. 1984. Depositional environment and regional correlation of the Ridgeley Member of the Old Port Formation. Abstracts with Programs - Geological Society of America **16**(1):24.

Hoskins, D. M. 1960. Fossils from the red beds of the Bloomsburg Formation of central Pennsylvania. Geological Society of America Bulletin **71**(12, Part 2):1891.

Hoskins, D. M. 1961. Stratigraphy and paleontology of the Bloomsburg Formation of Pennsylvania and adjacent states. Pennsylvania Geological Survey, Harrisburg, PA. 4th series, G Bulletin 36.

Howell, B. F., H. B. Roberts, and B. Willard. 1950. Subdivision and dating of the Cambrian of eastern Pennsylvania. Geological Society of America Bulletin **61**(12, Part 1):1355-1367.

Hueber, F. M., W. A. Bothner, N. L. Hatch Jr., S. C. Finney, and J. N. Aleinikoff. 1990. Devonian plants from southern Quebec and northern New Hampshire and the age of the Connecticut Valley trough. American Journal of Science **290**(4):360-395.

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, CO.

Inners, J. D. 1981. The fossiliferous Stoney Brook beds of Columbia County, Pennsylvania. Pennsylvania Geology **12**(5):8-13.

Inners, J. D. 1988. Favositid patch reef, Early Silurian, Allenwood, Pennsylvania, U.S.A. Pages 316-318 *in* Geldsetzer, H. H. J., N. P. James, and G. E. Tebbutt, editors. Reefs: Canada and adjacent areas. Canadian Society of Petroleum Geologists, Calgary, Canada. Memoir 13.

Jennings, J. R. 1975. *Protostigmaria*, a new plant organ from the lower Mississippian of Virginia. Palaeontology **18**(1, Part 1):19-24.

Jennings, J. R. 1985. Fossil plants from the Mauch Chunk Formation of Pennsylvania: morphology of *Adiantites antiquus*. Journal of Paleontology **59**(5):1146-1157.

Johannessen, K. M., E. M. Natel, and J. R. Ebert. 1997. An Upper Silurian, conodont-rich facies from the Rondout Formation of central New York: approximating the Ludlovian-Pridolian boundary and a note on possible diagenetic influences on conodont color alteration indices (CAI). Abstracts with Programs - Geological Society of America **29**(1):55.

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

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* Lucas, S. G., 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, NM. Bulletin 34. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed December 2009.

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

King, P. B. 1964. Geology of the central Great Smoky Mountains, Tennessee. U.S. Geological Survey Professional Paper 349-C. Online. http://pubs.er.usgs.gov/usgspubs/pp/pp349C. Accessed January 2010.

Kjellesvig-Waering, E. N. and W. P. Leutze. 1966. Eurypterids from the Silurian of West Virginia. Journal of Paleontology **40**(5):1109-1122.

Kleffner, M. A. 1991. Conodont biostratigraphy of the upper part of the Clinton Group and the Lockport Group (Silurian) in the Niagara Gorge region, New York and Ontario. Journal of Paleontology **65**(3):500-511.

Klose, W. F. II. 1982. Fossils from the Larksville mine fire. Pennsylvania Geology **13**(6):13-16.

Knaus, M. J., G. R. Upchurch Jr., and W. H. Gillespie. 2000. *Charbeckia macrophylla* gen. and sp. nov. from the Lower Mississippian Price (Pocono) Formation of southeastern West Virginia. Review of Palaeobotany and Palynology **111**(1-2):71-92.

Knecht, R. J., J. S. Benner, D. C. Rogers, and J. C. Ridge. 2009. *Surculichnus bifurcauda* n. igen., n. isp., a trace fossil from late Pleistocene glaciolacustrine varves of the Connecticut River valley, USA, attributed to notostracan crustaceans based on neoichnological experimentation. Palaeogeography, Palaeoclimatology, Palaeoecology **272**(3-4):232-239.

Knoll, A. H. and F. B. Keller. 1979. Late Precambrian microfossils from the Walden Creek Group, Ocoee Supergroup, Tennessee. Abstracts with Programs - Geological Society of America **11**(4):185.

Knopf, E. B. 1962. Stratigraphy and structure of the Stissing Mountain area, Dutchess County, New York. Stanford University Publications, Geological Sciences **7**(1).

Kobluk, D. R. 1982. First record of *Labyrinthus soraufi* Kobluk from the Southern Appalachians: Lower Cambrian Shady Dolomite, Virginia. Canadian Journal of Earth Sciences **19**(5):1094-1098.

Kobluk, D. R. 1985. Biota preserved within cavities in Cambrian *Epiphyton* mounds, upper Shady Dolomite, southwestern Virginia. Journal of Paleontology **59**(5):1158-1172.

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

Landing, E. and S. R. Westrop. 2006. Lower Ordovician faunas, stratigraphy, and sea-level history of the middle Beekmantown Group, northeastern New York. Journal of Paleontology **80**(5):958-980.

Lawton, D. E., F. J. Moye, J. B. Murray, B. J. O'Connor, H. M. Penley, G. S. Sandrock, W. E. Marsalis, M. S. Friddell, J. H. Hetrick, P. F. Huddlestun, R. E. Hunter, W. R. Mann, B. F. Martin, S. M. Pickering, F. J. Schneeberger, and J. D. Wilson. 1976. Geologic map of Georgia. Georgia Department of Natural Resources and Georgia Geological Survey, Atlanta, GA. Scale 1:500,000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_16532.htm. Accessed January 2010.

Lehman, D. and J. K. Pope. 1989. Upper Ordovician tempestites from Swatara Gap, Pennsylvania: depositional processes affecting the sediments and paleoecology of the fossil faunas. Palaios **4**(6):553-564.

Lehmann, D. 1988. The paleoecology of the Swatara Gap fauna. Pennsylvania Geology **19**(1):7-11. Online. http://www.dcnr.state.pa.us/topogeo/collecting/lehmann.pdf. Accessed February 2010.

Lehmann, D. 2002. Unusual rhombiferan-bearing shell bed in Upper Ordovician, Reedsville Shale of central Pennsylvania. Abstracts with Programs - Geological Society of America **34**(1):58.

Leutze, W. P. 1960. Silurian fish fossils in the Salina Basin. Geological Society of America Bulletin **71**(2):215-217.

Levin, H. L. 1999. The Earth through time (6th edition). Saunders College Publishing, Fort Worth, TX.

Lucas, S. G., D. L. Fillmore, and E. Simpson. 2006. Tetrapod footprint assemblage of the Mississippian Mauch Chunk Formation, Schuylkill County, Pennsylvania. Abstracts with Programs - Geological Society of America **38**(2):64.

Lyons, J. B., W. A. Bothner, R. H. Moench, and J. B. Thompson Jr. 1997. Bedrock geologic map of New Hampshire. U.S. Geological Survey, Reston, VA. Special Map. Scale 1:250,000.

Malinky, J. M. 1988. Early Paleozoic hyolitha from North America: reexamination of Walcott's and Resser's type specimens. Journal of Paleontology **62**(2):218-233.

Manns, F. T. and P. W. Goodwin. 1972. Algal mounds in the upper Stonehenge Formation of the Beekmantown Group (lower Ordovician) of Pennsylvania. Abstracts with Programs - Geological Society of America **4**(1):29.

Markello, J. R. and J. F. Read. 1978. Digitate stromatolitic bioherms and associated facies, Nolichucky Formation (Upper Cambrian), Southwest Virginia. AAPG Bulletin **62**(3):539.

Marvinney, R. G. 1984. The Forks Formation of northwestern Maine: evidence for a Late Ordovician to Late Silurian angular unconformity. Northeastern Geology **6**(3):151-160.

McDowell, R. R. and J. Q. Britton. 2006. Trace fossil size categories and source of food for some tracemakers: observations from the Upper Devonian of West Virginia. Abstracts with Programs - Geological Society of America **38**(3):72.

McDowell, R. C. and A. P. Schultz. 1990. Structural and stratigraphic framework of the Giles County area, a part of the Appalachian Basin of Virginia and West Virginia. U.S. Geological Survey, Reston, VA. Bulletin 1839-E. Online. http://pubs.er.usgs.gov/usgspubs/b/b1839E. Accessed January 2010.

McDowell, R. R., K. L. Avary, D. L. Matchen, and J. Q. Britton. 2007. The stratigraphic utility of the trace fossil *Pteridichnites biseriatus* in the Upper Devonian of eastern West Virginia and western Virginia, USA. Southeastern Geology **44**(4):191-202.

McMenamin, M. A. S., S. L. Pittenger, M. R. Carson, and E. M. Larrabee. 1994. Upper Precambrian-Cambrian faunal sequence, Sonora, Mexico, and Lower Cambrian fossils from New Jersey, United States. Pages 213-227 *in* Landing, E., editor. Studies in stratigraphy and paleontology in honor of Donald W. Fisher. New York State Museum, Albany, NY. Bulletin 481.

Metz, R. 1998. Silurian trace fossils from marginal marine deposits, Lizard Creek Member of the Shawangunk Formation, Delaware Water Gap, New Jersey. Northeastern Geology and Environmental Sciences **20**(2):101-116.

Metz, R. 2002. Trace fossils, including that of a myriapod-like arthropod tracemaker, from Silurian and Devonian strata of New Jersey. Abstracts with Programs - Geological Society of America **34**(1):72.

Metz, R. 2003. Ichnology of the Upper Silurian Wallpack Center Member (Decker Formation), northwestern New Jersey. Northeastern Geology and Environmental Sciences **25**(2):116-125.

Metz, R. 2006. Trace fossil research in the Delaware Water Gap National Recreation Area, New Jersey. Abstracts with Programs - Geological Society of America **38**(7):156.

Miller, C. E. Jr. 1982. Fossil collecting locality in the Keyser Formation at Mapleton, Huntingdon County, Pennsylvania. Pennsylvania Geology **13**(1):4-7.

Miller, N. G. and P. L. Nester. 2006. Paleoecology of a late Pleistocene wetland and associated mastodon remains in the Hudson Valley, southeastern New York State. Pages 291-304 *in* Greb, S. F. and W. A. DiMichele. Wetlands through time. Geological Society of America, Boulder, CO. Special Paper 399.

Miller, W. III., F. Webb Jr. and C. W. Harris. 1982. Biostratigraphic potential of the cryptodont bivalve *Buchiola retrostriata* from Upper Devonian shale, southwestern Virginia. Tulane Studies in Geology and Paleontology **17**(2):47-50.

Mitchell, R. W. 1980. Ordovician freshwater stromatolites in tidal flat carbonates, St. Paul Group, Central Appalachians. Abstracts with Programs - Geological Society of America **12**(7):485.

Morningstar, H. 1922. Pottsville fauna of Ohio. Ohio Geological Survey, Columbus, OH. 4th series, Bulletin 25. [full text available on Google Books]

Murphy, J. B. and J. D. Keppie. 2005. The Acadian Orogeny in the Northern Appalachians. International Geology Review **47**(7):663-687.

Murphy, J. B., J. D. Keppie, and R. D. Nance. 2007. What is the Acadian Orogeny? Abstracts with Programs - Geological Society of America **39**(1):69.

Nair, N., S. L. Dean, B. R. Kulander, and P. Lessing. 1992. Crinoid deformation in the Allegheny Plateau of West Virginia. Abstracts with Programs - Geological Society of America **24**(2):55.

Nelson, R. E., S. H. Lubkin, and P. Nester. 2002. Paleoenvironments of the Hyde Park, New York, Mastodon site, based on subfossil coleopteran remains. Abstracts with Programs - Geological Society of America **34**(6):547.

Neuman, R. B. and W. H. Nelson. 1965. Geology of the western Great Smoky Mountains, Tennessee. U.S. Geological Survey, Reston, VA. Professional Paper 349-D. Online. http://pubs.er.usgs.gov/usgspubs/pp/pp349D. Accessed January 2010.

North Carolina Geological Survey. 1985. Geologic map of North Carolina. North Carolina Department of Natural Resources and Community Development, Raleigh, NC. Scale 1:500,000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_16566.htm. Accessed January 2010.

Norton, N. J. and D. Allen. 1970. Analyses of palynomorph assemblages from mid-continent and eastern Devonian formations. Abstracts with Programs - Geological Society of America **2**(6):399-400.

Oleksyshyn, J. 1979. Fossil plants from the anthracite coal fields of eastern Pennsylvania and their stratigraphic value. Abstracts with Programs - Geological Society of America **11**(1):48.

Oleksyshyn, J. 1982. Fossil plants from the anthracite coal fields of eastern Pennsylvania. Pennsylvania Geological Survey, Harrisburg, PA. General Geology Report 72.

Oliver, W. A. Jr. 1989. An early Middle Devonian coal faunule from the Needmore Shale in south-central Pennsylvania and adjacent areas of West Virginia and Virginia. Pages C1-C11 *in* Sando, W. J., editor. Shorter contributions to paleontology and stratigraphy. U.S. Geological Survey, Reston, VA. Bulletin 1837. Online. http://pubs.er.usgs.gov/usgspubs/b/b1860. Accessed January 2010.

Orndorff, R. C. 1988. Latest Cambrian and earliest Ordovician conodonts from the Conococheague and Stonehenge limestones of northwestern Virginia. Page A1-A18 *in* Sando, W. J., editor. Shorter contributions to paleontology and stratigraphy. U.S. Geological Survey, Reston, VA. Bulletin 1837. Online. http://pubs.er.usgs.gov/usgspubs/b/b1837. Accessed January 2010.

Osberg, P. H., A. M. Hussey II, and G. M. Boone. 1985. Bedrock geologic map of Maine. Maine Geological Survey, Augusta, ME. Scale 1:500,000.

Osborne, W. E. and E. L. Yochelson. 1991. New discovery of *Salterella* in the Lower Cambrian Rome Formation, Appalachian fold-thrust belt, central Alabama. Southeastern Geology **32**(2):107-114.

Osgood, R. G. Jr. and A. G. Fischer. 1960. Structure and preservation of *Mastopora pyriformis*, an Ordovician dasycladacean alga. Journal of Paleontology **34**(5):896-902.

Ottinger, G. A. 1999. Depositional and diagenetic relationships of the Honaker-Nolichucky formational boundary (Middle Cambrian, Conasauga Group), Southern Appalachians. Thesis. University of Tennessee at Knoxville, Knoxville, TN.

Parris, D. C. and S. S. Albright. 1979a. Fossil resources of the Delaware Water Gap National Recreation Area; Part I: Silurian and Early Devonian fossils. Contractual Report to the National Park Service.

Parris, D. C. and S. S. Albright. 1979b. Fossil resources of the Delaware Water Gap National Recreation Area; Part II: Devonian fossils. Contractual Report to the National Park Service.

Parris, D. C. and K. M. Cruikshank. 1992. Graptolite biostratigraphy of the Ordovician Martinsburg Formation in New Jersey and contiguous areas. New Jersey Geological Survey, Trenton, NJ. Geological Survey Report 28. Online. http://www.state.nj.us/dep/njgs/pricelst/gsreport/gsr28.pdf. Accessed January 2010.

Powell, M. G. 2008. Timing and selectivity of the Late Mississippian mass extinction of brachiopod genera from the Central Appalachian Basin. Palaios **23**(8):525-534.

Ratcliffe, N. M. and R. R. Knowles. 1969. Fossil evidence from the "Manhattan Schist-Inwood Marble" sequence at Verplanck, New York. Page 368 *in* Abstracts for 1968. Geological Society of America, Boulder, CO. Special Paper 121.

Ratcliffe, N. M., A. G. Harris, and G. J. Walsh. 1999. Tectonic and regional metamorphic implications of the discovery of Middle Ordovician conodonts in cover rocks east of the Green Mountain Massif, Vermont. Canadian Journal of Earth Sciences **36**(3):371-382.

Read, C. B. 1955. Floras of the Pocono Formation and Price Sandstone in parts of Pennsylvania, Maryland, West Virginia, and Virginia. U.S. Geological Survey, Reston, VA. Professional Paper 263. Online. http://pubs.er.usgs.gov/usgspubs/pp/pp263. Accessed January 2010.

Read, J. F. and R. W. Pfeil. 1983. Fabrics of allochthonous reefal blocks, Shady Dolomite (Lower to Middle Cambrian), Virginia Appalachians. Journal of Sedimentary Petrology **53**(3):761-778.

Reese, S. O., A. B. Lutz, and J. R. Shaulis. 2004. The great Swatara Gap fossil migration. Pennsylvania Geology **34**(3):13-15.

Reinhardt, J. and E. Wall. 1975. Tomstown Dolomite (lower Cambrian), central Appalachian Mountains, and the habitat of *Salterella conulatan*. Geological Society of America Bulletin **86**(10):1377-1380.

Repetski, J. E., R. D. Hatcher Jr., C. S. Southworth, and J. R. Thigpen. 2006. Conodonts from the Walden Creek Group, southeastern Tennessee. Abstracts with Programs - Geological Society of America **38**(3):66.

Retallack, G. J. 2001. *Scoyenia* burrows from Ordovician palaeosols of the Juniata Formation in Pennsylvania. Palaeontology **44**(2):209-235.

Retallack, G. J., R. R. Hunt, and T. S. White. 2009. Late Devonian tetrapod habitats indicated by palaeosols in Pennsylvania. Journal of the Geological Society of London **166**(6):1143-1156.

Rice, N. E. 1958. Occurrence of glass sponges in the Devonian of West Virginia. Journal of Paleontology **32**(1):244-245.

Ridge, J. C., C. C. Beck, E. B. Voytek, R. L. Bayless, and J. L. Dean. 2009. Calibration of a unified New England varve chronology: deglaciation rates and moraine building in the Connecticut Valley of New Hampshire and Vermont. Abstracts with Programs - Geological Society of America **41**(3):36.

Rodgers, J. 1985. Bedrock geological map of Connecticut. Connecticut State Geological and Natural History Survey, Hartford, CT. Connecticut Natural Resources Atlas Series. Scale 1:125,000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_54245.htm. Accessed December 2009.

Root, S. I. 1968. Geology and mineral resources of southeastern Franklin County, Pennsylvania. Pennsylvania Geological Survey, Harrisburg, PA. Topographic and Geologic Atlas, 4th series, 119cd. Scale 1:24,000.

Rossbach, T. J. 2000. Limited migration and endemism of fossil invertebrates from the Brallier and Foreknobs formations (Upper Devonian) of Virginia and West Virginia. Abstracts with Programs - Geological Society of America **32**(2):A-70.

Rowley, D. B., W. S. F. Kidd, and L. L. Delano. 1979. Detailed stratigraphic and structural features of the Giddings Brook slice of the Taconic Allochthon in the Granville area. Pages 186-242 (Trip A-8) *in* Friedman, G. M., editor. Joint annual meeting of New York State Geological Association, 51st annual meeting and New England intercollegiate geological conference, 71st annual meeting. New York State Geological Association, Staten Island, NY.

Ryder, R. T., A. G. Harris, and J. E. Repetski. 1992. Revised edition 2003. Stratigraphic framework of Cambrian and Ordovician rocks in the central Appalachian Basin from Medina County, Ohio, through southwestern and south-central Pennsylvania to Hampshire County, West Virginia. U.S. Geological Survey, Reston, VA. Bulletin 1839-K. Online. http://pubs.er.usgs.gov/usgspubs/b/b1839K. Accessed January 2010.

Santucci, V. L., R. 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, CO.

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

Schram, F. R. 1988. *Pseudotealliocaris palincsari* n. sp., a pygocephalomorph from the Pocono Formation, Mississippian of Pennsylvania. Transactions of the San Diego Society of Natural History **21**(13):221-225.

Simonsen, A. H. 1988. Chesterian fossil site in the Mauch Chunk Formation, Chalk Hill, Pennsylvania. Northeastern Geology **10**(1):50-56.

Simpson, E. L. and K. A. Eriksson. 1989. Sedimentology of the Unicoi Formation in southern and central Virginia: evidence for late Proterozoic to Early Cambrian rift-to-passive margin transition. Geological Society of America Bulletin **101**(1):42-54.

Simpson, E. L. and K. A. Eriksson. 1990. Early Cambrian progradational and transgressive sedimentation patterns in Virginia: an example of the early history of a passive margin. Journal of Sedimentary Petrology **60**(1):84-100.

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

Skoog, S. Y., C. Venn, and E. L. Simpson. 1994. Distribution of *Diopatra cuprea* across modern tidal flats: implications for *Skolithos*. Palaios **9**(2):188-201.

Smith, C. J., E. L. Simpson, and D. Fillmore. 2009. The first reported arthropod trackways from the Pennsylvanian Llewellyn Formation: Bear Valley strip mine, Shamokin, PA. Abstracts with Programs - Geological Society of America **41**(3):88.

Smithson, T. R. 1982. The cranial morphology of *Greererpeton burkemorani* Romer (Amphibia, Temnospondyli). Zoological Journal of the Linnean Society **76**(1):29-90.

Sohl, L. E. 1993. The stratigraphy of the Limefort Member of the Allentown Formation: an Upper Cambrian carbonate within the Kittatinny Supergroup. Abstracts with Programs - Geological Society of America **25**(2):81.

Sokal, M. A. and R. I. Hall. 2003. Use of sedimentary diatom assemblages to assess environmental changes during the late Pleistocene at a mastodon site in Hyde Park, New York State. Abstracts with Programs - Geological Society of America **35**(3):76.

Stamm, R. G. 1997. Late Mississippian conodont biostratigraphy of the Appalachian Basin: preliminary correlations to the Eastern Interior Basin and eustatic curves. Abstracts with Programs - Geological Society of America **29**(2):48.

Stanford, S. D. 1993. Late Wisconsinan glacial geology of the New Jersey Highlands. Northeastern Geology **15**(3-4):210-223.

Stein, W. E. Jr. 1982. *Iridopteris eriensis* from the Middle Devonian of North America, with systematics of apparently related taxa. Botanical Gazette (Chicago) **143**(3):401-416.

Stein, W. E. Jr., D. C. Wight, and C. B. Beck. 1983. *Arachnoxylon* from the Middle Devonian of southwestern Virginia. Canadian Journal of Botany **61**(4):1283-1299.

Stock, C. W. and A. E. Holmes. 1986. Upper Silurian/Lower Devonian Stromatoporoidea from the Keyser Formation at Mustoe, Highland County, west-central Virginia. Journal of Paleontology **60**(3):555-580.

Strother, P. K. 1988. New species of *Nematothallus* from the Silurian Bloomsburg Formation of Pennsylvania. Journal of Paleontology **62**(6):967-982.

Strother, P. K. 2008. A new Cambrian acritarch from the Nolichucky Shale, eastern Tennessee, U.S.A. Palynology **32**:205-212.

Strother, P. K. and J. H. Beck. 1993. Terrestrial organic remains from the Silurian Wills Creek Formation. Abstracts with Programs - Geological Society of America **25**(6):A-81.

Sumrall, C. D., C. E. Brett, and M. L. McKinney. 2009. A new agelacrinitid edrioasteroid attached to a large hardground clast from the McKenzie Member of the Mifflintown Member (Silurian) of Pennsylvania. Journal of Paleontology **83**(5):794-803.

Suter, D. R. and C. G. Tillman. 1973. The conodont *Multioistodus* from supratidal limestones in the Beekmantown Formation of the Appalachians of west-central Virginia. Abstracts with Programs - Geological Society of America **5**(5):441-442.

Tczap, B. and C. G. Tillman. 1982. New Early Mississippian syncarid crustacean from the Price Formation, Virginia. Virginia Journal of Science **33**(3):155.

Thompson, A. M. 1976. Probable algal origin of greenschist-facies metamorphic carbonates, Appalachian Piedmont, Alabama. Journal of Sedimentary Petrology **46**(2):402-410.

Titus, R. 1982a. Fossil communities, paleoecology and tectonic history of the Trenton Group of central New York State. Pages B1-B34 *in* Globensky, Y., editor. Field trips guidebook for the Third North American paleontological convention. North American Paleontological Convention, Quebec, Canada.

Titus, R. 1982b. Fossil communities of the middle Trenton Group (Ordovician) of New York State. Journal of Paleontology **56**(2, Part 1):477-485.

Titus, R. 1986. Fossil communities of the upper Trenton Group (Ordovician) of New York State. Journal of Paleontology **60**(4):805-824.

Titus, R. and B. Cameron. 1976. Fossil communities of the lower Trenton Group (middle Ordovician) of central and northwestern New York State. Journal of Paleontology **50**(6):1209-1225.

Tomescu, A. M. F., G. W. Rothwell, and G. C. Nadon. 2003. Earliest communities of complex terrestrial organisms: structurally simple and systematically diverse. Abstracts with Programs - Geological Society of America **35**(6):458.

Tomescu, A. M. F., L. M. Pratt, G. W. Rothwell, P. K. Strother, and G. C. Nadon. 2009. Carbon isotopes support the presence of extensive land floras pre-dating the origin of vascular plants. Palaeogeography, Palaeoclimatology, Palaeoecology **283**(1-2):46-59.

Trexler, J. P., G. H. Wood Jr. and H. H. Arndt. 1962. Uppermost Devonian and Lower Mississippian rocks of the western part of the anthracite region of eastern Pennsylvania. Pages C36-C39 *in* Geological Survey research 1962. U.S. Geological Survey, Reston, VA. Professional Paper 450-C.

Unrug, R. and S. Unrug. 1990. Paleontological evidence of Paleozoic age for the Walden Creek Group, Ocoee Supergroup, Tennessee. Geology **18**(11):1041-1045.

Unrug, R., W. I. Ausich, J. Bednarczyk, R. J. Cuffey, B. L. Mamet, S. L. Palmes, and S. Unrug. 2000. Paleozoic age of the Walden Creek Group, Ocoee Supergroup, in the western Blue Ridge, Southern Appalachians: implications for evolution of the Appalachian margin of Laurentia. Geological Society of America Bulletin **112**(7):982-996.

Uutala, A. J. 1990. *Chaoborus* (Diptera: Chaoboridae) mandibles: paleolimnological indicators of the historical status of fish populations in acid-sensitive lakes. Journal of Paleolimnology **4**(2):139-151.

van Staal, C. R. and J. B. Whalen. 2006. Magmatism during the Salinic, Acadian, and Neoacadian orogenies. Abstracts with Programs - Geological Society of America **38**(2):31.

van Staal, C. R., V. McNicoll, P. Valverde-Vaquero, S. M. Barr, L. R. Fyffe, and D. N. Reusch. 2004. Ganderia, Avalonia, and the Salinic and Acadian orogenies. Abstracts with Programs - Geological Society of America **36**(2):128-129.

Virginia Division of Mineral Resources. 1993. Geologic map of Virginia. Virginia Division of Mineral Resources, Richmond, VA. Scale 1:500,000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_34878.htm. Accessed January 2010.

Warshauer, S. M. and R. Smosna. 1978. Paleoecologic controls of the ostracode communities in the Tonoloway Limestone (Silurian: Pridoli) of the central Appalachians. Abstracts with Programs - Geological Society of America **10**(2):90.

Wei-Haas, M. L., B. Glumac, and H. A. Curran. 2007. *Sphenothallus*-like fossils from the upper Martinsburg Formation (Upper Ordovician) in northeastern Tennessee. Abstracts with Programs - Geological Society of America **39**(2):96.

Wight, D. C. and C. B. Beck. 1984. Sieve cells in phloem of a Middle Devonian progymnosperm. Science **225**(4669):1469-1471.

Willard, B. 1936. The Onondaga Formation in Pennsylvania. Journal of Geology **44**(5):578-603.

Willard, B. 1961. Stratigraphy of the Cambrian sedimentary rocks of eastern Pennsylvania. Geological Society of America Bulletin **72**(12):1765-1776.

Williams, E. G. 1979. Marine and fresh water fossiliferous beds in the Pottsville and Allegheny groups of western Pennsylvania. Pages 35-49 *in* Ferm, J. C., J. C. Horne, G. A. Weisenfluh, and J. R. Staub. Carboniferous depositional environments in the Appalachian region. University of South Carolina Department of Geology, and Carolina Coal Group, Columbia, SC.

Willoughby, R. 1976. Lower and middle Cambrian fossils from the Shady Formation, Austinville, Virginia. Abstracts with Programs - Geological Society of America **8**(2):301-302.

Wilshusen, J. P. 1983. Geology of the Appalachian Trail in Pennsylvania. Pennsylvania Geological Survey, Harrisburg, PA. General Geology Report 74.

Wintsch, R. P., J. F. Sutter, M. J. Kunk, J. N. Aleinikoff, and J. L. Boyd. 1993. Alleghanian assembly of Proterozoic and Paleozoic lithotectonic terranes in south central New England: new constraints from geochronology and petrology. Pages H.1-H.30 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Wintsch, R. P., J. N. Aleinikoff, G. J. Walsh, W. A. Bothner, A. M. Hussey II, and C. M. Fanning. 2007. SHRIMP U-Pb evidence for a Late Silurian age of metasedimentary rocks in the Merrimack and Putnam-Nashoba Terranes, eastern New England. American Journal of Science **307**(1):119-167.

Woodcock, T., M. Smith, and J. Hall. 2000. Will the real *Taeniaster* please stand up ophiuroids from Swatara Gap, Ordovician Martinsburg Formation, Pennsylvania. Abstracts with Programs - Geological Society of America **32**(2):84.

Zen, E-an. 1966. Stockbridge Formation, Walloomsac Formation, Egremont Phyllite, Everett Formation. Pages A30-A32 *in* Changes in stratigraphic nomenclature by the U.S. Geological Survey 1965. U.S. Geological Survey, Reston, VA. Bulletin 1244-A.

Zen, E-an, R. Goldsmith, N. M. Ratcliffe, P. Robinson, R. S. Stanley, N. L. Hatch, A. F. Shride, E. G. A. Weed, and D. R. Wones. 1983. Bedrock geologic map of Massachusetts. U.S. Geological Survey, Reston, VA. Scale 1:250,000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_16357.htm. Accessed December 2009.

Additional References

Albright, S. S. 1990. Faunal lists of New Jersey's Silurian and Devonian formations within the Delaware Water Gap National Recreation Area. Pages 12-20 *in* Gallagher, W. B., editor. Paleontology and stratigraphy of the lower Paleozoic deposits of the Delaware Water Gap area. Geological Association of New Jersey, Trenton, NJ. Annual Field Conference 4.

Aleinikoff, J. N., R. P. Wintsch, R. P. Tollo, D. M. Unruh, C. M. Fanning, and M. D. Schmitz. 2007. Ages and origins of rocks of the Killingworth Dome, south-central Connecticut: implications for the tectonic evolution of southern New England. American Journal of Science **307**(1):63-118.

Arndt, H. H., G. H. Wood Jr., and J. P. Trexler. 1962. Subdivision of the Catskill Formation in the western part of the anthracite region of Pennsylvania. Pages C32-C36 *in* Geological Survey research 1962. U.S. Geological Survey, Reston, VA. Professional Paper 450-C.

Beck, C. B. and W. E. Stein Jr. 1993. *Crossia virginiana* gen. et sp. nov., a new member of the Stenokoleales from the Middle Devonian of southwestern Virginia. Palaeontographica. Abteilung B: Paläophytologie **229**(4-6):115-134.

Beck, C. B., W. E. Stein, and D. C. Wight. 1979. The Millboro Shale flora: a preliminary report. Page 30 *in* Abstracts of papers to be presented at the meetings of the Botanical Society of America and certain affiliated groups at Oklahoma State University. Botanical Society of America, St. Louis, MO. Miscellaneous Series Publication 157.

Bretsky, P. W. Jr. 1970. Upper Ordovician ecology of the central Appalachians. Peabody Museum of Natural History Bulletin 34.

Brett, C. E., editor. 1986. Dynamic stratigraphy and depositional environments of the Hamilton Group (Middle Devonian) in New York State. Part I. New York State Museum, Albany, NY. Bulletin 457.

Chadwick, G. H. 1918. Stratigraphy of the New York Clinton. Geological Society of America Bulletin **29**:327-368.

Decker, C. E. and I. B. Gold. 1958.Upper Cambrian graptolites from Virginia and Tennessee. Journal of Paleontology **32**(3):401-432.

DeWindt, J T. 1974. Acanthodian scales from the Bloomsburg Formation (?Middle and Upper Silurian) of central Pennsylvania. Journal of Paleontology **48**(3):594-595.

Dineen, R. J. and W. B. Rogers. 1979. Sedimentary environments in glacial Lake Albany in the Albany section of the Hudson-Champlain Lowlands. Pages 87-119 (Trip A-3) *in* Friedman, G. M., editor. Joint annual meeting of New York State Geological Association, 51st annual meeting and New England intercollegiate geological conference, 71st annual meeting. New York State Geological Association, Staten Island, NY.

Drake, A. A. Jr. and J. B. Epstein. 1967. The Martinsburg Formation (Middle and Upper Ordovician) in the Delaware Valley, Pennsylvania-New Jersey. U.S. Geological Survey, Reston, VA. Bulletin 1244-H. Online. http://pubs.er.usgs.gov/usgspubs/b/b1244H. Accessed January 2010.

Ewing, H. E. 1930. A fossil arachnid from the lower Carboniferous shales (Pocono formation) of Virginia. Entomological Society of America Annals **23**(4):641-643.

Fisher, D. W. 1953. Additions to the stratigraphy and paleontology of the Lower Clinton in western New York. Bulletin of the Buffalo Society of Natural Sciences **21**(2):26-36.

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

Holmes, R. 1984. The Carboniferous amphibian *Proterogyrinus scheelei* Romer, and the early evolution of tetrapods. Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences **306**(1130):431-527.

Hotton, N. III. 1970. *Mauchchunkia bassa*, gen. et sp. nov., an anthracosaur (Amphibia, Labrinthodontia) from the upper Mississippian. Kirtlandia **12**.

Howell, B. F. 1945. *Skolithos*, *Diplocraterion*, and *Sabellidites* in the Cambrian Antietam sandstone of Maryland. Bulletin of the Wagner Free Institute of Sciences of Philadelphia **20**(4):33-40.

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. TIC# D-88 National Park Service, Fort Collins, CO.

Jillson, W. R. 1966. Fish coprolites in the Onondaga limestone of eastern central Kentucky. Transactions of the Kentucky Academy of Science **27**:82-84.

Karabinos, P., J. N. Aleinikoff, and C. M. Fanning. 1999. Distinguishing Grenvillian basement from pre-Taconian cover rocks in the Northern Appalachians. American Journal of Science **299**(6):502-515.

Karabinos, P., H. M. Stoll, and J. C. Hepburn. 2003. The Shelburne Falls arc – lost arc of the Taconic orogeny. Pages B3-1-B3-17 *in* Brady, J. and J. Chaney, editors. New England Intercollegiate Geologic Conference, Amherst, MA.

Kidd, W. S. F., A. Plesch, and F. W. Vollmer. 1995. Lithofacies and structure of the Taconic flysch, melange, and allochthon, in the New York Capital District. Pages 57-80 (Trip A-4) *in* Garver, J. I. and J. A. Smith, editors. Field trip guidebook for the 67th annual meeting of the New York State Geological Association. New York State Geological Association, Staten Island, NY.

King, P. B., W. B. Hamilton, and R. B. Neuman. 1958. Stratigraphy of Ocoee series, Great Smoky Mountains, Tennessee and North Carolina. Geological Society of America Bulletin **69**(8):947-966.

Landing, E. and C. E. Brett, editors. 1991. Dynamic stratigraphy and depositional environments of the Hamilton Group (Middle Devonian) in New York State. Part II. New York State Museum, Albany, NY. Bulletin 468.

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

McGhee, G. R. Jr. 1979. The benthic marine fauna of the Foreknobs Formation (Late Devonian) in Maryland, West Virginia, and Virginia. Pages 93-100 *in* Avary, K. L., editor. Devonian clastics in West Virginia and Maryland. Field trip guide: October 3-5, 1979. West Virginia Geological and Economic Survey, Morgantown, WV.

Newton, C. R. 1979. Biofacies patterns in the Needmore Shale: paleoenvironmental and paleobathymetric implications. Pages 77-82 *in* Avary, K. L., editor. Devonian clastics in West Virginia and Maryland. Field trip guide: October 3-5, 1979. West Virginia Geological and Economic Survey, Morgantown, WV.

Nolde, J. E. Biofacies analysis of Late Ordovician-age central Appalachian faunas. Virginia Journal of Science **41**(2):93.

Parris, D. C., K. M. Cruikshank, and J. L. Rich. 1990. New biostratigraphic information on the Ordovician Martinsburg Formation of New Jersey and adjacent areas. Pages 21-59 *in* Gallagher, W. B., editor. Paleontology and stratigraphy of the lower Paleozoic deposits of the Delaware Water Gap area. Geological Association of New Jersey, Trenton, NJ. Annual Field Conference 4.

Pfefferkorn, H. W., W. H. Gillespie, D. A. Resnick, and M. H. Scheihing. 1984. Reconstruction and architecture of medullosan pteridosperms (Pennsylvanian). The Mosasaur **2**:1-8.

Reed, J. C. Jr. 1954. The geology story of the Blue Ridge. Potomac Appalachian Trail Club Bulletin **23**(4):111-119.

Romer, A. S. 1970. A new anthracosaurian labyrinthodont, *Proterogyrinus scheelei*, from the lower Carboniferous. Kirtlandia **10**.

Skehan, J. W. 2008. Roadside geology of Connecticut and Rhode Island. Mountain Press Publishing Company, Missoula, MT.

Shapiro, R. S. and S. M. Awramik. 2006. *Favosamaceria cooperi* new group and form: a widely dispersed, time-restricted thrombolite. Journal of Paleontology **80**(3):411-422.

Shear, W. A. 2000. *Gigantocharinus szatmaryi*, a new trigonotarbid arachnid from the Late Devonian of North America (Chelicerata, Arachnida, Trigonotarbida). Journal of Paleontology **74**(1):25-31.

Smosna, R. A. and S. M. Warshauer. 1979. A very Early Devonian patch reef and its ecological setting. Journal of Paleontology **53**(1):142-152.

Stose, G. W. 1931. Geology of the Appalachian Trail between the Susquehanna River and the Virginia-Tennessee line. Potomac Appalachian Trail Club, Washington, D.C.

Stose, G. W. 1931. Geology of the Appalachian Trail from the Potomac River to Rockfish Gap. Potomac Appalachian Trail Club, Washington, D.C.

Strother, P. K. and J. H. Beck, J. H. 1995. Plant spores from lateral equivalents to the Delaware Water Gap section. Pages 209-221 *in* Baker, J. E. B., 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, Trenton, NJ. Annual Field Conference 12.

Swartz, F. M. 1939. The Keyser limestone and Helderberg group. Pages 29-91 *in* The Devonian of Pennsylvania. Pennsylvania Topographic and Geologic Survey, Harrisburg, PA. Bulletin **C 49**(12, Part 2).

Taylor, W. A. and C. H. Wellman. 2009. Ultrastructure of enigmatic phytoclasts (banded tubes) from the Silurian-Lower Devonian: evidence for affinities and role in early terrestrial ecosystems. Palaios **24**(3):167-180.

Tucker, R. D. and P. Robinson. 1990. Age and setting of the Bronson Hill magmatic arc: a re-evaluation based on U-Pb zircon ages in southern New England. Geological Society of America Bulletin **102**(10):1404-1419.

Van Diver, B. B. 1985. Roadside geology of New York. Mountain Press Publishing Company, Missoula, MT.

Van Diver, B. B. 1987. Roadside geology of Vermont and New Hampshire. Mountain Press Publishing Company, Missoula, MT.

Van Diver, B. B. 1990. Roadside geology of Pennsylvania. Mountain Press Publishing Company, Missoula, MT.

Williams, E. G. 1958. Fossil zones in the Pottsville and Allegheny rocks of western Pennsylvania. Geological Society of America Bulletin **69**(12, Part 2):1662-1663.

Wilson, H. M., E. B. Daeschler, and S. Desbiens. 2005. New flat-backed archipolypodan millipedes from the Upper Devonian of North America. Journal of Paleontology **79**(4):738-744.

Wyckoff, J. 1979. Geology along the Appalachian Trail. Appalachian Trailway News **40**(2):4-7.

Data Sets

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

Connecticut Digital Geologic Map
2000-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by U.S. Geological Survey and Connecticut Geological and Natural History Survey staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=CT.

Georgia Digital Geologic Map
1999-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by Georgia Department of Natural Resources staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=GA.

Maine Digital Geologic Map
2005-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by Maine Office of GIS staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=ME.

Maryland Digital Geologic Map
2005-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by U.S. Geological Survey staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=MD.

Massachusetts Digital Geologic Map
1998-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by Boston College staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=MA.

New Hampshire Digital Geologic Map
2006-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by U.S. Geological Survey staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=NH.

New Jersey Digital Geologic Map
1999-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by New Jersey Geological Survey staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=NJ.

New York Digital Geologic Map
1999-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by New York State Museum staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=NY.

North Carolina Digital Geologic Map
1998-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by North Carolina Geological Survey and North Carolina Center for Geographic Information and Analysis staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=NC.

Pennsylvania Digital Geologic Map
2001-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by Pennsylvania Geological Survey staff; status: Active. Online.
http://tin.er.usgs.gov/geology/state/state.php?state=PA.

Tennessee Digital Geologic Map
2000-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by U.S. Geological Survey staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=TN.

Vermont Digital Geologic Map
2006-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by U.S. Geological Survey and Vermont Geological Survey staff; status: Active. Online.
http://tin.er.usgs.gov/geology/state/state.php?state=VT.

Virginia Digital Geologic Map
2003-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by Virginia Division of Mineral Resources staff; status: Active. Online.
http://tin.er.usgs.gov/geology/state/state.php?state=VA.

West Virginia Digital Geologic Map
1998-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by West Virginia Division of Environmental Protection staff; status: Active. Online.
http://tin.er.usgs.gov/geology/state/state.php?state=WV.

Boston Harbor Islands National Recreation Area

Boston Harbor Islands National Recreation Area (BOHA) consists of thirty-four islands and former islands in Boston Harbor. These islands have a variety of natural and cultural resources, and provide diverse recreational opportunities. They are managed in partnership with nonfederal owners and managers. BOHA was authorized November 12, 1996. It encompasses 599.85 ha (1,482.25 acres), 99.35 ha (245.51 acres) of which are under federal administration.

There are a number of other NPS units in Boston which are not officially included in the Northeast Temperate Network, but which are within the network's geographic area. These units are briefly mentioned here because of their great geological similarity to BOHA. Among these units are Adams National Historical Park (ADAM), Boston African American National Historic Site (BOHA), Boston National Historical Park (BOST), Frederick Law Olmsted National Historic Site (FRLA), John Fitzgerald Kennedy National Historic Site (JOFI), and Longfellow National Historic Site (LONG). Salem Maritime National Historic Site (SAMA), though farther away (18 km [11 miles] north of The Graves, the nearest BOHA property), has a similar geologic setting to BOHA.

Geologic Background

BOHA's islands are located in Boston Harbor, Massachusetts, divided among Norfolk, Plymouth, and Suffolk counties, just offshore of Boston and its associated cities and suburbs. Most are within the area partially enclosed by Winthrop and Nantasket peninsulas, with a few farther out to sea. In alphabetical order, these islands include Bumpkin Island, Button Island, Calf Island, Deer Island, Gallops Island, Georges Island, Grape Island, The Graves, Great Brewster Island, Green Island, Hangman Island, Langlee Island, Little Brewster Island, Little Calf Island, Long Island, Lovells Island, Middle Brewster Island, Moon Island, Nixes Mate, Nut Island, Outer Brewster Island, Peddocks Island (with Prince Head), Raccoon Island, Ragged Island, Rainsford Island, Sarah Island, Shag Rocks, Sheep Island, Slate Island, Snake Island, Spectacle Island, Thompson Island, and Worlds End (note that spelling varies slightly between sources, such as Bumkin versus Bumpkin, or Racoon versus Raccoon). The inner harbor islands are mostly composed of one or more drumlins (ovoid hills composed of glacial debris) that may or may not have exposed bedrock, while the outer harbor islands (Calf Island, The Graves, Great Brewster Island, Green Island, Little Brewster Island, Little Calf Island, Middle Brewster Island, Outer Brewster Island, and Shag Rocks) have exposed bedrock (Masterson et al. 1996). The greater Boston area is built over the eroded remains of a Late Proterozoic structural basin known as the Boston Basin (see the appendix for a geological time scale), heavily affected by recent glacial advances and retreats. Three large rivers drain into the Atlantic via Boston Harbor. The Charles and Mystic rivers empty into the northwestern corner of the harbor, and the Neponset River empties through Dorchester Bay, southwest of Thompson Island. Quincy Bay and Hingham Bay separate most of BOHA's islands from the southern margin of the harbor. Eastward beyond the islands are Massachusetts Bay and then the greater Atlantic Ocean.

Paleontological aspects of the islands have been discussed in a number of papers (Niles 1869; Upham 1889; Crosby and Ballard 1894; Clark 1923; Judson 1949; Belknap 1980; Jones 1980; Fisher and Jones 1982; Jones and Fisher 1990; Newman et al. 1990; Oldale and Colman 1992; Humphrey et al. 1993; Luedtke and Rosen 1993; Newman et al. 1993; Newman and Mickelson 1994; Masterson et al. 1996; Colgan and Newman 1999; Colgan and Rosen 2001; Orton and Colgan 2001; Rosen and FitzGerald 2004; Bailey 2005, 2009; Patterson et al. 2005; McMenamin et al. 2007); however, many of these include only brief mentions of the presence of Pleistocene shells. The most detailed report on fossils from what is now within BOHA property is Crosby and Ballard (1894), concerning the Pleistocene assemblage. Proterozoic fossils are also now being found within BOHA, representing organisms that lived before the evolution of hard parts (Bailey 2005; McMenamin et al. 2007). Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held for BOHA during July 2007, which resulted in a geologic scoping summary (Thornberry-Ehrlich 2008); this is an internal NPS document.

Most of New England is made up of exotic accreted terranes, which are blocks of crust that originated somewhere other than their present location and are demonstrably different from surrounding rocks. The timing of assembly and the origins of the various terranes are heavily debated (Skehan 2001; Wintsch et al. 1993, 2007). The Boston Basin is part of one such terrane, known under several names, including the Milford-Dedham Zone (Kaye 1982; Zen et al. 1983; Hatch et al. 1984; Goldsmith and Weed 1991), the Boston-Avalon Terrane (Hepburn et al. 1987, 1993), and the Avalon Terrane (Skehan 2001). To be consistent with the BOHA geologic scoping summary (Thornberry-Ehrlich 2008), Avalon will be used here. The Avalon Terrane is bordered on the west by the Nashoba Terrane. The Bloody Bluff Fault, named for a feature in Minute Man National Historical Park (MIMA; see the MIMA summary in this report for more information), separates the two terranes. This fault zone traces a much older zone of disturbance (the Burlington Mylonite Zone) that developed approximately 610 Ma (million years ago) where the Avalon Terrane was overriding another plate (Skehan 2001).

The Avalon Terrane separated from the landmass to which it was originally attached approximately 550 Ma. One interpretation of the events that followed is that the Avalon Terrane was part of a larger continental fragment that split into multiple slivers. These slivers periodically collided with each other on their way to the proto-North American continent called Laurentia, where they were accreted onto what is now the east coast by approximately 370 Ma (Rast and Skehan 1990; Skehan 2001). Other authors reject this interpretation (Acaster and Bickford 1999). Regardless of how it arrived, by some point in the Late Paleozoic, the Avalon Terrane had collided with Laurentia during the larger collisional events that resulted in the assembly of the supercontinent Pangaea (Levin 1999; Skehan 2001).

The majority of the rocks underlying the Boston area formed during the Avalonian Orogeny, a mountain-building event that occurred during the late Proterozoic (Hepburn et al. 1993; Skehan 2001). The Boston Basin formed at this time as a rift basin within a volcanic arc (Hepburn et al. 1993; Skehan 2001). When the basin formed, it was at mid-latitudes (38° at approximately 596 Ma), probably in the Southern Hemisphere, where the Avalon Terrane would have been either attached to, or located near, what is now West Africa (Thompson et al. 2007). The Boston Basin rocks that date to the Avalonian Orogeny include igneous rocks that formed during a period of intrusions and volcanic eruptions between 610 and 585 Ma (Colgan and Rosen 2001), and slightly altered sedimentary rocks (metasedimentary rocks) deposited over these igneous rocks. As the orogeny waned, the setting shifted from compression and uplift associated with the orogeny to extension with rifting, which eventually formed a marine basin (Goldsmith and Weed 1991; Skehan and Rast 1992).

The most prominent bedrock sedimentary rocks of the Boston Basin, known as the Boston Bay Group, are present at BOHA. They were deposited at a time of active volcanism when the basin was deepening (Kaye 1982). Several models of deposition have been proposed for the Boston Bay Group; Rehmer (1986) presents a discussion of glacial deposition, marine debris flows, a glaciomarine combination, and basin edge deposition. Most of the differences are due to whether or not there was a glacial influence, and the extent of terrestrial deposition. The sediment source for the rocks of the Boston Bay Group was to the south and west (modern directions), which caused coarser rocks to be deposited in the southern part of the basin (Roxbury Conglomerate) and progressively finer rocks to be deposited toward the north (Cambridge Argillite, fossiliferous within BOHA as discussed below) (Billings 1976; Bailey 1987). As the basin continued to subside, the finer sediments spread south, covering the coarser rocks (Bailey and Ball 1985).

During the Cambrian period, sediments were deposited in the Boston area, when the depositional environment had changed from a subsiding basin to a stable shelf (Goldsmith and Weed 1991), but these are not present at BOHA. There was probably later Paleozoic deposition over the basin, as elsewhere in the Avalon Terrane, but any trace is now eroded (Masterson et al. 1996). Multiple episodes of deformation, including folding and faulting, occurred during the plate collisions and accompanying orogenies of the Paleozoic. However, although pervasively folded and faulted, the Boston Basin rocks are only weakly metamorphosed (Kaye 1982). Igneous intrusions are often associated with these collisional events (Goldsmith and Weed 1991). The breakup of Pangaea began during the Late Triassic-Early

Jurassic, and in eastern Massachusetts was responsible for more faulting and the formation of additional igneous and sedimentary rocks (Kaye 1982; Goldsmith and Weed 1991). Igneous rocks from this time are exposed on BOHA's Brewster islands (Skehan 2001). The geologic history of the Boston area has been relatively quiet since Pangaea broke up, although there have been some large earthquakes, such as those of 1727 and 1755 (Brankman and Braise 2008). As with the late Paleozoic, coastal plain sedimentary rocks were probably formed in the Boston area during the Cretaceous and early Cenozoic, comparable to those of extreme southeast Massachusetts, but they are now eroded away. In this case, they would have been eroded during a global sea level low at approximately 25 Ma (Masterson et al. 1996).

The Boston area was greatly affected by Pleistocene glaciation (between 2.59 Ma and approximately 10,000 years ago), which among other things is responsible for the formation of drumlins that compose the central parts of most BOHA islands (Kaye 1976). Although the glacial history of Boston is not completely understood, there are two prominent tills (unsorted glacial deposits), dating to different parts of the last glacial period (Wisconsinan, postdating approximately 125,000 years ago) (Colgan and Rosen 2001); the dating is discussed more fully under "Quaternary rocks and sediments" below. Reconstructing the most recent glacial activity has proven particularly complex because Boston was along a zone where two glacial lobes met (the Narragansett Bay-Buzzards Bay lobe on the west and the Cape Cod Bay lobe on the east; Skehan 2001). This configuration led to weak flow (glaciers flow fastest at their centers) and relatively little till deposition (Kaye 1976). Additionally, Boston was near the marine margin at that time, causing the ice to behave differently depending on whether it flowed atop land or water (Kaye 1976).

The deglaciation of the harbor began approximately 15,000 radiocarbon years before present (note that radiocarbon dates are not the same as calendar dates, and that radiocarbon years require calibration to yield calendar years. Uncalibrated radiocarbon dates in publications are often denoted with "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. Therefore, dates that are not labeled with "calendar years" or something similar should be assumed to be uncalibrated radiocarbon dates). At this time Boston Harbor was still depressed from the weight of the ice sheets, and thus the local sea level was higher, at least 22 m (72 ft) above its present elevation. A glaciomarine clay known informally as the Boston Blue Clay was deposited across the Boston area at this time (Colgan and Rosen 2001; Rosen and FitzGerald 2004). Glacial lakes also formed intermittently from temporarily dammed meltwater, such as Glacial Lake Bouvé south of the harbor in Hingham (Crosby and Grabou 1896; Skehan 2001). With the retreat of the heavy mass of glacial ice, the crust began to rise within a thousand years (this phenomenon is known as isostatic rebound), and by 12,000 radiocarbon years before present, local sea level was 40 m (130 ft) lower than its present elevation. The eventual rise of global sea level, from the return of water from ice, then caused marine waters to encroach upon the area again; Back Bay was inundated approximately 5,600 radiocarbon years before present (Colgan and Rosen 2001; Rosen and FitzGerald 2004). The present sea level of the harbor was attained about 2,000 years ago (Jones and Fisher 1990). Humans entered the area by the time that sea level was rising, as shown by the presence of Paleoindian sites (Luedtke and Rosen 1993), such as at Great Esker Park just south of BOHA (Colgan and Rosen 2001). By the latter half of the 19th century, humans had become a major influence on the surface geology, removing sediments from high areas to fill low areas, such as parts of the Boston Harbor (Kaye 1976).

From oldest to youngest, the bedrock geology of BOHA consists of the Dedham Granite (Ediacaran Period), the Boston Bay Group's Roxbury Conglomerate and Cambridge Argillite (Ediacaran), and igneous rocks from the Early Jurassic rifting (Kaye 1980; Zen et al. 1983). The surficial geology of BOHA is a combination of older bedrock, drumlins and till from the recent glacial periods, beach deposits, and artificial fill (Kaye 1978). Fossils from BOHA include soft-bodied organisms from the Cambridge Argillite and a diverse assemblage of mostly marine organisms from Quaternary rocks and sediments.

The various non-network units mentioned above are over the same geologic units as BOHA, with the Roxbury Conglomerate in the bedrock of ADAM and FRLA, the Cambridge Argillite in the bedrock of ADAM, BOAF, BOST, JOFI, and LONG, and Proterozoic igneous rocks under SAMA (Kaye 1980; Zen et al. 1983).

The Roxbury Conglomerate (or Formation), underlying the Cambridge Argillite, is not presently known to be fossiliferous anywhere, but may prove to be in the future. Thus, for completeness, it is discussed here briefly. The Roxbury Conglomerate is the basal formation of the Boston Bay Group (Goldsmith and Weed 1991), and was deposited sometime between 593 and 570 Ma (Thompson et al. 2007). It is often subdivided into three members. From oldest to youngest, these are the Brookline (conglomerate and claystone/mudstone), Dorchester (claystone/mudstone and sandstone), and Squantum members (poorly sorted conglomerate in clay) (Goldsmith and Weed 1991). The base of the formation interbeds with volcanic rocks (the Brighton Melaphyre or Volcanics) (Goldsmith and Weed 1991), and the upper part interbeds with the Cambridge Argillite (Billings 1976). The famous "puddingstone" that is the state rock of Massachusetts is an example of Roxbury Conglomerate (Colgan and Rosen 2001).

The depositional environment of the Roxbury Conglomerate has been the subject of much debate, with models built around glacial, marine debris flows, glaciomarine combinations, and terrestrial alluvial fans (Rehmer 1986; Smith and Socci 1990; Hepburn et al. 1993). Modern interpretation have generally favored debris flows on marine fan and slope settings for most of the rocks (Smith and Socci 1990; Goldsmith and Weed 1991; Thompson and Bowring 2000). While fossils are not known from the Roxbury Conglomerate, it had been thought for many years that the Dorchester Member had tree trunk fossils from the Late Paleozoic (Burr and Burke 1900; Bailey and Newman 1978). These were later shown to be sandstone pipes (Bailey and Newman 1978). The most likely fossils for the Roxbury Conglomerate would probably be similar to those of the Cambridge Argillite: microfossils, algal mats, and Ediacaran forms.

Sources of Paleontological Resources

The fossils of BOHA present opportunities for education, interpretation, and continued or future scientific research in the park.

Boston Bay Group: Cambridge Argillite (Ediacaran)

The Cambridge Argillite (or Slate or Formation) is nearly entirely composed of argillite, a general term for fine-grained rock (clay-sized particles) that is not layered or fissile (layered mudrocks are shale). There are also minor amounts of sandstone and low-grade metamorphosed sandstone (quartzite) (Goldsmith and Weed 1991), and volcanic ash (Caldwell 1993; Thompson et al. 1996). The lower Cambridge Argillite grades out of the upper part of the underlying Roxbury Conglomerate (Billings 1976, 1979). The Cambridge Argillite is more than 5,000 m (16,400 ft) thick (Thompson and Bowring 2000), and is thickest in the north (Billings 1976, 1979). Several BOHA islands have the Cambridge Argillite as a bedrock unit, including Bumpkin, Gallops, Georges, Grape, Lovell, Peddocks (Masterson et al. 1996), Calf, Little Brewster, Middle Brewster, Outer Brewster (Skehan 2001), and Slate (McMenamin et al. 2007). Outcrops are known on some, including Calf, Little Brewster, Middle Brewster, Outer Brewster (Skehan 2001), Grape, and Slate (McMenamin et al. 2007). However, some rocks mapped as Cambridge Argillite on the south margin of the Boston Basin, including some *Aspidella* sites (see below), may actually be from a different, unnamed unit (Thompson and Bowring 2000).

From the early part of the 20th century until about 1980, the Cambridge Argillite, the rest of the Boston Bay Group, and the Boston Basin were thought to be late Paleozoic in age. This erroneous conclusion was based on sandstone pipes from the upper Roxbury Conglomerate that were interpreted as tree trunk casts (Bailey and Newman 1978). The discovery of fossils that are most abundant at the very end of the Proterozoic, a time period then called the Vendian but now known as the Ediacaran (extending from 635 to 542 Ma), established a much older age (Lenk et al. 1982a, 1982b). The Cambridge Argillite is now known to be younger than 570 Ma, based on a dated ash bed (Thompson et al. 2007), which places it within the late Ediacaran.

The depositional and paleoenvironmental conditions for the Boston Bay Group have long been disputed, hinging on the presence or absence of glacial influence. The traditional interpretation of the Cambridge Argillite was that it was deposited in a glacial lake (Caldwell 1993). For the last few decades geologists have usually interpreted it as being composed of deep marine density flows (Bailey and Galli 1985;

Goldsmith and Weed 1991; Caldwell 1993; Bailey and Bland 2000), although the formation could be a combination of multiple depositional settings including shallower tidal-, wave-, or wind-influenced environments (McMenamin et al. 2007; Williams et al. 2008). The Cambridge Argillite was deposited in the deeper part of the Boston Basin, and as the basin subsided, its depositional area expanded southward (Bailey and Galli 1985).

Fossils of the Cambridge Argillite include microbial mats now altered to pyrite (the brass-colored metallic mineral also known as "fool's gold"), fossils apparently belonging to Ediacaran biota (Bailey 2005), the Ediacaran form *Aspidella* (McMenamin et al. 2007), and a variety of microfossils including spherical forms, filaments, and colonies identified as *Bavlinella* cf. *faveolata*; the microfossils are also altered to pyrite (Lenk et al. 1982a, 1982b). The microfossils are sometimes described as "acritarchs," a nebulous group of fossil forms that are classified together on the basis that they cannot be identified as anything else. Ediacaran can refer to a division of time, as noted above, or a type of extinct organism. Fossils described as "Ediacaran biota" belong to a group of enigmatic soft-bodied organisms, the structure and relationships of which are unknown. The group briefly flourished before the evolution of hard body parts, an innovation that marks the beginning of the Cambrian Period. Within the Cambridge Argillite, fossils are known from near the base (Thompson et al. 1996).

Several fossil occurrences are known from the Cambridge Argillite (or what is mapped as the Cambridge Argillite; Bailey 2009) within BOHA, preserving evidence of the oldest known organisms from a NETN park. Fossils described as *Aspidella terranovica*, otherwise known as "ring fossils," have been found in Cambridge Argillite rocks at Grape and Slate islands (McMenamin et al. 2007). These ring fossils can be found in great concentrations, up to 200 individuals per 400 cm^2, but rarely touch. Elliptical examples were probably deformed by tectonic compression from an original circular state (Bailey 2009). The original organism was probably benthic and largely sessile (Bailey and Bland 2000). Research of the fossils is currently ongoing (R. Bailey, Department of Earth and Environmental Sciences, Northeastern University, pers. comm., February 2010). Ediacaran fossils may have been known from the area for decades, as Clark (1923) reported on "*Aspidella*-like markings" from Crow Point that he thought had been glacially transported from Slate Island. At the time, the fossils were interpreted as inorganic, the result of gas escaping vents through mud (Clark 1923).

Bailey (2005) also noted the presence of Ediacaran-like fossils and microbial mats now altered to pyritized laminations (pyrite is the brass-colored metallic mineral also known as fool's gold) on Boston Harbor islands including Grape, Raccoon, and Slate. The specific geologic unit was not stated, but since Ediacaran fossils are known from the Cambridge Argillite of Grape and Slate islands (McMenamin et al. 2007; Bailey 2009), and fossils have not been recorded from the Roxbury Conglomerate, it seems safe to regard these as coming from the Cambridge Argillite.

Quaternary rocks and sediments (Pleistocene-Holocene)

The surficial geology of BOHA is a combination of beach deposits, Pleistocene-age stratified drift and till, bedrock outcrops, artificial fill over salt marsh and shallow marine deposits (Kaye 1978), and a few postglacial dunes, particularly on Lovells and Thompson islands (Thornberry-Ehrlich 2008). The till in particular is known for fossils at BOHA, and other Quaternary deposits in and around Boston (including at BOHA) are also fossiliferous. Quaternary marine fossils have been reported from the Boston area for over two hundred years, when shells were found in glacial deposits at Telegraph Hill, Hull (just across Hull Gut from Peddocks Island), during the American Revolution (Crosby and Ballard 1894).

The Quaternary stratigraphy of Boston Harbor is complex (Kaye 1976), involving at least two glacial tills and possibly a third, with multiple glaciomarine clays (Colgan and Rosen 2001) and younger deposits (Masterson et al. 1996). For the purposes of this report it is simplest to consider the islands in terms of an older lower till (sometimes called the drumlin till, because it comprises the bulk of the drumlins), a younger overlying till, and a veneer of young beach deposits (Masterson et al. 1996). The two tills are separated by a layer of sand (Skehan 2001). The upper till dates to the end of the last major glacial period (the Wisconsinan), but the age of the lower till is uncertain. At one time the lower till was thought to have

been deposited during the penultimate glacial period (the Illinoian); however, this is unlikely based on the presence of fossils dating to the interglacial period that occurred after the Illinoian. Thus, it appears to have been deposited during a Wisconsinan glacial advance, but not the most recent (Colgan and Rosen 2001). Surrounding the islands are marine and estuarine sediments (Masterson et al. 1996). These date to two periods: the early postglacial interval (represented by the Boston Blue Clay, roughly 15,000 years old), and the interval of rising (transgressive) sea levels that began approximately 12,000 years ago and inundated Back Bay approximately 5,600 years ago (Colgan and Rosen 2001). While these marine and estuarine sediments are not present on the islands, their fossils may wash up occasionally on the landmasses. Swamp and marsh deposits are also found, with peat, plant fossils, and microfossils (Shimer 1918; Johnson 1942a; Wilson 1949). These deposits are of great interest because their fossils record changes in climate and other environmental factors over the present postglacial period.

Numerous reports of Quaternary fossils are known from BOHA. The oldest report, made in 1869, is of bivalve and gastropod shells from Fort Warren on Georges Island. These were recovered from a depth of 33 m (100 ft) below the surface by G. E. Pierce while sinking a well in the center of the fort (Niles 1869). Pleistocene fossils are found in the unoxidized and unleached lower portion of the lower glacial till (drumlin till) (Kaye 1976; Newman and Mickelson 1994; Colgan and Newman 1999; Colgan and Rosen 2001). Microfossils are abundant in some lower tills, such as at Long Island (Colgan and Rosen 2001). The lower till fossils may be partially replaced by silica (Rosen and FitzGerald 2004), and represent shallow marine and estuarine organisms (Colgan and Rosen 2001). Fossils are not known to be present in the upper till (Skehan 2001). The most detailed description of BOHA fossils is Crosby and Ballard (1894), which reports 39 taxa from 13 localities on eight BOHA islands, among other localities. Until recently, investigations into the Quaternary fossil record of BOHA have been focused on Pleistocene glacial till deposits, but more recent paleoecological materials are now being found as well.

Islands with reports of fossils include Calf, Deer, Georges, Great Brewster, Long, Lovells, Moon, Nut, Peddocks (including Prince Head), and Rainsford. Peddocks Island in particular has numerous fossils (Upham 1889; Crosby and Ballard 1894; Colgan and Rosen 2001). Shells are also very common on some surfaces at Grape Island (Fisher and Jones 1982), and there are numerous microfossils on Long Island, including foraminifera (protists that form "shells," usually out of carbonate) and ostracodes (seed shrimp) (Orton and Colgan 2001). Shells from Deer, Georges, Great Brewster, Long, Lovells, Moon, Nut, and Peddocks islands and Prince Head, mostly from bivalves and gastropods, were described by Crosby and Ballard (1894). Peddocks Island, Deer Island, Moon Island, and Great Brewster Island had the most diverse assemblages (in that order). Fossils of sponges, stony corals, bivalves, gastropods, barnacles, crabs, and worm tubes were recovered from the islands (Crosby and Ballard 1894).

Overall, the Quaternary fossil assemblage from BOHA includes foraminifera (Colgan and Rosen 2001), peat (Patterson et al. 2005), charcoal, pollen (pollen at Grape Island; Jones and Fisher 1990), hickory nuts (Luedtke and Rosen 1993), sponges, stony corals, bivalves, gastropods, barnacles, crabs (Crosby and Ballard 1894), ostracodes (Colgan and Rosen 2001), worm tubes (Crosby and Ballard 1894), fish, reptiles, birds, dogs, deer, unidentified mammals (Luedtke and Rosen 1993), and humans (Humphrey et al. 1993); these organisms did not all exist at the same time, though. Among the oldest remains are shells from Peddocks Island's lower till, thought to date to the last interglacial (Sangamonian) (Belknap 1979, 1980; Newman et al. 1990), now thought to have spanned the time period between 125,000 and 75,000 years ago, approximately, on the basis of amino acid racemization dates (Belknap 1979; Stea et al. 1992) and correlation to similar analyses on Nantucket Island that are tied to a uranium-series dated coral (Oldale et al. 1982). Shells of similar age are known from Great Brewster Island, Long Island, and Prince Head (Colgan and Newman 1999). Among the younger fossils, a human skeleton dated to 4,100 radiocarbon years before present has been found on Peddocks Island (Humphrey et al. 1993); shell middens at Bass Point on Long Island (where the hickory nuts and most of the vertebrate bones were found) were left between roughly 2,000 and 1,000 years ago (Luedtke and Rosen 1993); and peat on Calf Island is dated to between 840 and 860 AD at a depth of 92 cm (36 in) (Patterson et al. 2005). Note that the National Park Service defines a fossil as any remains of life preserved in a geologic context, without attaching a date as a cutoff between "fossil" and "modern."

The greater Boston area has some types of Quaternary fossils that have not yet been found or documented in detail yet within BOHA. Because of the island nature of the park, there is the possibility that fossils from elsewhere in the harbor will erode and wash up on BOHA units. With respect to Pleistocene marine invertebrates, some shells are known to have been colonized by bryozoans (Shimer 1918). The Boston Blue Clay has yielded foraminifera, diatoms (algae with silica "shells"), pollen (Judson 1949), mollusks, barnacles, and ostracodes (Kaye 1976). The Holocene-age marine and estuarine deposits surrounding the BOHA islands have shells and organic deposits (Masterson et al. 1996). Plants dating to the time after the last glacial period, including swamp plants, deciduous leaves, and tree stumps, are known from several localities (Shimer 1918). Beetle fragments are known from peat deposits at Cambridge (Argus and Davis 1962). Peat deposits of former marshes, from the brief period between glacial rebound and sea level rise, can be richly fossiliferous (Kaye 1982). The most diverse Holocene finds in the Boston area come from the Boylston Street Fishweir, a site of interest for both archeological and paleontological aspects. At this site, prehistoric people built a series of fishweirs (fish traps made of stick fences) (Johnson 1949) between 4,700 and 3,700 radiocarbon years before present (Newby and Webb 1994). Post-Boston Blue Clay sediments began to accumulate at this site approximately 5,630 radiocarbon years before present, when marine transgression and submergence began (Rosen et al. 1993). Sediments examined during the excavations have yielded foraminifera (Stetson and Parker 1942), dinoflagellates (a type of plankton that move using whip-like flagella) (as *Hystrichospera*; Wilson 1949), the euglenid *Trachelomonas* (another type of flagellate plankton) (Wilson 1949), diatoms (Linder 1942), spores, pollen (Knox 1942), seeds, fruits (Barghoorn 1949), grass fragments, sedges, roots, other plant tissues, fungi, sponge spicules, insect chitin (Johnson 1942a), bivalves, gastropods (Clench 1942), marine worms (Wilson 1949), barnacles (Lindquist 1942), cladocerans (water fleas) (Wilson 1949), worm and sponge trace fossils on mollusks (Nelson 1942), mollusk borings on wood (Johnson 1942b), small fish bones (Johnson 1942a), bones of a shorebird (perhaps a Greater Yellowlegs; Johnson 1942b), and organic debris (Johnson 1942a). Most of these fossils are from peat immediately above the Boston Blue Clay (Johnson 1942a; Wilson 1949).

Large mammal fossils are quite rare in Massachusetts, although a horn core and attached skull material from a bison were recovered from Late Pleistocene deposits at Harvard, 45 km (28 miles) northwest of central Boston (Romer 1951). Mastodon and mammoth teeth are known from the floor of Massachusetts Bay as well, dating to the early portion of the current postglacial interval, when local sea level was relatively low (Oldale et al. 1988).

Park Collections

BOHA does not currently have fossil collections, because of land ownership. BOHA staff are involved with collection approval (M. Albert, BOHA stewardship program manager, pers. comm., January 2010).

Parties affiliated with several institutions have done paleontological research on BOHA units. For example, a member of the Boston Society of Natural History (now the Museum of Science [Boston]) made the Fort Warren well find (Niles 1869), and at least some of the collections mentioned by Crosby and Ballard (1894) were in the collections of the society's museum at that time. Colgan and Newman (1999), who discussed dating of shells from Great Brewster, Long, and Peddocks islands, were affiliated with Northeastern University of Boston. Members of the University of Massachusetts (Amherst)'s Department of Natural Resource Conservation undertook the Calf Island paleoecological work (Patterson et al. 2005). While the institutions may not have specimens in their collections, they may have notes and other records of interest. Mark McMenamin (pers. comm., January 2010) reported that no Cambridge Argillite specimens from BOHA were taken to Mount Holyoke College.

Cultural Resource Contexts

The islands of BOHA are known for their archeology; 21 of them are also included in the Boston Harbor Islands Archeological District of the U.S. National Register of Historic Places. While Paleoindian artifacts are known elsewhere from Boston, the oldest material collected at BOHA is an Early Archaic point from Long Island (Luedtke and Rosen 1993), indicating that people have been visiting the islands for at least the

last several thousand years. Clamming was a major use. For example, prehistoric people used Grape Island for clamming (Fisher and Jones 1982; Masterson et al. 1996), with multiple midden sites (Jones and Fisher 1983; Jones and Fisher 1990). One midden site is thought to have been occupied between 1600 and 900 radiocarbon years before present (Jones 1980; Fisher and Jones 1982; Jones and Fisher 1990). Long Island is another prominent clamming site, particularly Bass Point, which has faunal remains and Early and Middle Woodland artifacts among its middens (Luedtke and Rosen 1993). Unlike some other areas, the stones selected by prehistoric people for tools in the Boston area are not potentially fossiliferous, instead being varieties of volcanic rock (Luedtke 1998; Hollander and Hermes 1999; Hermes 2000). Evidence of prehistoric human presence and association with paleontological resources is not limited to faunal material and charcoal; as noted above, a human skeleton dating to several thousand years ago has been found on Peddocks Island (Humphrey et al. 1993). 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

- The NPS Geologic Resources Division coordinated a geologic resource inventory scoping session for BOHA during July 2007, which includes a discussion on paleontological resources, recommends a field-based paleontological resource inventory, and notes some concern regarding fossil theft (Thornberry-Ehrlich 2008). The summary also notes the potential impact of rising sea level and increased erosion on natural resources in the park.
- Documented paleontological resources at BOHA to date consist of fossils from the Ediacaran-age Cambridge Argillite (enigmatic organisms) and Quaternary rocks and sediments (foraminifera, peat, pollen, and invertebrate remains are most common, with some vertebrate material as well).
- BOHA has deposits that are geologically very young, which can make it difficult to determine what material is a "fossil" and what would be considered "modern." The National Park Service defines a fossil as any remains of life preserved in a geologic context. This definition does not include an arbitrary date where older specimens are considered fossils, and younger specimens are not. The "geologic context" phrase is intended to imply some level of antiquity. Generally, specimens dating back to the late Pleistocene are considered fossils. Late Holocene (last few hundred or thousand years, "Recent") specimens are usually considered modern and not fossils. Pleistocene remains may differ from younger remains by having dark staining and being heavily worn and bored, but this does not always hold true. Surface and subsurface specimens collected at BOHA span this range between Pleistocene and Holocene. Regardless of what label is assigned to them, these specimens are important natural resources and valuable pieces of the history of life on earth.
- Park staff should be encouraged to observe exposed sedimentary rocks and unlithified sediments for fossil material while conducting their usual duties. Staff should photodocument and potentially 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. 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).
- Future archeological excavations or infrastructure developments should consider scheduling site monitoring by a trained paleontologist in order to document and protect fossil resources.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

Literature Cited

Acaster, M. and M. E. Bickford. 1999. Geochronology and geochemistry of Putnam-Nashoba Terrane metavolcanic and plutonic rocks, eastern Massachusetts: constraints on the early Paleozoic evolution of eastern North America. Geological Society of America Bulletin **111**(2):240-253.

Argus, G. W. and M. B. Davis. 1962. Microfossils from a late-glacial deposit at Cambridge, Massachusetts. American Midland Naturalist **67**(1):106-117.

Bailey, R. H. 1987. Stratigraphy of the Boston Bay Group, Boston area, Massachusetts. Pages 209-212 *in* Roy, D. C., editor. Northeastern section of the Geological Society of America. Geological Society of America, Boulder, CO. Centennial Field Guide **5**.

Bailey, R. H. 2005. Stratigraphy and depositional setting of Neoproterozoic strata on southern Boston Harbor islands, Boston Bay Group, Massachusetts. Abstracts with Programs - Geological Society of America **37**(1):71.

Bailey, R. H. 2009. Retrodeformation and distribution analysis of an Ediacaran fossil from the Boston Bay Group, eastern Massachusetts. Abstracts with Programs - Geological Society of America **41**(7):629.

Bailey, R. H. and B. H. Bland. 2000. Ediacaran fossils from the Neoproterozoic Boston Bay Group, Boston area, Massachusetts. Abstracts with Programs - Geological Society of America **32**(7):11.

Bailey, R. H. and K. G. Galli. 1985. Sedimentary tectonics and sandstone petrogenesis: Boston Basin, Massachusetts. Abstracts with Programs - Geological Society of America **17**(1):3.

Bailey, R. H. and W. A. Newman. 1978. Origin and significance of cylindrical sedimentary structures from the Boston Bay Group, Massachusetts. American Journal of Science **278**(5):703-714.

Barghoorn, E. S. Jr. 1949. Paleobotanical studies of the Fishweir and associated deposits. Pages 49-83 *in* Johnson, F., editor. The Boylston Street Fishweir II. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology **4**(1).

Belknap, D. F. 1979. Application of amino acid geochronology to stratigraphy of Late Cenozoic emerged marine units of the Atlantic Coastal Plain. Dissertation. University of Delaware, Newark, DE.

Belknap, D. F. 1980. Amino acid geochronology and the Quaternary of New England and Long Island. Program and Abstracts - American Quaternary Association **6**:16-17.

Billings, M. P. 1976. Geology of the Boston Basin. Pages 5-30 *in* Lyons, P. C. and A. H. Brownlow, editors. Studies in New England geology. Geological Society of America, Boulder CO. Memoir 146.

Billings, M. P. 1979. Bedrock geology of the Boston Basin. Pages 47-64 *in* Cameron, B., editor. Carboniferous basins of southeastern New England. American Geological Institute, Falls Church, VA.

Brankman, C. M., and L. G. Baise. 2008. Liquefaction susceptibility mapping in Boston, Massachusetts. Environmental & Engineering Geoscience **14**(1):1-16.

Burr, H. T. and R. E. Burke. 1900. The occurrence of fossils in the Roxbury conglomerate. Proceedings of the Boston Society of Natural History **29**:179-184. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/proceedingsbost10unkngoog]

Caldwell, D. W. 1993. Volcanic origin of the Boston Bay Group, Massachusetts. Abstracts with Programs - Geological Society of America **25**(2):7-8.

Carto, S. L. and N. Eyles. 2007. The Neoproterozoic Squantum member, Boston Basin: glacial or non-glacial. Abstracts with Programs - Geological Society of America **39**(6):632.

Clark, T. H. 1923. New fossils from the vicinity of Boston. Proceedings of the Boston Society of Natural History **36**(8):473-485. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/proceedingsofbos36bostuoft]

Clench, W. J. 1942. The mollusks. Pages 45-48 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Colgan, P. M. and W. A. Newman. 1999. Amino acid evidence for the age of the lower till in Boston Harbor, Massachusetts. Abstracts with Programs - Geological Society of America **31**(2):A-10.

Colgan, P. M. and P. S. Rosen. 2001. Quaternary environments and history of Boston Harbor, Massachusetts. Pages I1-I20 *in* West, D. P. Jr. and R. H. Bailey, editors. Guidebook for geological field trips in New England. Geological Society of America, Boulder, CO.

Crosby, W. O. and H. O. Ballard. 1894. Distribution and probable age of the fossil shells in the drumlins of the Boston Basin. American Journal of Science **48**(288):486-496. [full text available on Google Books, but must be searched for using regular Google search]

Crosby, W. O. and A. W. Grabau. 1896. Glacial lakes of the Boston Basin. American Geologist **17**:128-130. [full text available on Google Books]

Fisher, J. J. and J. R. Jones. 1982. Origin and development of a cuspate foreland at Grape Island, Boston Harbor, Massachusetts. Pages 511-518 *in* Farquhar, O. C., editor. Geotechnology in Massachusetts. University of Massachusetts Graduate School, Amherst, MA.

Goldsmith, R. and E. G. A. Weed. 1991. Stratigraphy of the Milford-Dedham Zone, eastern Massachusetts: an Avalonian terrane. Pages E1-E62 *in* Hatch, N. L. Jr., editor. The bedrock geology of Massachusetts. U.S. Geological Survey, Reston, VA. Professional Paper 1366-E-J. Online. http://pubs.er.usgs.gov/usgspubs/pp/pp1366EJ. Accessed December 2009.

Hatch, N. L. Jr., E-an Zen, R. Goldsmith, N. M. Ratcliffe, P. Robinson, R. S. Stanley, and D. R. Wones. 1984. Lithotectonic assemblages as portrayed on the new bedrock geologic map of Massachusetts. American Journal of Science **284**(9):1026-1034.

Hepburn, J. C., M. Hill, and R. Hon. 1987. The Avalonian and Nashoba terranes, eastern Massachusetts, U.S.A.: an overview. Maritime Sediments and Atlantic Geology **23**(1):1-12.

Hepburn, J. C., R. Hon, G. R. Dunning, R. H. Bailey, and K. Galli. 1993. The Avalon and Nashoba terranes (eastern margin of the Appalachian Orogen in southeastern New England). Pages X.1-X.31 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Hermes, O. D. 2000. What is this stuff anyway? Characterizing lithics in southeastern New England. Abstracts with Programs - Geological Society of America **32**(7):416.

Hollander, S. A. and O. D. Hermes. 1999. Petrological characterization of "Saugus Jasper". Abstracts with Programs - Geological Society of America **31**(2):A-24.

Humphrey, J., J. Hager, and D. Woodhouse. 1993. A geohistorical boat tour of Boston Harbor. Pages W.1-W.16 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Johnson, F. 1942a. The cross section of the building excavation. Pages 13-23 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Johnson, F. 1942b. Miscellaneous identifications and discussion. Pages 130 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Johnson, F. 1949. Introduction. Pages 3-5 *in* Johnson, F., editor. The Boylston Street Fishweir II. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology **4**(1).

Jones, J. R. 1980. Carbon-14 dating of a cuspate foreland ridge: Grape Island, Boston Harbor, Massachusetts. Abstracts with Programs - Geological Society of America **12**(2):44.

Jones, J. R. and J. J. Fisher. 1983. The relationship between late Holocene coastal environments and prehistoric shellfish subsistence patterns: Boston Harbor, Massachusetts. Abstracts with Programs - Geological Society of America **15**(3):180.

Jones, J. R. and J. J. Fisher. 1990. Environmental factors affecting prehistoric shellfish utilization: Grape Island, Boston Harbor, Massachusetts. Pages 137-146 *in* Lasca, N. P. and J. Donahue, editors. Archaeological geology of North America. Geological Society of America, Boulder, CO. Centennial Special Volume 4.

Judson, S. S. Jr. 1949. The Pleistocene stratigraphy of Boston, Massachusetts and its relation to the Boylston Street Fishweir. Pages 7-48 *in* Johnson, F., editor. The Boylston Street Fishweir II. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology **4**(1).

Kaye, C. A. 1976. Outline of the Pleistocene geology of the Boston Basin. Pages 46-63 *in* Cameron, B., editor. Geology of southeastern New England: a guidebook for field trips to the Boston area and vicinity. Science Press, Princeton, NJ. Annual Meeting - New England Intercollegiate Geological Conference 68.

Kaye, C. A. 1978. Surficial geologic map of the Boston area, Massachusetts. U.S. Geological Survey, Reston, VA. Open-File Report 78-111. Online. http://pubs.er.usgs.gov/usgspubs/ofr/ofr78111. Accessed December 2009.

Kaye, C. A. 1980. Bedrock geologic maps of the Boston North, Boston South, and Newton quadrangles, Massachusetts. U.S. Geological Survey, Reston, VA. Miscellaneous Field Studies Map 1241. Scale 1:24,000.

Kaye, C. A. 1982. Bedrock and Quaternary geology of the Boston area, Massachusetts. Reviews in Engineering Geology **5**:25-40.

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* Lucas, S. G., 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, NM. Bulletin 34. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed December 2009.

Knox, A. S. 1942. The pollen analysis of the silt and the tentative dating of the deposits. Pages 105-129 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Lenk, C., P. K. Strother, C. A. Kaye, and E. S. Barghoorn. 1982a. Precambrian age of the Boston Basin: new evidence from microfossils. Science **216**(4546):619-620.

Lenk, C., P. K. Strother, E. S. Barghoorn, and C. A. Kaye. 1982b. Petrified palynomorphs from the Cambridge Argillite, Cambridge, Massachusetts. Palynology **6**:283.

Levin, H. L. 1999. The Earth through time (6th edition). Saunders College Publishing, Fort Worth, TX.

Linder, D. H. 1942. The diatoms. Pages 67-81 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Lindquist, R. L. 1942. Notes on *Balanus eburneus* Gould. Pages 65-66 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Luedtke, B. E. 1998. Rediscovery of the Wyoming Quarry Site, Melrose, MA. Abstracts with Programs - Geological Society of America **30**(1):58-59.

Luedtke, B. E. and P. S. Rosen. 1993. Archaeological geology on Long Island, Boston Harbor. Pages T.1-T.15 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Masterson, J. P., B. D. Stone, and R. R. Rendigs. 1996. Geohydrology and potential water-supply development on Bumkin, Gallops, Georges, Grape, Lovell, and Peddocks islands, eastern Massachusetts. U.S. Geological Survey, Reston, VA. Open-File Report 96-117. Online. http://pubs.er.usgs.gov/usgspubs/ofr/ofr96117. Accessed December 2009.

McMenamin, M. A. S., J. D. Beuthin, E. Anderson, A. Lavarreda, K. O'Donnell, W. S. Persons, and J. Williams. 2007. Fossiliferous laminites of the Proterozoic Cambridge Argillite, Boston Basin. Abstracts with Programs - Geological Society of America **39**(6):564.

Nelson, T. C. 1942. The oysters. Pages 49-64 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Newby, P. E. and T. Webb III. 1994. Radiocarbon-dated pollen and sediment records from near the Boylston Street fishweir site in Boston, Massachusetts. Quaternary Research **41**(2):214-224.

Newman, W. A. and D. M. Mickelson. 1994. Genesis of Boston Harbor drumlins, Massachusetts. Sedimentary Geology **91**(1-4):333-343.

Newman, W. A., R. C. Berg, P. S. Rosen, and H. D. Glass. 1990. Pleistocene stratigraphy of the Boston Harbor drumlins, Massachusetts. Quaternary Research **34**(2):148-159.

Newman, W. A., D. M. Mickelson, R. C. Berg, R. R. Rendigs, R. N. Oldale, and R. H. Bailey. 1993. Pleistocene geology of the Boston Basin and its adjacent surroundings. Pages U.1-U.24 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Niles, W. H. 1869. [On the occurrence of shells of existing species in a boring at Fort Warren, Boston Harbor.] Proceedings of the Boston Society of Natural History 12:244, 364. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/proceedingsofbos68bost]

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

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., J. R. Grimes, and F. C. Whitmore Jr. 1988. Late-Wisconsinan elephant teeth from the western Gulf of Maine. Abstracts with Programs - Geological Society of America **20**(1):59.

Orton, A. M. and P. M. Colgan. 2001. Microfossils in the drumlin till of Boston Harbor, Massachusetts. Abstracts with Programs - Geological Society of America **33**(1):65.

Patterson, W. A., J. A. Richburg, K. H. Clark, and S. Shaw. 2005. Paleoecology of Calf Island in Boston's Outer Harbor. Northeastern Naturalist **12**(special issue 3):31-48.

Rast, N. and J. W. Skehan. 1990. The late Proterozoic geologic setting of the Boston Basin. Pages 235-247 *in* Socci, A. D., J. W. Skehan, and G. W. Smith, editors. Geology of the composite Avalon Terrane of southern New England. Geological Society of America, Boulder, CO. Special Paper 245.

Rehmer, J. 1986. The Squantum tilloid member of the Roxbury Conglomerate of Boston, Massachusetts. Pages 756-759 *in* Hambrey, M. J. and W. B. Harland, editors. Earth's pre-Pleistocene glacial record. Cambridge earth science series. Cambridge University Press, Cambridge, United Kingdom.

Romer, A. S. 1951. *Bison crassicornis* in the late Pleistocene of New England. Journal of Mammalogy **32**(2):230-231.

Rosen, P. S. and D. M. FitzGerald. 2004. Processes and evolution of Boston Harbor islands: Peddocks and Lovells Islands. B6-1-B6-18 *in* Hansen, L., editor. Guidebook for field trips in the eastern Massachusetts region. New England Intercollegiate Geologic Conference, Amherst, MA. Annual Meeting - New England Intercollegiate Geological Conference 96.

Rosen, P. S., B. M. Brenninkmeyer, and L. M. Maybury. 1993. Holocene evolution of Boston inner harbor, Massachusetts. Journal of Coastal Research **9**(2):363-377.

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

Sayles, R. W. 1914. The Squantum tillite. Bulletin of the Museum of Comparative Zoology **66**:141-175. [full text available on Google Books]

Shimer, H. W. 1918. Postglacial history of Boston. Proceedings of the American Academy of Arts and Sciences **53**(6):441-463.

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

Skehan, J. W. and N. Rast. 1992. The Avalon Superterrane and the enigma of the Nashoba. Abstracts with Programs - Geological Society of America **24**(7):A289.

Smith, G. W. and A. D. Socci. 1990. Late Precambrian sedimentary geology of the Boston Basin. Pages 75-84 *in* Socci, A. D., J. W. Skehan, and G. W. Smith, editors. Geology of the composite Avalon Terrane of southern New England. Geological Society of America, Boulder, CO. Special Paper 245.

Stea, R. R., R. J. Mott, D. F. Belknap, and U. Radtke. 1992. The Pre-Late Wisconsinan chronology of Nova Scotia, Canada. Pages 185-206 *in* Clarke, P. U. and P. D. Lea, editors. The last interglacial transition in North America. Geological Society of America, Boulder, CO. Special Paper 270.

Stetson, H. C. and F. L. Parker. 1942. Mechanical analysis of the sediments and the identification of the Foraminifera from the building excavation. Pages 41-44 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Thompson, M. D. and S. A. Bowring. 2000. Age of the Squantum "tillite," Boston Basin, Massachusetts: U-Pb zircon constraints on terminal Neoproterozoic glaciation. American Journal of Science **300**(8):630-655.

Thompson, M. D., O. D. Hermes, S. A. Bowring, C. E. Isachsen, J. R. Besancon, and K. L. Kelly. 1996. Tectonostratigraphic implications of late Proterozoic U-Pb zircon ages in the Avalon Zone of southeastern New England. Pages 179-191 *in* Nance, R. D. and M. D. Thompson, editors. Avalonian and related peri-Gondwanan terranes of the Circum-North Atlantic. Geological Society of America, Boulder, CO. Special Paper 304.

Thompson, M. D., A. M. Grunow, and J. Ramezani. 2007. Late Neoproterozoic paleogeography of the southeastern New England Avalon Zone: insights from U-Pb geochronology and paleomagnetism. Geological Society of America Bulletin **119**(5-6):681-696.

Thornberry-Ehrlich, T. 2008. Geologic resource evaluation scoping summary: Boston Harbor Islands National Recreation Area. National Park Service, Geologic Resources Division, Denver, CO. Online. http://www.nature.nps.gov/GEOLOGY/inventory/publications/s_summaries/BOHA_gre_scoping_summary_2008-0930.pdf. Accessed December 2009.

Upham, W. 1889. Marine shells and fragments of shells in the till near Boston. Proceedings of the Boston Society of Natural History **24**:127-141. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/proceedingsofbos24bostuoft]

Williams, J., C. F. Lohrengel, J. D. Beuthin, and M. A. S. McMenamin. 2008. Laminites in the Cambridge Argillite (Ediacaran), Hewitt's Cove, Hingham, Massachusetts. Abstracts with Programs - Geological Society of America **40**(1):69.

Wilson, L. R. 1949. A microfossil analysis of the Lower Peat and associated sediments at the John Hancock Fishweir site. Pages 84-98 *in* Johnson, F., editor. The Boylston Street Fishweir II. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology **4**(1).

Wintsch, R. P., J. F. Sutter, M. J. Kunk, J. N. Aleinikoff, and J. L. Boyd. 1993. Alleghanian assembly of Proterozoic and Paleozoic lithotectonic terranes in south central New England: new constraints from geochronology and petrology. Pages H.1-H.30 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Wintsch, R. P., J. N. Aleinikoff, G. J. Walsh, W. A. Bothner, A. M. Hussey II, and C. M. Fanning. 2007. SHRIMP U-Pb evidence for a Late Silurian age of metasedimentary rocks in the Merrimack and Putnam-Nashoba Terranes, eastern New England. American Journal of Science **307**(1):119-167.

Zen, E-an, R. Goldsmith, N. M. Ratcliffe, P. Robinson, R. S. Stanley, N. L. Hatch, A. F. Shride, E. G. A. Weed, and D. R. Wones. 1983. Bedrock geologic map of Massachusetts. U.S. Geological Survey, Reston, VA. Scale 1:250,000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_16357.htm. Accessed December 2009. Accessed December 2009.

Additional References

Allen, G. M. 1920. Bison remains from New England. Journal of Mammalogy **1**(4):161-164.

Bailey, R. H. and B. H. Bland. 2001. Recent developments in the study of the Boston Bay Group. Pages U1-U23 *in* West, D. P. Jr. and R. H. Bailey, editors. Guidebook for geological field trips in New England. Geological Society of America, Boulder, CO.

Bailey, R. H. and K. E. Fletcher. 2002. Microbially induced sedimentary structures and preservation of Ediacaran-like fossils in the Boston Bay Group, Massachusetts. Abstracts with Programs - Geological Society of America **34**(6):247.

Barber, R. J. 1984. Archaeology on Thompson Island. Pages 409-416 *in* Hanson, L. S., editor. Geology of the Coastal Lowlands: Boston, MA to Kennebunk, ME. New England Intercollegiate Geologic Conference, Amherst, MA. Annual Meeting - New England Intercollegiate Geological Conference 76.

Bland, B. H. 2000. *Aspidella*, *Cyclomedusa* and related forms from Boston, Newfoundland and the United Kingdom. Abstracts with Programs - Geological Society of America **32**(7):12.

Caldwell, D. W. 1984. Surficial geology and archaeology on Thompson Island, Boston Harbor, Massachusetts. Pages 402-408 *in* Hanson, L. S., editor. Geology of the Coastal Lowlands: Boston, MA to Kennebunk, ME. New England Intercollegiate Geologic Conference, Amherst, MA. Annual Meeting - New England Intercollegiate Geological Conference 76.

Cardoza, K. D., J. C. Hepburn, and R. Hon. 1990. Geochemical constraints on the paleotectonic settings of two late Proterozoic mafic volcanic suites, Boston-Avalon Zone, eastern Massachusetts. Pages 113-131 *in* Socci, A. D., J. W. Skehan, and G. W. Smith, editors. Geology of the composite Avalon Terrane of southern New England. Geological Society of America, Boulder, CO. Special Paper 245.

Clapp, F. G. 1901. Geological history of the Charles River in Massachusetts. Technology Quarterly **14**:171-201. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/technologyquart13artsgoog]

Crosby, W. O. 1903. A study of the geology of the Charles River estuary and Boston Harbor. Technology Quarterly **16**:64-92. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/technologyquart04artsgoog]

Fay, L. P. 1986. Fossils of Rhode Island. Rocks and Minerals **61**(5):278-279.

Gehling, J. G., G. M. Narbonne, and M. M. Anderson. 2000. The first named Ediacaran body fossil, *Aspidella terranovica*. Palaeontology **43**(3):427-456. Online. http://www3.interscience.wiley.com/journal/120703866/abstract (full text is free). Accessed January 2010.

Hepburn, J. C. 2008. Mid-Paleozoic arc accretion on the eastern side of the Appalachian Orogen, eastern Massachusetts and adjacent areas. Abstracts with Programs - Geological Society of America **40**(2):75.

Himmelstoss, E. A., D. M. FitzGerald, P. S. Rosen, and J. R. Allen. 2006. Bluff evolution along coastal drumlins: Boston Harbor Islands, Massachusetts. Journal of Coastal Research **22**(5):1230-1240.

Jones, J. R., J. R. Keegan, and J. F. O'Connell. 1981. Reconstruction of glacial subenvironments: Thompson Island, Boston Harbor, Massachusetts. Abstracts with Programs - Geological Society of America **13**(3):140.

Kaye, C. A. 1961. Pleistocene stratigraphy of Boston, Massachusetts. Pages B73-B76 *in* Geological Survey research 1961: short papers in the geologic and hydrologic sciences. U.S. Geological Survey, Reston, VA. Professional Paper 424-B.

Koteff, C., G. R. Robinson, R. Goldsmith, R. and W. B. Thompson. 1993. Delayed postglacial uplift and synglacial sea levels in coastal central New England. Quaternary Research **40**(1):46-54.

Khoo, M. A., J. Ramezani, and M. D. Thompson. 2008. Age and stratigraphic affinity of Neoproterozoic conglomerate at Neponset River Gorge, Milton, MA: constraints from U-Pb geochronology. Abstracts with Programs - Geological Society of America **40**(6):146.

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

Morse, E. S. 1920. On certain fossil shells in the boulder clay of Boston Basin. American Journal of Science **49**(291):157-165.

Murphy, J. B., J. D. Keppie, and R. D. Nance. 2007. What is the Acadian Orogeny? Abstracts with Programs - Geological Society of America **39**(1):69.

Newman, W. A., R. C. Berg, P. S. Rosen, and H. D. Glass. 1987. Pleistocene stratigraphy of the Boston Harbor drumlins, Boston, Massachusetts. Abstracts with Programs - Geological Society of America **19**(1):32.

Persons, W. S. IV. 2008. A field and laboratory study of the Ediacaran fossils of Hewitt's Cove: evidence of tectonic deformation and consideration of paleobiology. Pages 229-233 *in* de Wet, A. P., editor. 21st Keck research symposium in geology: short contributions. Keck Geology Consortium, Lancaster, PA. Online. http://keckgeology.org/files/pdf/symvol/21st/avalonia/persons.pdf. Accessed January 2010.

Rhodin, A. G. J. 1992. Chelonian zooarchaeology of eastern New England: turtle bone remains from Cedar Swamp and other prehistoric sites. Bulletin of the Massachusetts Archaeological Society **53**(1):21-30. Online. http://www.chelonian.org/wp-content/uploads/file/Rhodin_1992_CedarSwamp.pdf. Accessed January 2010.

Richardson, J. B. III. 1985. Prehistoric man on Martha's Vineyard. Oceanus **28**(1):35-42. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/oceanusv2801wood]

Rosen, P. S., L. Maybury, B. Brenninkmeyer, and P. Newby. 1989. Estuarine stratigraphy of Boston inner harbor: Boylston Street Fishweir site. Abstracts with Programs - Geological Society of America **21**(2):63.

Sears, J. H. 1905. The physical geography, geology, mineralogy, and paleontology of Essex County. The Essex Institute, Salem, MA. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/physicalgeograph00searuoft]

Smith, G. W. and A. D. Socci. 1986. Late Precambrian diamictites of the Boston Basin, Boston, Massachusetts. Abstracts with Programs - Geological Society of America **18**(1):66.

Thomson, K. S. 2008. The legacy of the mastodon: the golden age of fossils in America. Yale University, New Haven, CT.

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

Wu, F., R. Van der Voo, and R. J. E. Johnson. 1986. Eocambrian paleomagnetism of the Boston Basin: evidence for displaced terrane. Geophysical Research Letters **13**(13):1450-1453.

Data Sets

Boston Harbor Islands National Recreation Area Collections
1996–present. (collection records; maps; etc.). Originated by BOHA staff; status: Active.

Boston Harbor Islands National Recreation Area Paleontological Archives
1996–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Massachusetts Digital Geologic Map
1998-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by Boston College staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=MA.

Museum of Science (Boston) (formerly Boston Society of Natural History)
1996-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by MOS staff; status: Active.

Northeastern University
1996-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by NU staff; status: Active.

University of Massachusetts Amherst
1996-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by UMA staff; status: Active.

Marsh-Billings-Rockefeller National Historical Park

Marsh-Billings-Rockefeller National Historical Park (MABI) was established August 26, 1992, as Marsh-Billings National Historical Park. It was renamed as Marsh-Billings-Rockefeller National Historical Park October 21, 1998. MABI was established in recognition of the site's place in the history of conservation. The site was the birthplace of George Perkins Marsh, and the home of other figures in conservation, including Frederick Billings, who developed a managed forest and farm there, and Mary French Rockefeller and Laurance S. Rockefeller. MABI encompasses 260.24 ha (643.07 acres), 224.63 ha (555.07 acres) of which are under federal administration.

Geologic Background

MABI is located in eastern Vermont in Windsor County, abutting the town of Woodstock. It is partially bordered on its eastern end by the Ottauquechee River and tributary Barnard Brook, part of the Connecticut River drainage system. It is about 20 km (12 miles) west of Lebanon, New Hampshire, and about 32 km (20 miles) northwest of Claremont, New Hampshire. Saint-Gaudens National Historic Site (SAGA), with similar geology, is about 17 km (11 miles) southeast of MABI (see the SAGA summary in this report for more information). Structurally, the area is found on a saddle between the Chester Dome and Pomfret Dome, on the eastern flank of the upwarp of the Green Mountains (P. Thompson 2007). Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held during July 2007. The geology of MABI and SAGA was described in a geologic scoping summary by the National Park Service (2008), an internal NPS document.

The geologic history of northern New England has been a source of controversy due to the complex geology arising from several large events. New England was assembled during the Paleozoic, a relatively recent few hundred million years ago (see the appendix for a geological time scale), as part of the formation of the supercontinent Pangaea. Shortly after it was assembled it was subjected to the stresses that separated eastern North America from Africa and Europe, forming the Atlantic Ocean. These events greatly distorted the preexisting geology.

The rocks underlying MABI began as Paleozoic marine sediments that were deformed during the Acadian Orogeny (mountain building event), one of several tectonic events leading to the formation of Pangaea, but rocks in the vicinity record more ancient events. West of MABI is the Green Mountain Massif and other rocks of the Grenville Province, an area uplifted and metamorphosed by the earlier (over 1.03 Ga, or billion years old) Grenville Orogeny (Karabinos et al. 1999). Approximately 590 Ma (million years ago), continental rifting in the area began to open an ocean basin (the Iapetus Ocean), causing the Grenville Province to become what would now be the eastern margin of the North American continent. This margin persisted until approximately 510 Ma, when the local tectonic system shifted from spreading to convergence (Kim and Wunsch 2009). The North American landmass of this time is known as Laurentia, the technical term for the core of the continent; this name commonly appears in scientific publications.

The underlying geology of the Connecticut River Valley in New Hampshire and Vermont is composed of the Connecticut Valley-Gaspé Trough, a middle Paleozoic structural low sandwiched by the Shelburne Falls volcanic arc on the west and the Bronson Hill Arc on the east (Karabinos et al. 2003; Rankin et al. 2007). The Shelburne Falls Arc formed between approximately 485 and 470 Ma, and the Bronson Hill Arc was active between approximately 455 and 440 Ma; the Connecticut Valley-Gaspé Trough formed between them shortly afterward (Karabinos et al. 2003). All three reached their present positions as a result of the Taconic (or Taconian) and Acadian orogenies.

The Taconic Orogeny began during the Ordovician, during the same period that the volcanic arcs were active (Kim and Wunsch 2009). Exactly what happened during the orogeny is debated, and models with one or two subduction zones and continental collision with one or two volcanic arcs have been proposed (Karabinos et al. 2003). The net effects were that much of the Iapetus Ocean was destroyed, the ocean

basin sediments were disrupted and in some cases forced long distances to the west, and slivers of land that formed elsewhere were sutured to Laurentia (including the Shelburne Falls and Bronson Hill arcs), moving the margin of the continent east and causing the formation of a mountain range (Doolan 1996; Kim and Wunsch 2009). The Connecticut Valley-Gaspé Trough formed between the Shelburne Falls and Bronson Hill arcs during the Silurian as a result of temporary extensional forces between periods of collisions (Doolan 1996; Karabinos et al. 2003), and was the setting for the deposition of MABI's bedrock. At the time, the trough supported a seaway, and the sedimentary rocks deposited in it began as turbidites (underwater sediment avalanche units) (Naylor 1989).

Collision occurred along the margin again beginning around 375 Ma, at the onset of the Acadian Orogeny (Karabinos et al. 1999). During this event, the great forces deformed and folded the Connecticut Valley-Gaspé Trough sediments. The Acadian Orogeny was responsible for the final assembly of the various small continental blocks that make up New England (Doolan 1996). The later Alleghenian Orogeny, when the African part of Gondwana collided with North America, had most of its effects elsewhere, but the rifting that pulled Africa from North America during the Triassic and Jurassic produced faults in the vicinity (J. Thompson et al. 1993). The MABI-SAGA area of Vermont and New Hampshire then became geologically quiet, with the exception of igneous rocks that intruded approximately 122 Ma and were later exposed by erosion as nearby Mount Ascutney (Schniederman 1989; J. Thompson et al. 1993).

More recently, glacial activity during the Pleistocene (between 2.59 Ma and approximately 12,000 years ago) scoured and reworked the preexisting topography of New England. The most recent glacial advance of the area was represented by the Hudson-Champlain lobe of the Laurentide Ice Sheet (NPS 2008). It overprinted previous glacial activity and left a great quantity of loose sediments. As the ice sheet retreated, vast lakes of glacial meltwater formed in valleys that were blocked by ice and sediment dams. The largest of these in New England was Glacial Lake Hitchcock, which was present in what is now the Connecticut River Valley and adjoining tributary valleys. First appearing about 17,900 years ago in the lower valley, it extended north as the ice sheets continued retreating. The MABI area was not deglaciated until after 14,700 years ago. Glacial Lake Hitchcock then occupied the nearby section of the Connecticut River Valley and persisted until about 12,600 years ago (Benner et al. 2009). This lake was not present at MABI, but doubtless had some influence on the area given the presence of the Ottauquechee River, which would have fed into the lake. The history of Glacial Lake Hitchcock has been studied through the use of varves (annual sediment layers) that allow for a very detailed chronology of events (Ridge and Larsen 1990; Ridge et al. 1999). Humans first appeared in New England over ten thousand years ago (Curran and Dincauze 1977).

From oldest to youngest, the bedrock and surficial geology at MABI include the Waits River Formation and its Mount Toms Member (Silurian), the Standing Pond Volcanics (Silurian), the Gile Mountain formation (Devonian), Pleistocene till (unsorted glacial sediment), and Holocene peat, muck, alluvium, and river terrace, floodplain, and river deposits (DeSimone 2006; P. Thompson 2006). Most of the park is underlain by the Waits River Formation, with small parts of eastern MABI underlain by the Standing Pond Volcanics and Gile Mountain Formation (P. Thompson 2006). The Paleozoic bedrock units are not exposed at the surface at MABI at a mappable scale (DeSimone 2006), but outcrops are found throughout the park (Lautzenheiser 2002). Marl with plant remains has been recovered from Holocene deposits at MABI, and there is at least one fossil from another location in park collections. The Waits River Formation and Gile Mountain Formation are potential sources, but are metamorphosed and known for being generally unfossiliferous.

Sources of Paleontological Resources

The fossils of MABI present opportunities for education, interpretation, and continued or future scientific research in the park. A fossil fish in the museum collections (see Park Collections, below) connects the Billings or Rockefeller families to fossil resources near Fossil Butte National Monument in southwest Wyoming.

Quaternary rocks and sediments (Pleistocene-Holocene)

The Quaternary rocks and sediments of MABI are a mix of Pleistocene till and Holocene river, floodplain, and wetland deposits. The Pleistocene till is heterogeneous with grain sizes varying from silt to boulders, and can be more than 3 m (10 ft) thick. Holocene river activity at MABI left terrace deposits composed of silt- to cobble-sized grains, generally less than 5 m (15 ft) thick. Alluvial deposits, including those derived from floodplains, river bottomlands, and environments associated with river channels, are composed of silt, fine sand, and gravel. Finally, peat and other muck deposits from wetlands and swamps are also present. They are composed of clay, silt, and organic material (DeSimone 2006). With its organic composition, the peat and muck deposits are promising deposits for finding fossils at MABI.

Marl (lime-rich mudstone) associated with the Pogue at MABI is known to be fossiliferous. The Pogue is a manmade pond formed over a former upland bog by damming in 1890 (Wilke et al. 2002). Marl pieces with plant remains were collected by a seasonal ranger from the vicinity of the Pogue (K. Jones, MABI ecologist, and C. Marts, MABI resource manager, pers. comm., January and February 2010). These specimens are currently in MABI collections (MABI 4331) and include imprints of veined leaves, twigs, and grass stems (L. Anderson, MABI museum curator, pers. comm., September 2009). Fossiliferous Holocene-age marl in Vermont is best developed in lakes and ponds over the Waits River Formation, on the east side of the Green Mountains and the western border of the state. The marl is often called shell marl, as it is composed of the remains of freshwater bivalves and gastropods. It was valued as a fertilizer (Z. Thompson 1853). Marl beds are often found under peat; as a water body fills and shallows, mosses begin to encroach over it, forming peat layers. The location that would become the Pogue was noted for its rich marl and overlying peat (Hitchcock et al. 1861).

Quaternary fossils are generally uncommon in Vermont and New Hampshire (Curran and Dincauze 1977), with the exception of the area associated with Glacial Lake Hitchcock. As noted above, this lake was not present at MABI, but probably influenced the area through its connection on the Ottauquechee River. A variety of fossils are known from deposits of the lake along the Connecticut River Valley. These include remains of spores, plants (Knecht et al. 2009), snails (Ridge et al. 2009), crustaceans (Knecht et al. 2009), midges, and ostracodes, a single bone from a dace-like fish, and trace fossils from worm-like invertebrates, tadpole shrimp, and at least two types of fish, one a large fish (possibly brook trout), the other a sculpin (Benner et al. 2009). Plant fossils range from organic muck (gyttja) to leaves, twigs, and wood (Ridge et al. 1999). Plant fossils are known from postglacial ponds as well (Hollick 1931). Some terrestrial vertebrate fossils are also known from central Vermont, including large bones found in 1848 near Mount Holly, 30 km (18 miles) southwest of MABI and identified as mammoth bones by Louis Agassiz (possibly mastodon instead) (Johnson 1998).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within MABI. However, they are known to preserve fossils elsewhere, and future field investigations within the park may uncover fossils in them.

Waits River Formation (Silurian)

The Waits River Formation and the associated Gile Mountain Formation have long been controversial, with multiple interpretations of age and stratigraphy. For example, now-rejected interpretations include an Ordovician date for the two (Lyons 1955), and the Waits River Formation being younger than the Gile Mountain Formation (Murthy 1958). The confusion is in part due to the Paleozoic deformation (just finding indicators of which direction was up has been problematic), in part because the two units have similar lithologies and may be both vertically and laterally transitional with the other (Lyons 1955; Fisher and Karabinos 1980), and in part because they have poor fossil records (Hueber et al. 1990; Rankin et al. 2007). The Standing Pond Volcanics are found between the two at some locations, but these rocks are discontinuous and do not strictly follow the Waits River-Gile Mountain contact (Karabinos 1998). It is interpreted as having been erupted during the deposition of the Waits River-Gile Mountain sediments (Aleinikoff and Karabinos 1990).

The Waits River and Gile Mountain formations both include abundant schist and some marble or related rocks. They differ in that the Gile Mountain Formation has a significant proportion of quartzite (originally sandstone), and less marble (originally limestone) (Hatch et al. 1988). The two formations grade into each other over a zone measuring approximately 100 to 500 m (300 to 1,600 ft) (Fisher and Karabinos 1980), and approach each other's composition south of the MABI-SAGA area (Lyons 1955). It has even been suggested that the Waits River Formation represents in part a more western facies (broadly, a specific depositional environment) of the Gile Mountain Formation (Rankin et al. 2007). The Waits River Formation is interpreted as having been deposited by turbidites (Hueber et al. 1990), with periodic volcanic events (Walsh and Armstrong 1997) like the one that formed the Standing Pond Volcanics. Sediments came from the Bronson Hill Arc to the east (Rankin et al. 2007).

The Waits River Formation of MABI and its vicinity is largely composed of schist, although there is a small proportion of metamorphic rock enriched in calcium silicate minerals (P. Thompson 2006). Schists are usually metamorphosed clastic sedimentary rocks (sedimentary rocks formed of smaller rock fragments), while calc-silicate rocks usually are metamorphosed impure carbonate rocks like impure limestone. The Mount Toms Member has a much smaller proportion of calc-silicate rocks (P. Thompson 2006). The calc-silicate rocks of the area include sandy marble (Becker 2007). Interbedded schist and punky-weathering sandy marble are characteristic of Waits River Formation rocks in the Woodstock area (P. Thompson 2007). The metamorphic grade of the area is garnet to kyanite (Lyons 1955), which indicates intermediate- to high-grade metamorphic activity. The thickness of the unit is variable; it is known to be 760 m (2,500 ft) thick in the Woodstock quadrangle (Lyons 1955). MABI outcrops of the Waits River Formation can be found throughout the park, particularly in the southern section. Two large outcrops are present on the east slope of Mount Tom and on the eastern face of the West Ridge (Lautzenheiser 2002).

A Silurian date for the Waits River Formation and Devonian date for the Gile Mountain Formation are currently accepted (Walsh et al. 2009); more precise dating has been elusive. The Waits River Formation is thought to date to the middle or late Silurian, because the overlying Standing Pond Volcanics are cut by an igneous dike dated to 423 ± 4 Ma (Aleinikoff and Karabinos 1990). This has implications for the deposition of the Waits River Formation and Gile Mountain Formation, which has been dated to the late Early Devonian on the basis of plant fossils found in the correlative Compton Formation of Quebec (between 407 and 398 Ma; Hueber et al. 1990). Barring some error, such as an incorrect date, or mistaken Gile Mountain-Compton Formation correlation (Moench et al. 1995), or the presence of a significant heretofore-undiscovered unconformity or unconformities between or within the Waits River and Gile Mountain formations (Aleinikoff and Karabinos 1990; Hueber et al. 1990), the dates imply a long period of continuous deposition. This is inconsistent with some assessments of the deposition (Aleinikoff and Karabinos 1990), but Hueber et al. (1990) note that the time between the individual turbidity currents is unknown.

The Waits River Formation is sparsely fossiliferous, and no fossils have been reported from it in the MABI area (Hueber et al. 1990). Doll (1984) mentioned a cephalopod from the Waits River-Barton River Formation, which was found at Clyde Dam near Newport, Vermont, 145 km (90 miles) north-northeast of MABI (the Barton River Formation is sometimes used for part of the Waits River Formation [Lyons 1955]). Doll (1984) and Bothner and Finney (1986) also reported graptolites (a type of extinct free-floating colonial animal) from the unit, but reports of graptolites in Waits River and Gile Mountain Formation rocks have been discounted by Hueber et al. (1990) as a combination of pseudofossils (objects or features that resemble but aren't fossils) and plant fossil fragments. A report of Ordovician cup corals from the Montpelier area 70 km (45 miles) north of MABI (Cady 1950) is also controversial, and could be another example of pseudofossils (Hueber et al. 1990; L. Becker, Vermont State Geologist, pers. comm., October 2009). Fossils from the Waits River Formation aside from the cephalopod include microfossils (Dennis 1956), plant fragments pertaining to trimerophytes (a group of early vascular plants) and unidentified plants, and crinoid and other echinoderm fragments (Hueber et al. 1990). As with Doll's cephalopod, Hueber et al. (1990)'s localities are distant from MABI. They include Berlin Corners,

Vermont, 65 km (40 miles) north of MABI; Montpelier, Vermont; and Woodbury, Vermont, 90 km (55 miles) to the north.

Gile Mountain Formation (Devonian)

The Gile Mountain Formation, like the Waits River Formation, is a metamorphosed sedimentary unit. As noted, the two are similar in composition, with the Gile Mountain Formation having more quartzite and less marble (Hatch et al. 1988). It is transitional with the older Waits River Formation (Fisher and Karabinos 1980) and is also interpreted as representing turbidites (Hueber et al. 1990). The subunit Meetinghouse Slate Member, mostly composed of dark pelites (metamorphosed mudstones/shales) is found to the east (Rankin et al. 2007). As per the general difficulties surrounding these units, the Meetinghouse Slate Member has been interpreted as at the base of the Gile Mountain Formation (the older interpretation, still in use; Rankin et al. 2007), or at the top of the unit (Hatch 1988; Hueber et al. 1990). The Gile Mountain Formation of the MABI area is composed of schist, quartzite, and some calc-silicate rocks (P. Thompson 2006). It is not exposed at the surface at MABI (DeSimone 2006).

The age of the Gile Mountain Formation is a matter of some controversy, as discussed above. It has been dated to the Emsian stage of the Early Devonian (407 to 398 Ma) based on correlation with the Compton Formation of Quebec, which has plant fossils of that age (Hueber et al. 1990).

As with the Waits River Formation, fossils are extremely rare in the Gile Mountain Formation. Doll (1984) reported that corals, trilobites, and crinoids were present in a unit he identified as the Westmore-Giles Mountain Formation of the Westmore area, 130 km (80 miles) north-northeast of MABI (the Westmore Formation is an old name for a subdivision of the Waits River Formation thought to be equivalent to the Gile Mountain Formation [Lyons 1955; Murthy 1958]). Hueber et al. (1990) reported remains of *Prototaxites* (a giant fungus) from a site on Indian Stream, far northern New Hampshire, 175 km (110 miles) northeast of MABI. No fossils have been reported from this unit at MABI.

Park Collections

The museum collections of MABI have several specimens that may be paleontological in nature, with two pieces of interest that were collected within MABI and one specimen collected from another NPS unit. Mentioned earlier in the Quaternary section, MABI 4331 is comprised of two pieces of marl with imprints of veined leaves, twigs, and grass stems (L. Anderson, pers. comm., September 2009), collected from the Pogue (K. Jones, pers. comm., January 2010). MABI 3940 is a specimen of the perch-like fish *Priscacara liops* in a piece of limestone from the Eocene-age Green River Formation of Wyoming (L. Anderson, pers. comm., September 2009) (see cover of report). According to Arvid Aase (Fossil Butte National Monument museum specialist, pers. comm. to MABI, October 2008), the rock itself is consistent with the "18 Inch Layer" at Fossil Lake (Fossil Butte National Monument), and the style of preparation indicates the fossil was prepared sometime between the late 1800s and early 1900s. It was purchased for an unknown price. Janet Houghton (MABI museum curator, pers. comm. to A. Aase, October 2008) reports that the specimen was most likely obtained by a member of the Billings or Rockefeller families.

Additionally, there are several specimens in the collections that may be fossil or recent. These include pieces of pine driftwood (MABI 2498 and 2499), several bivalve shells (MABI 8287, 8288, 8289, and 8290) and corals (MABI 8411 and 8412) from Laurance Rockefeller's collections, and bivalve shells (MABI 8773, 8774, 8775, and 8776) from Mary Rockefeller's collections. There is little provenance information for most of these specimens, but the coral pieces may have come from Virgin Islands National Park (L. Anderson, pers. comm., September 2009). There is a possibility that at least some of these specimens are Pleistocene to early Holocene in age, although given that personally-collected seashells in particular are often pristine specimens, it is more likely that the specimens are only tens to hundreds of years old.

Cultural Resource Contexts

At this time, the fossil resources at MABI as described above also have cultural resource contexts, as they were obtained elsewhere and brought to what is now the park by people (with the exception of the marl pieces of MABI 4331). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

In addition to surficial outcrops, many structures at MABI use local stone, either quarried on-site or from nearby properties once owned by Frederick Billings. These include retaining walls and pasture field walls, carriage road bridges, culverts, building foundations and pillars, garden elements, and property markers (K. Jones, pers. comm., January 2010). While not known to be fossiliferous, these provide additional architectural "outcrops" of local geology, tying together natural history and human history.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division coordinated a geologic resource inventory scoping session for MABI and SAGA during July 2007 (NPS 2008). The participants of the scoping meetings developed a series of recommendations for future work that should be consulted.
- Documented paleontological resources at MABI to date consist of a fossil fish in park collections, with other specimens in the collections that may be fossils. It would be of interest to establish the provenance of the marl specimens.
- Park staff should be encouraged to observe exposed sedimentary material for fossil material while conducting their usual duties. Staff should photodocument and potentially 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. 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).
- Future archeological excavations or infrastructure developments should consider scheduling site monitoring by a trained paleontologist in order to document and protect fossil resources.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

Literature Cited

Aleinikoff, J. N. and P. Karabinos. 1990. Zircon U-Pb data for the Moretown and Barnard volcanic members of the Missisquoi Formation and a dike cutting the Standing Pond Volcanics, southeastern Vermont. Pages D1-D10 *in* Slack, J. F., editor. Summary results of the Glens Falls CUSMAP project, New York, Vermont, and New Hampshire. U.S. Geological Survey, Reston, VA. Bulletin 1887. Online. http://pubs.er.usgs.gov/usgspubs/b/b1887. Accessed October 2009.

Becker, L. R., D. De Simone, P. J. Thompson, and M. H. Gale. 2007. Groundwater resources of Woodstock, Vermont. Abstracts with Programs - Geological Society of America **39**(1):90.

Benner, J. S., J. C. Ridge, and R. J. Knecht. 2009. Timing of post-glacial reinhabitation and ecological development of two New England, USA, drainages based on trace fossil evidence. Palaeogeography, Palaeoclimatology, Palaeoecology **272**(3-4):212-231.

Bothner, W. A. and S. C. Finney. 1986. Ordovician graptolites in central Vermont: Richardson revived. Abstracts with Programs - Geological Society of America **18**(6):548.

Cady, W. M. 1950. Fossil cup corals from the metamorphic rocks of central Vermont. American Journal of Science **248**(7):488-497.

Curran, M. L. and D. F. Dincauze. 1977. Paleoindians and paleo-lakes: new data from the Connecticut drainage. Annals of the New York Academy of Sciences **288**:333-348.

Dennis, J. G. 1956. The geology of the Lyndonville area, Vermont. Vermont Geological Survey, Montpelier, VT. Bulletin 8.

DeSimone, D. 2006. Surficial geologic map of Woodstock, Vermont. Digital data by M. Gale. Vermont Geological Survey, Montpelier, VT. Open-File Report VG06-5. Scale 1:24,000.

Doll, C. G. 1984. Fossils from the metamorphic rocks of the Silurian-Devonian Magog Belt in northern Vermont. Vermont Geology 3.

Doolan, B. 1996. The geology of Vermont. Rocks & Minerals **71**(4):218-225. Online. http://www.anr.state.vt.us/dec/geo/pdfdocs/VermontGeoWebDoolan.pdf. Accessed February 2010.

Fisher, G. W. and P. Karabinos. 1980. Stratigraphic sequence of the Gile Mountain and Waits River formations near Royalton, Vermont. Geological Society of America Bulletin **91**(5):282-286.

Hatch, N. L. Jr. 1988. Some revisions to the stratigraphy and structure of the Connecticut Valley trough, eastern Vermont. American Journal of Science **288**(10):1041-1059.

Hatch, N. L. Jr., P. Robinson, and R. S. Stanley. 1988. Stratigraphy of the Connecticut Valley Belt. Pages B1-B34 *in* Hatch, N. L. Jr., editor. The bedrock geology of Massachusetts. U.S. Geological Survey, Reston, VA. Professional Paper 1366 A-D. Online. http://pubs.er.usgs.gov/usgspubs/pp/pp1366AD. Accessed October 2009.

Hitchcock, E., E. Hitchcock Jr., A. D. Hager, and C. H. Hitchcock. 1861. Report on the geology of Vermont: descriptive, theoretical, economical, and scenographical; Volume I. State of Vermont, Proctorville, VT. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/reportongeologyo00vermrich]

Hollick, C. A. 1931. Plant remains from a Pleistocene lake deposit in the upper Connecticut River Valley. Brittonia **1**(1):35-55.

Hueber, F. M., W. A. Bothner, N. L. Hatch Jr., S. C. Finney, and J. N. Aleinikoff. 1990. Devonian plants from southern Quebec and northern New Hampshire and the age of the Connecticut Valley trough. American Journal of Science **290**(4):360-395.

Johnson, C. W. 1998. The nature of Vermont: introduction and guide to a New England environment. University Press of New England, Hanover, NH.

Karabinos, P. 1998. Tectonic and stratigraphic development of the Connecticut Valley Trough in the New England Appalachians. Abstracts with Programs - Geological Society of America **30**(7):191.

Karabinos, P., S. D. Samson, J. C. Hepburn, and H. M Stoll. 1998. Taconian Orogeny in the New England Appalachians: collision between Laurentia and the Shelburne Falls Arc. Geology **26**(3):215-218.

Karabinos, P., J. N. Aleinikoff, and C. M. Fanning. 1999. Distinguishing Grenvillian basement from pre-Taconian cover rocks in the Northern Appalachians. American Journal of Science **299**(6):502-515.

Karabinos, P., H. M. Stoll, and J. C. Hepburn. 2003. The Shelburne Falls arc – lost arc of the Taconic orogeny. Pages B3-1-B3-17 *in* Brady, J. and J. Chaney, editors. New England Intercollegiate Geologic Conference, Amherst, MA.

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* Lucas, S. G., 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, NM. Bulletin 34. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed September 2009.

Kim, J. and D. Wunsch. 2009. Physiography and bedrock geology. Pages 5-11*in* Brown, R. A., editor. Where the great river rises: an atlas of the Connecticut River watershed in Vermont and New Hampshire. Dartmouth College Press, Lebanon, NH.

Knecht, R. J., J. S. Benner, D. C. Rogers, and J. C. Ridge. 2009. *Surculichnus bifurcauda* n. igen., n. isp., a trace fossil from late Pleistocene glaciolacustrine varves of the Connecticut River valley, USA, attributed to notostracan crustaceans based on neoichnological experimentation. Palaeogeography, Palaeoclimatology, Palaeoecology **272**(3-4):232-239.

Lautzenheiser, T. 2002. Marsh-Billings-Rockefeller National Historical Park, Woodstock, Vermont: natural community report. Unpublished National Park Service Report. On file at MABI.

Lyons, J. B. 1955. Geology of the Hanover Quadrangle, New Hampshire-Vermont. Geological Society of America Bulletin **66**(1):105-145.

Moench, R. H., G. M. Boone, W. A. Bothner, E. L. Boudette, N. L. Hatch Jr., A. M. Hussey III, R. G. Marvinney, and J. N. Aleinikoff. 1995. Geologic map of the Sherbrooke-Lewiston area, Maine, New Hampshire, and Vermont, United States, and Quebec, Canada. U.S. Geological Survey, Reston, VA. Miscellaneous Investigations Series Map 1898-D. Scale 1:250,000.

Murthy, V. R. 1958. A revision of the lower Paleozoic stratigraphy in eastern Vermont. Journal of Geology **66**(3):276-287.

National Park Service, Geologic Resources Division. 2008. Geologic resource evaluation scoping summary: Marsh-Billings-Rockefeller National Historical Park & Saint-Gaudens National Historic Site. National Park Service, Geologic Resources Division, Denver, CO. Online. http://www.nature.nps.gov/geology/inventory/publications/s_summaries/MABI-SAGA_gre_scoping_summary_2008-0924.pdf. Accessed September 2009.

Naylor, R. S. 1989. Role of the Connecticut Valley Gaspé Trough in the Acadian Orogeny. Abstracts with Programs - Geological Society of America **21**(2):54.

Nicholson, S.W., C. L. Dicken, J. D. Horton, M. P. Foose, J. A. L. Mueller, and R. Hon. 2006. Preliminary integrated geologic map databases for the United States: Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, Rhode Island, and Vermont. U.S. Geological Survey, Reston, VA. Open-File Report 2006-1272. Online. http://pubs.usgs.gov/of/2006/1272/. Accessed September 2009.

Rankin, D. W., R. A. Coish, R. D. Tucker, Z. X. Peng, S. A. Wilson, and A. A. Rouff. 2007. Silurian extension in the upper Connecticut Valley, United States and the origin of middle Paleozoic basins in the Quebec Embayment. American Journal of Science **307**(1):216-264.

Ridge, J. C. and F. D. Larsen. 1990. Re-evaluation of Antevs' New England varve chronology and new radiocarbon dates of sediments from glacial Lake Hitchcock. Geological Society of America Bulletin **102**(7):889-899.

Ridge, J. C., M. R. Besonen, M. Brochu, S. L. Brown, J. W. Callahan, G. J. Cook, R. S. Nicholson, and N. J. Toll. 1999. Varve, paleomagnetic, and ^{14}C chronologies for late Pleistocene events in New Hampshire and Vermont (U.S.A.). Geographie Physique et Quaternaire **53**(1):79-107.

Ridge, J. C., C. C. Beck, E. B. Voytek, R. L. Bayless, and J. L. Dean. 2009. Calibration of a unified New England varve chronology: deglaciation rates and moraine building in the Connecticut Valley of New Hampshire and Vermont. Abstracts with Programs - Geological Society of America **41**(3):36.

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

Schneiderman, J. S. 1989. The Ascutney Mountain Breccia: field and petrologic evidence for an overlapping relationship between Vermont sequence and New Hampshire sequence rocks. American Journal of Science **289**(6):771-811.

Thompson, J. B. Jr., J. L. Rosenfeld, and C. P. Chamberlain. 1993. Sequence and correlation of tectonic and metamorphic events in southeastern Vermont. Pages B.1-B.26 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(1).

Thompson, P. J. 2006. Bedrock geologic map of Woodstock, Vermont. Digital data by M. Gale and G. Farrugia. Vermont Geological Survey, Montpelier, VT. Open-File Report VG06-4. Scale 1:24,000.

Thompson, P. J. 2007. Folded east-verging Woodstock Nappe (Quaboagian?) deformed by domes, east-central Vermont. Abstracts with Programs - Geological Society of America **39**(1):51.

Thompson, Z. 1853. Appendix to the history of Vermont, natural, civil and statistical. Published by the author, Burlington, VT. [full text available on Google Books]

Walsh, G. J. and T. R. Armstrong. 1997. Lithostratigraphic relationships in the Connecticut Valley Trough, southeastern Vermont. Abstracts with Programs - Geological Society of America **29**(1):87.

Walsh, G. J., J. Kim, and M. H. Gale. 2009. Bedrock geology of the Montpelier area, central Vermont. Annual Meeting - New England Intercollegiate Geological Conference 101. Trip C4.

Wilke, S., L. Morrissey, J. T. Morrissey, and J. Morrissey. 2002. Cultural landscape report for the forest at Marsh-Billings-Rockefeller National Historical Park: site history and existing conditions. National Park Service, Woodstock, VT.

Additional References

Benner, J. S., J. C. Ridge, and N. K. Taft. 2008. Late Pleistocene freshwater fish (Cottidae) trackways from New England (USA) glacial lakes and a reinterpretation of the ichnogenus *Broomichnium* Kuhn. Palaeogeography, Palaeoclimatology, Palaeoecology **260**(3-4):375-388.

Curran, K. and D. F. Dincauze. 1999. Archaeological chronometry for Connecticut River valley surfaces. Abstracts with Programs - Geological Society of America **31**(2):A-11.

Hatch, N. L. Jr. 1989. Day 3: The Connecticut Valley Trough. Pages 39-43 *in* Lyons, J. B., W. A. Bothner, B. L. Doolan, N. L. Hatch Jr., R. H. Moench, and R. S. Stanley, leaders. Metamorphism and tectonics of eastern and central North America: Volume 2, a transect through the New England Appalachians. Hanshaw, P. M., editor. Field trips for the 28th International Geological Congress. American Geophysical Union, Washington, DC.

Hatch, N. L. Jr. 1991. Revisions to the stratigraphy of the Connecticut Valley trough, eastern Vermont. Pages 5-7 *in* Stratigraphic notes, 1989-90. U.S. Geological Survey, Reston, VA. Bulletin 1935. Online. http://pubs.er.usgs.gov/usgspubs/b/b1935. Accessed October 2009.

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°. Carnegie Institution of Washington Publication 322. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/pleistoceneofnor00hayouoft]

Karabinos, P. 2006. Accretion of northern Appalachian arc terranes. Abstracts with Programs - Geological Society of America **38**(3):20.

Karabinos, P. and J. C. Hepburn. 2006. Silurian subduction under the Laurentian margin in the New England Appalachians. Abstracts with Programs - Geological Society of America **38**(2):32-33.

Koteff, C., J. R. Stone, F. D. Larsen, and J. H. Hartshorn. 1987. Glacial Lake Hitchcock and postglacial uplift. U.S. Geological Survey, Reston, VA. Open-File Report 87-329. Online. http://pubs.er.usgs.gov/usgspubs/ofr/ofr87329. Accessed October 2009.

Larsen, F. D. 1987. Glacial Lake Hitchcock in the valleys of the White and Ottauquechee rivers, east-central Vermont. Pages 29-52 *in* Westerman, D. S., editor. Guidebook for field trips in Vermont: Volume 2. Norwich University, Northfield, VT.

Levin, H. L. 1999. The Earth through time (6th edition). Saunders College Publishing, Fort Worth, TX.

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

Ratcliffe, N. M., J. N. Aleinikoff, T. R. Armstrong, G. J. Walsh, and W. E. Hames. 2001. Intrusive relations and isotopic ages of Devonian granites in southern and central Vermont: evidence for a prolonged Acadian Orogeny and partitioning of compressional strain. Abstracts with Programs - Geological Society of America **33**(6):81.

Rittenour, T. M., J. Brigham-Grette, and M. E. Mann. 2000. El Nino-like climate teleconnections in New England during the late Pleistocene. Science **288**(5468):1039-1042.

Stone, B. D. and J. R. Stone. 2009. A deep glacial varve record from the Hadley Basin, Glacial Lake Hitchcock, Sunderland, Massachusetts. Abstracts with Programs - Geological Society of America **41**(3):36.

Thorson, R. M. and C. A. Schile. 1995. Deglacial eolian regimes in New England. Geological Society of America Bulletin **107**(7):751-761.

Walsh, G. J., T. R. Armstrong, and N. M. Ratcliffe. 1996. Digital bedrock geologic map of the Vermont part of the 7.5 X 15 minute Mount Ascutney and Springfield quadrangles, Vermont. U.S. Geological Survey, Reston, VA. Open-File Report 96-733-A. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_18694.htm. Accessed October 2009.

Westerman, D. S. 2007. The tectonic origins of Devonian magmatism in northeastern Vermont: a speculative model. Abstracts with Programs - Geological Society of America **39**(1):53.

Data Sets

Marsh-Billings-Rockefeller National Historical Park Paleontological Archives
1992–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Marsh-Billings-Rockefeller National Historical Park Collections
1992–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by MABI staff; status: Active.

Marsh-Billings-Rockefeller National Historical Park Digital Geologic Map
2008-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online.
http://science.nature.nps.gov/nrdata/datastore.cfm?ID=45850.

Vermont Digital Geologic Map
2006-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by U.S. Geological Survey and Vermont Geological Survey staff; status: Active. Online.
http://tin.er.usgs.gov/geology/state/state.php?state=VT.

Minute Man National Historical Park

Minute Man National Historical Park (MIMA) includes lands associated with the American Revolution battles of Lexington and Concord. These battles, which occurred April 19, 1775, were the setting for the "shot heard 'round the world," historically, the beginning of the war. Among the sites and monuments within MIMA boundaries are sections of Battle Road, Minute Man Statue, North Bridge, and The Wayside–a restored house that was at times home to the families of Louisa May Alcott, Nathaniel Hawthorne, and children's author Margaret Sidney. MIMA was designated as a national historic site April 14, 1959, and redesignated September 21, 1959. Its boundaries changed October 24, 1992 and March 30, 2009. It encompasses 392. 88 ha (970.83 acres), 321.47 ha (794.37 acres) of which are under federal administration.

Lowell National Historical Park (LOWE) is not officially included in the Northeast Temperate Network, but is within the network's geographic area. Although its geologic history includes a different underlying crustal block than at MIMA, it is briefly mentioned here because its fossil resources would be similar to what might be present at MIMA. LOWE is located within the town of Lowell in northeastern Massachusetts, 21 km (13 miles) north of Concord. It was authorized June 5, 1978, to commemorate and preserve cultural resources related to the Industrial Revolution. It encompasses 57.20 ha (141.34 acres), 12.74 ha (31.49 acres) of which are under federal administration.

Geologic Background

MIMA is located between Concord and Lexington, Massachusetts, in east-central Middlesex County. Central Boston is 18 km (11 miles) southeast of Lexington and 26 km (16 miles) southeast of Concord. MIMA is divided into three parcels. The easternmost, North Bridge Unit, is north of Concord, along both sides of the Concord River just northwest of the confluence where the Assabet River and Sudbury River join to form the Concord River. Southeast of the North Bridge parcel is the small Wayside unit. The bulk of the park's acreage is east and southeast of The Wayside, along Battle Road–the Battle Road unit. The Concord-Lexington area is dominated by glacial features, including former glacial lake beds, meltwater deltas, drumlins, and kettle ponds (Thornberry-Ehrlich 2008). Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held for MIMA during July 2007, which resulted in a geologic scoping summary (Thornberry-Ehrlich 2008); this is an internal NPS document. Herbster (2005) also has a useful summary of the park's geology.

Most of New England is made up of exotic accreted terranes, which are blocks of crust that originated somewhere other than their present location and are demonstrably different from surrounding rocks. The timing of assembly and the origins of the various terranes are heavily debated (Skehan 2001; Wintsch et al. 1993, 2007). MIMA overlies the boundary between two such terranes. The bulk of MIMA is in the Nashoba Terrane, whereas its eastern extreme is in the Avalon Terrane (Zen et al. 1983; names after Thornberry-Ehrlich 2008). The Avalon Terrane is known under several other names, including the Milford-Dedham Zone (Kaye 1982; Zen et al. 1983; Hatch et al. 1984; Goldsmith and Weed 1991) and the Boston-Avalon Terrane (Hepburn et al. 1987, 1993). To be consistent with the MIMA geologic scoping summary (Thornberry-Ehrlich 2008), Avalon will be used here. The Bloody Bluff Fault, named for the Bloody Bluff of American Revolution fame at MIMA, is the border between the Nashoba and Avalon terranes. The fault is well-exposed in MIMA. Geologists surmise that the Avalon Terrane slid under the Nashoba Terrane while also moving north along this fault (Thornberry-Ehrlich 2008) as the two collided during the Paleozoic (see the appendix for a geological time scale) (Skehan 2001). The fault zone traces a much older zone of crustal disturbance (the Burlington Mylonite Zone) that developed at approximately 610 Ma (million years ago) when the Avalon Terrane was overriding another fragment of the Earth's crust (Skehan 2001). LOWE is also near a terrane boundary, between the Nashoba Terrane and the Merrimack Terrane to the west (Zen et al. 1983). The Nashoba-Merrimack terrane boundary is the Clinton-Newbury fault zone (Hepburn et al. 1987).

Each terrane has its own distinct history and geology. The Avalon Terrane, for example, is interpreted as a late Proterozoic continental volcanic arc (Hepburn et al. 1993). The Nashoba Terrane is thought to be a heavily deformed and metamorphosed late Proterozoic or early Paleozoic volcanic arc (Hepburn et al. 1993; Kay et al. 2009), possibly incorporating fragments of older continental crust. It formed by approximately 500 Ma (Kay et al. 2009). The Merrimack Terrane is thought to have formed in a back-arc basin (Wintsch et al. 2007). A back-arc basin forms by crustal extension that occurs within an overriding plate at a subduction zone (the basin is thus "behind" the volcanic arc that forms from magma produced over a subducting plate). The Avalon Terrane separated from the landmass to which it was originally attached roughly 550 Ma. One interpretation of the geologic events that followed the detachment is that the Avalon Terrane was part of a larger continental fragment that split into multiple slivers, including the Nashoba and Merrimack terranes as well. These slivers then periodically collided with each other on their way to the proto-North American continent called Laurentia, where they accreted onto what is now the east coast by approximately 370 Ma (Rast and Skehan 1990; Skehan 2001). Other authors reject this interpretation; Acaster and Bickford (1999), for example, postulate that the Merrimack Terrane formed as an oceanic trough west of the incoming Nashoba Terrane, which was then a volcanic arc west of the Avalon Terrane. After the three terranes had collided with North America, they were further displaced by the subsequent Late Paleozoic collision with Africa in what is called the Alleghenian Orogeny, the last great mountain building event of the Appalachians (Acaster and Bickford 1999).

Regardless of how they formed and arrived, by some point in the Late Paleozoic the Merrimack, Nashoba, and Avalon terranes had collided with Laurentia during the larger collisional events that resulted in the assembly of the supercontinent Pangaea (Levin 1999; Skehan 2001). Multiple episodes of deformation, including folding and faulting, occurred during the plate collisions and accompanying orogenies (mountain-building events) of the Paleozoic (Kaye 1982; Hepburn et al. 1993). Igneous intrusions commonly accompanied these collisions (Goldsmith and Weed 1991; Acaster and Bickford 1999; Skehan 2001). Pangaea then broke up during the Mesozoic, with rifting between northeastern North America and western Africa during the Late Triassic and Early Jurassic (Levin 1999). The geologic history of eastern Massachusetts has been relatively quiet since Pangaea broke up, although there have been some large earthquakes, such as those of 1727 and 1755 (Brankman and Braise 2008).

The MIMA area was greatly affected by Pleistocene glaciation (between 2.59 Ma and approximately 12,000 years ago). During the most recent glaciation, the Narraganset Bay-Buzzards Bay ice lobe advanced over the area and then retreated. As it retreated, its impounded meltwater formed a pair of glacial lakes (Skehan 2001). The first was Glacial Lake Sudbury, formed south of MIMA. It stopped growing when its deltas built up on the north end, blocking incoming glacial meltwater (Koteff 1963). Just south of MIMA, Walden Pond, made famous by Henry David Thoreau's writings, is a kettle lake that formed approximately 15,000 years ago from a block of ice trapped within Glacial Lake Sudbury's basin (Colman and Friesz 2001). The retreating glacier's meltwater pooled to the north after Glacial Lake Sudbury became inaccessible, forming Glacial Lake Concord, which covered most of MIMA (Koteff 1963). The lake's levels were relatively stable over two periods, when it was 56 m (185 ft) deep and 44 m (145 ft) deep (Thornberry-Ehrlich 2008).

After the ice sheets and glacial lakes had disappeared, the periglacial climate was still cold and harsh (Thorson and McBride 1988; Ashley and Stone 1995; Ashley et al. 1999). Dry conditions persisted until approximately 9,500 years ago (Shuman et al. 2001). Humans first appeared in the area during the harsher climatic conditions. They were present in southern New York over 12,500 years ago (Curran and Dincauze 1977), and had MIMA in the Concord River drainage by at least 10,000 years ago (Ritchie et al. 1990). The combined Concord/Sudbury/Assabet river drainage was an attractive area for prehistoric settlement (Herbster 2005).

From oldest to youngest, the bedrock geology of MIMA consists of: unnamed Proterozoic intrusive rocks, and metamorphosed volcanic and sedimentary rocks (also possibly including some Ordovician-Silurian and Devonian rocks; Hepburn et al. 1993) from the Avalon Terrane; and the Shawsheen Gneiss (Proterozoic or early Paleozoic), metamorphosed volcanic rocks of the Marlboro Formation (Cambrian

or Ordovician), the Andover Granite (Ordovician-Silurian or Devonian), the Sharpners Pond Diorite (Silurian), undifferentiated Straw Hollow Diorite and Assabet Diorite (Devonian), and unnamed Silurian granite and granodiorite, all from the Nashoba Terrane (Zen et al. 1983, with dating after Acaster and Bickford [1999] and Skehan [2001]). The ages of some of these geologic units are uncertain, particularly the Marlboro Formation, which in recent years has been dated to between 540 and 515 Ma (Skehan 2001), and 500 and 473 Ma (Acaster and Bickford 1999). Another temporally complicated unit is the Andover Granite, which forms most of the bedrock of MIMA. It formed over multiple phases of intrusions, and its rocks have been dated to 450 Ma, 412 Ma (Skehan 2001), and 360 Ma (Acaster and Bickford 1999). None of these rock units have been reported to include fossils, which is not surprising given that most fall into one or more of the following categories: the wrong types of rocks to have fossils; rocks that have been heavily metamorphosed and/or deformed; and rocks that formed before the evolution of organisms with hard body parts. Similarly, LOWE's bedrock consists of rocks that are unlikely to be fossiliferous: metamorphosed sedimentary rocks of the Silurian-age Berwick Formation (Merrimack Terrane), and the Tadmuck Brook Schist of uncertain age (Nashoba Terrane) (Zen et al. 1983).

The surficial geologic units of MIMA includes artificial fill, postglacial floodplain and swamp deposits, coarse- and fine-stratified deposits from glacial meltwater, and thin till, with some bedrock exposures (two large areas with outcrops are in the Battle Road unit, including Fiske Hill) (J. Stone and B. Stone 2006). It is not known if fossils are present within MIMA, although as Thornberry-Ehrlich (2008) notes, they are always possible in glacial deposits. Additionally, postglacial swamp deposits such as those of the North Bridge and Battle Road units include peat, which is known to be fossiliferous elsewhere.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic unit within MIMA. However, it has produced fossils elsewhere, and future investigations within the park may uncover fossils in it.

Quaternary rocks and sediments (Pleistocene-Holocene)

The surficial geology of MIMA includes a wide variety of glacial and postglacial deposits, ranging from glacial till, to deposits associated with glacial lakes (glacio-lacustrine), to glacial outwash, to more recent swamp and river deposits. These deposits are spread throughout the park's units, although the river deposits are concentrated in the North Bridge unit along the Concord River, and most of the till is in the Battle Road unit. Grain size ranges from clay to boulders (J. Stone and B. Stone 2006). Fossils may be found in any of these deposits, although the most likely source is swamp deposits, which preserve pollen and other plant fossils. Such fossils are very useful for paleoecological and paleoclimatological reconstructions of the past 15,000 years since the glaciers retreated.

Fossiliferous deposits at localities with comparable geologic histories and settings to those at MIMA are found throughout Massachusetts and neighboring states. Although better known for marine and estuarine fossils, Boston has a number of terrestrial localities from former lakes and swamps. Peat deposits at these places can be richly fossiliferous (Kaye 1982). Postglacial plants, including swamp plants, deciduous leaves, and tree stumps, are known from several localities (Shimer 1918), and beetle fragments are known from peat at Cambridge (Argus and Davis 1962). A diverse estuarine-influenced peat marsh assemblage is known from the Boylston Street Fishweir, including foraminifera (protists that form "shells," usually out of carbonate), dinoflagellates (a type of plankton that move using whip-like flagella) (as *Hystrichospera*; Wilson 1949), the euglenid *Trachelomonas* (another type of flagellate plankton), diatoms (algae with silica "shells"), spores, pollen, seeds, fruits, grass fragments, sedges, roots, other plant tissues, fungi, sponge spicules, insect chitin, cladocerans (water fleas), and fish and bird bones (Johnson 1942a, 1942b; Barghoorn 1949; Wilson 1949). This assemblage dates to just after 5,630 radiocarbon years before present (Rosen et al. 1993) (note that radiocarbon dates are not the same as calendar dates, and that radiocarbon years require calibration to yield calendar years. Uncalibrated radiocarbon dates in publications are often denoted with "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. Therefore, dates that are not labeled with "calendar years" or something similar should be assumed

to be uncalibrated radiocarbon dates). See the Boston Harbor Islands National Recreation Area (BOHA) summary for a detailed discussion of Boston's Quaternary fossils.

Similar finds from swamp, pond, and lake deposits have been reported from a number of locations within approximately 100 km (60 miles) of MIMA. These include: neighboring Walden Pond (Russell et al. 1993; Winkler 1993; Köster et al. 2004, 2005); Tom Swamp, 72 km (45 miles) west-northwest of Concord (Davis 1958; Bender et al. 1982; Gaudreau 1982, 1986; Steventon and Kutzbach 1983, 1984); Winneconnet Pond, 55 km (34 miles) south-southeast of Lexington (Suter 1985); Titicut Swamp, 61 km (38 miles) south-southeast of Lexington (Bender et al. 1981; Nelson 1984; Russell et al. 1993); Williams Street Bog, 66 km (41 miles) south-southeast of Lexington (Davis 1960, 1961); Mashapaug Pond, Rhode Island, 77 km (48 miles) south of Concord (Bernabo 1977; Russell et al. 1993); Gould's Bog, 71 km (44 miles) west-northwest of Concord (Davis 1958); Makepeace Cedar Swamp, 72 km (45 miles) southeast of Lexington (Newby et al. 1994, 1995, 2000); Pleasant Street Bog, 76 km (47 miles) west-northwest of Concord (Davis 1958); Crooked Pond, 84 km (52 miles) southeast of Lexington (Newby et al. 1995; Shuman et al. 2001); and near Epsom, New Hampshire, 97 km (60 miles) north of Lexington (Julian et al. 2009). Most of these are pollen sites, although some, like Walden Pond (Köster et al. 2004, 2005) and the Epsom site (Julian et al. 2009) also have published diatom records. Diatoms, pollen, other microfossils, and gyttja (organic muck) are known from Walden Pond, although the fossils analyzed so far only date back roughly 1,600 years at most (Russell et al. 1993; Winkler 1993; Köster et al. 2004, 2005). Makepeace Cedar Swamp has the most diverse published assemblage of these organic deposits, including diatoms, pollen, spores, seeds, sedge achene, twigs and wood, and fungal remains (Newby et al. 1994; Newby et al. 2000). The National Oceanic and Atmospheric Administration's paleoclimatology databases (accessible from http://www.ncdc.noaa.gov/paleo/) include information about many of these sites; see especially the lake and pollen databases.

Large mammal fossils are quite rare in Massachusetts, although a horn core and attached skull material from a bison were recovered from Late Pleistocene deposits at Harvard, 21 km (13 miles) west-northwest of Concord (Romer 1951). Mastodon and mammoth teeth are known from the floor of Massachusetts Bay as well, dating to the early portion of the current postglacial interval, approximately 11,000 years ago, when local sea level was relatively low (Oldale et al. 1988).

Park Collections

MIMA has no paleontological material in its collections to date (T. Wallace, MIMA curator, pers. comm., January 2010).

Cultural Resource Contexts

Fossils have not yet been reported from cultural resource contexts at MIMA. There are numerous sites in the vicinity, with a record of cultural activity going back over 10,000 years. At least 35 prehistoric sites have been found within MIMA, although only the Old North Bridge site has been studied at a professional level (Herbster 2005). Shell middens in coastal areas such as Boston Harbor have produced a variety of human-associated fossils, including the remains of hickory nuts, mollusks, fish, reptiles, birds, dogs, deer, and unidentified mammals (Luedtke and Rosen 1993). There is at least one report of a shell midden near MIMA: Clam Shell or Clamshell Bluff near Concord on the Sudbury River, less than half a km (one third of a mile) south of the North Bridge unit (Herbster 2005); this site is now developed. Also known as the Concord Shell Heap site, the location also had a noteworthy accumulation of turtle bones, including remains of eight species (Rhodin 1995). Stone tools are sometimes made from fossils or fossiliferous material, but this is unlikely in eastern Massachusetts. The stones selected by prehistoric people for tools here are not potentially fossiliferous, instead being varieties of volcanic rock (Luedtke 1998; Hollander and Hermes 1999; Hermes 2000). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Rocks from outside sources were used to repair rock walls at MIMA (Thornberry-Ehrlich 2008); these rocks came from a farm in Gloucester, Massachusetts, over 48 km (30 miles) northeast of Lexington. These stones were glacial fieldstones (L. Sideris, MIMA chief of planning and communications, pers. comm., January 2010). As the rocks of that area are mostly igneous (Zen et al. 1983), they are unlikely to be fossiliferous.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division coordinated a geologic resource inventory scoping session for MIMA during July 2007, which includes a discussion on paleontological resources (Thornberry-Ehrlich 2008). Fossils are not presently known from MIMA. The most likely potential source for fossils at the park is in the Quaternary deposits.
- Investigation of peat deposits would be useful to establish their ages and fossil resources present, if any. Peat deposits are known to be fossiliferous elsewhere and can be very useful for paleoecological reconstructions of the recent past.
- Park staff should be encouraged to observe the Quaternary sedimentary material for fossil material while conducting their usual duties. Staff should photodocument and potentially 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. 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).
- Future archeological excavations or infrastructure developments should consider scheduling site monitoring by a trained paleontologist in order to document and protect fossil resources.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

Literature Cited

Acaster, M. and M. E. Bickford. 1999. Geochronology and geochemistry of Putnam-Nashoba Terrane metavolcanic and plutonic rocks, eastern Massachusetts: constraints on the early Paleozoic evolution of eastern North America. Geological Society of America Bulletin **111**(2):240-253.

Argus, G. W. and M. B. Davis. 1962. Microfossils from a late-glacial deposit at Cambridge, Massachusetts. American Midland Naturalist **67**(1):106-117.

Ashley, G. M. and J. R. Stone. 1995. The paleoclimate record for southern New England, 15 ka to 12 ka. Abstracts with Programs - Geological Society of America **27**(1):27-28.

Ashley, G. M., J. R. Stone, and D. M. Peteet. 1999. Chronology and paleoclimate implications from radiocarbon-dated paleobotanical records, Connecticut River valley, CT. Abstracts with Programs - Geological Society of America **31**(2):A-2.

Barghoorn, E. S. Jr. 1949. Paleobotanical studies of the Fishweir and associated deposits. Pages 49-83 *in* Johnson, F., editor. The Boylston Street Fishweir II. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology **4**(1).

Bender, M. M., D. A. Baerreis, R. A. Bryson, and R. L. Steventon. 1981. University of Wisconsin Radiocarbon dates XVIII. Radiocarbon **23**:145-161.

Bender, M. M., D. A. Baerreis, R. A. Bryson, and R. L. Steventon. 1982. University of Wisconsin radiocarbon dates XIX. Radiocarbon **24**:83-100.

Bernabo, J. C. 1977. Sensing climatically and culturally induced environmental changes using palynological data. Dissertation. Brown University, Providence, RI.

Brankman, C. M., and L. G. Baise. 2008. Liquefaction susceptibility mapping in Boston, Massachusetts. Environmental & Engineering Geoscience **14**(1):1-16.

Colman, J. A. and P. J. Friesz. 2001. Geohydrology and limnology of Walden Pond, Concord, Massachusetts. U.S. Geological Survey, Reston, VA. Water-Resources Investigation Report 2001-4137. Online. http://pubs.water.usgs.gov/wri014137. Accessed December 2009.

Curran, M. L. and D. F. Dincauze. 1977. Paleoindians and paleo-lakes: new data from the Connecticut drainage. Annals of the New York Academy of Sciences **288**:333-348.

Davis, M.B. 1958. Three pollen diagrams from central Massachusetts. American Journal of Science **256**:540-570.

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.

Gaudreau, D. C. 1982. Holocene vegetational history of central New England and the Hudson River valley. Program and Abstracts - American Quaternary Association **7**:93.

Gaudreau, D. C. 1986. Late-Quaternary vegetational history of the northeast: paleoecological implications of topographic patterns in pollen distributions. Dissertation. Yale University, New Haven, CT.

Goldsmith, R. and E. G. A. Weed. 1991. Stratigraphy of the Milford-Dedham Zone, eastern Massachusetts: an Avalonian terrane. Pages E1-E62 *in* Hatch, N. L. Jr., editor. The bedrock geology of Massachusetts. U.S. Geological Survey, Reston, VA. Professional Paper 1366-E-J. Online. http://pubs.er.usgs.gov/usgspubs/pp/pp1366EJ. Accessed December 2009.

Hatch, N. L. Jr., E-an Zen, R. Goldsmith, N. M. Ratcliffe, P. Robinson, R. S. Stanley, and D. R. Wones. 1984. Lithotectonic assemblages as portrayed on the new bedrock geologic map of Massachusetts. American Journal of Science **284**(9):1026-1034.

Hepburn, J. C., M. Hill, and R. Hon. 1987. The Avalonian and Nashoba terranes, eastern Massachusetts, U.S.A.: an overview. Maritime Sediments and Atlantic Geology **23**(1):1-12.

Hepburn, J. C., R. Hon, G. R. Dunning, R. H. Bailey, and K. Galli. 1993. The Avalon and Nashoba terranes (eastern margin of the Appalachian Orogen in southeastern New England). Pages X.1-X.31 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Herbster, H. 2005. Archaeological overview and assessment: Minute Man National Historical Park. The Public Archaeology Laboratory, Inc., Pawtucket, RI. Report 1706.

Hermes, O. D. 2000. What is this stuff anyway? Characterizing lithics in southeastern New England. Abstracts with Programs - Geological Society of America **32**(7):416.

Hollander, S. A. and O. D. Hermes. 1999. Petrological characterization of "Saugus Jasper". Abstracts with Programs - Geological Society of America **31**(2):A-24.

Johnson, F. 1942a. The cross section of the building excavation. Pages 13-23 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Johnson, F. 1942b. Miscellaneous identifications and discussion. Pages 130 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Julian, M. E., J. E. Johnson, and S. C. Phillips. 2009. Opportunistic stratigraphy: glacial lake sediments revealed during the May 15-16, 2006 Suncook River avulsion in Epsom, New Hampshire. Abstracts with Programs - Geological Society of America **41**(3):91.

Kay, A., J. C. Hepburn, Y. D. Kuiper, and J. Inglis. 2009. Nd isotopic constraints on the origin of the Nashoba Terrane, eastern Massachusetts. Abstracts with Programs - Geological Society of America **41**(3):98.

Kaye, C. A. 1982. Bedrock and Quaternary geology of the Boston area, Massachusetts. Reviews in Engineering Geology **5**:25-40.

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* Lucas, S. G., 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, NM. Bulletin 34. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed December 2009.

Köster, D., J. M. Racca and R. Pienitz. 2004. Diatom-based inference models and reconstructions revisited: methods and transformations. Journal of Paleolimnology **32**(3):233-246.

Köster D., R. Pienitz, B. B. Wolfe, S. Barry, D. R. Foster, and S. S. Dixit. 2005. Paleolimnological assessment of human-induced impacts on Walden Pond (Massachusetts, USA) using diatoms and stable isotopes. Aquatic Ecosystem Health & Management **8**(2):117-131.

Koteff, C. 1963. Glacial lakes near Concord, Massachusetts. Pages C142-C144 *in* Geological Survey Research 1963. U.S. Geological Survey, Reston, VA. Professional Paper 475-C.

Levin, H. L. 1999. The Earth through time (6th edition). Saunders College Publishing, Fort Worth, TX.

Luedtke, B. E. 1998. Rediscovery of the Wyoming Quarry Site, Melrose, MA. Abstracts with Programs - Geological Society of America **30**(1):58-59.

Luedtke, B. E. and P. S. Rosen. 1993. Archaeological geology on Long Island, Boston Harbor. Pages T.1-T.15 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Nelson, S. 1984. Upland and wetland vegetational changes southeastern Massachusetts: a 12,000 year record. Northeastern Geology **6**:181-191.

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 **13**:145.

Newby, P., J. Kaye, J. Lynch, and T. Webb III. 1995. Holocene water-level fluctuations in southeastern New England. Abstracts with Programs - Geological Society of America **27**(1):71.

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.

Oldale, R. N., J. R. Grimes, and F. C. Whitmore Jr. 1988. Late-Wisconsinan elephant teeth from the western Gulf of Maine. Abstracts with Programs - Geological Society of America **20**(1):59.

Rast, N. and J. W. Skehan. 1990. The late Proterozoic geologic setting of the Boston Basin. Pages 235-247 *in* Socci, A. D., J. W. Skehan, and G. W. Smith, editors. Geology of the composite Avalon Terrane of southern New England. Geological Society of America, Boulder, CO. Special Paper 245.

Rhodin, A. G. J. 1995. Archaeological turtle bone remains from Concord Shell Heap. Bulletin of the Massachusetts Archaeological Society **56**(2):71-82. Online. http://www.chelonian.org/wp-content/uploads/file/Rhodin_1995_ConcordShellheap.pdf. Accessed January 2010.

Ritchie, D., M. K. King, C. Vogt, and P. Fragola. 1990. Archeological investigations of Minute Man National Historical Park, volume II: an estimation approach to prehistoric sites. National Park Service, Division of Cultural Resources Management, North Atlantic Regional Office, Boston, MA. Cultural Resources Management Study 23.

Romer, A. S. 1951. *Bison crassicornis* in the late Pleistocene of New England. Journal of Mammalogy **32**(2):230-231.

Rosen, P. S., B. M. Brenninkmeyer, and L. M. Maybury. 1993. Holocene evolution of Boston inner harbor, Massachusetts. Journal of Coastal Research **9**(2):363-377.

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**:647-644.

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

Shimer, H. W. 1918. Postglacial history of Boston. Proceedings of the American Academy of Arts and Sciences **53**(6):441-463.

Shuman, B., J. Bravo, J. Kaye, J. A. Lynch, P. Newby, and T. Webb III. 2001. Late Quaternary water-level variations and vegetation history at Crooked Pond, southeastern Massachusetts. Quaternary Research **56**(3):401-410.

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

Steventon, R. L. and J. E. Kutzbach. 1983. University of Wisconsin radiocarbon dates XX. Radiocarbon **25**:152-168.

Steventon, R. L. and J. E. Kutzbach. 1984. University of Wisconsin radiocarbon dates XXI. Radiocarbon **26**:135-147.

Stone, J. R. and B. D. Stone. 2006. Surficial geologic map of the Clinton-Concord-Grafton-Medfield 12-quadrangle area in east central Massachusetts. U.S. Geological Survey, Reston, VA. Open-File Report 2006-1260-A. Scale 1:24,000. Online. http://pubs.usgs.gov/of/2006/1260/A/. Accessed December 2009.

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.

Thornberry-Ehrlich, T. 2008. Geologic resource evaluation scoping summary: Minute Man NP & Saugus Iron Works NHS. National Park Service, Geologic Resources Division, Denver, CO. Online. http://www.nature.nps.gov/geology/inventory/publications/s_summaries/MIMA-SAIR_gre_scoping_summary_2008-0930.pdf. Accessed December 2009.

Thorson, R. M. and K. McBride. 1988. The Bolton Spring Site, Connecticut: early Holocene human occupation and environmental changes in southern New England. Geoarchaeology **3**(3):221-234.

Wilson, L. R. 1949. A microfossil analysis of the Lower Peat and associated sediments at the John Hancock Fishweir site. Pages 84-98 *in* Johnson, F., editor. The Boylston Street Fishweir II. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology **4**(1).

Winkler, M. G. 1993. Changes at Walden Pond during the last 600 years: microfossil analyses of Walden Pond sediments. Pages 199-211 *in* Schofield, E. A. and R. C. Baron, editors. Thoreau's world and ours: a natural legacy. North American Press (Fulcrum Publishing), Golden, CO.

Wintsch, R. P., J. F. Sutter, M. J. Kunk, J. N. Aleinikoff, and J. L. Boyd. 1993. Alleghanian assembly of Proterozoic and Paleozoic lithotectonic terranes in south central New England: new constraints from geochronology and petrology. Pages H.1-H.30 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Wintsch, R. P., J. N. Aleinikoff, G. J. Walsh, W. A. Bothner, A. M. Hussey II, and C. M. Fanning. 2007. SHRIMP U-Pb evidence for a Late Silurian age of metasedimentary rocks in the Merrimack and Putnam-Nashoba Terranes, eastern New England. American Journal of Science **307**(1):119-167.

Zen, E-an, R. Goldsmith, N. M. Ratcliffe, P. Robinson, R. S. Stanley, N. L. Hatch, A. F. Shride, E. G. A. Weed, and D. R. Wones. 1983. Bedrock geologic map of Massachusetts. U.S. Geological Survey, Reston, VA. Scale 1:250,000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_16357.htm. Accessed December 2009. Accessed December 2009.

Additional References

Allen, G. M. 1920. Bison remains from New England. Journal of Mammalogy **1**(4):161-164.

Baker, V. G. 1980. Archeological overview and evaluation: Minute Man National Historical Park, Massachusetts. Cultural Resources Management Study No. 2. National Park Service, Washington, D.C.

Bell, K. G. and D. C. Alvord. 1976. Pre-Silurian stratigraphy of northeastern Massachusetts. Pages 179-216 *in* Page, L. R., editor. Contributions to the stratigraphy of New England. Geological Society of America, Boulder, CO. Memoir 148.

Faison, E. K., D. R. Foster, W. W. Oswald, B. C. S. Hansen, and E. Doughty. 2006. Early Holocene openlands in southern New England. Ecology **87**(10):2537-2547.

Gaudreau, D. C. and T. Webb III. 1985. Late-Quaternary pollen stratigraphy and isochrone maps for the northeastern United States. Pages 247-280 *in* Bryant, V. M. Jr. and R. G. Holloway, editors. Pollen records of late-Quaternary North American sediments. American Association of Stratigraphic Palynologists Foundation, Dallas, TX.

Goldsmith, R. and P. Robinson. 1991. Stratigraphy of the Nashoba Zone, eastern Massachusetts: an enigmatic terrane. Pages F1-F22 *in* Hatch, N. L. Jr., editor. The bedrock geology of Massachusetts. U.S. Geological Survey, Reston, VA. Professional Paper 1366-E-J. Online. http://pubs.er.usgs.gov/usgspubs/pp/pp1366EJ. Accessed December 2009.

Goldthwait, J. W. 1905. The sand plains of glacial Lake Sudbury. Bulletin of the Museum of Comparative Zoology **42**(geological series 6):263-301. [full text available on Google Books]

Hepburn, J. C. 2008. Mid-Paleozoic arc accretion on the eastern side of the Appalachian Orogen, eastern Massachusetts and adjacent areas. Abstracts with Programs - Geological Society of America **40**(2):75.

Kaye, C. A. 1961. Pleistocene stratigraphy of Boston, Massachusetts. Pages B73-B76 *in* Geological Survey research 1961: short papers in the geologic and hydrologic sciences. U.S. Geological Survey, Reston, VA. Professional Paper 424-B.

Kaye, C. A. 1976. Outline of the Pleistocene geology of the Boston Basin. Pages 46-63 *in* Cameron, B., editor. Geology of southeastern New England: a guidebook for field trips to the Boston area and vicinity. Science Press, Princeton, NJ. Annual Meeting - New England Intercollegiate Geological Conference 68.

Knox, A. S. 1942. The pollen analysis of the silt and the tentative dating of the deposits. Pages 105-129 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Koteff, C. 1964. Surficial geology of the Concord Quadrangle, Massachusetts. U.S. Geological Survey, Reston, VA. Geologic Quadrangle Map 331. Scale 1:24,000. Online. http://pubs.er.usgs.gov/usgspubs/gq/gq331. Accessed December 2009.

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

Murphy, J. B., J. D. Keppie, and R. D. Nance. 2007. What is the Acadian Orogeny? Abstracts with Programs - Geological Society of America **39**(1):69.

Newby, P. E. and T. Webb III. 1994. Radiocarbon-dated pollen and sediment records from near the Boylston Street fishweir site in Boston, Massachusetts. Quaternary Research **41**(2):214-224.

Newby, P., P. Tzedakis, and T. Webb III. 1987. Pollen and sediment records for Nipmuck Pond, Mendon, Massachusetts. The Public Archaeology Laboratory, Inc., Pawtucket, RI.

Newby, P., R. S. Webb, and T. Webb III. 1986. Pollen and sediment records for Houghton's Pond in eastern Massachusetts: final report. The Public Archaeology Laboratory, Inc., Pawtucket, RI.

Newman, W. A., D. M. Mickelson, R. C. Berg, R. R. Rendigs, R. N. Oldale, and R. H. Bailey. 1993. Pleistocene geology of the Boston Basin and its adjacent surroundings. Pages U.1-U.24 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston

GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

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

Rast, N. and J. W. Skehan. 1993. Changing tectonic environments of the Avalon Superterrane and the Nashoba Terrane in Massachusetts. Journal of Geodynamics **17**(1-2):1-20.

Rhodin, A. G. J. 1992. Chelonian zooarchaeology of eastern New England: turtle bone remains from Cedar Swamp and other prehistoric sites. Bulletin of the Massachusetts Archaeological Society **53**(1):21-30. Online. http://www.chelonian.org/wp-content/uploads/file/Rhodin_1992_CedarSwamp.pdf. Accessed January 2010.

Skehan, J. W. and N. Rast. 1992. The Avalon Superterrane and the enigma of the Nashoba. Abstracts with Programs - Geological Society of America **24**(7):A289.

Sneddon, L. and L. Kaplan. 1987. Pollen analysis from Cedar Swamp Pond, Westborough, Massachusetts. Archaeological Quarterly of the W. Elmer Ekblaw Chapter of the Massachusetts Archaeological Society **9**(2).

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

Thompson, M. D. and J. Ramezani. 2008. Refined ages of Paleozoic plutons as constraints on Avalonian accretion in southeastern New England. Abstracts with Programs - Geological Society of America **40**(2):14.

Thompson, M. D., A. M. Grunow, and J. Ramezani. 2007. Late Neoproterozoic paleogeography of the southeastern New England Avalon Zone: insights from U-Pb geochronology and paleomagnetism. Geological Society of America Bulletin **119**(5-6):681-696.

Wones, D. R. and R. Goldsmith. 1991. Intrusive rocks of eastern Massachusetts. Pages I1-I61 *in* Hatch, N. L. Jr., editor. The bedrock geology of Massachusetts. U.S. Geological Survey, Reston, VA. Professional Paper 1366-E-J. Online. http://pubs.er.usgs.gov/usgspubs/pp/pp1366EJ. Accessed December 2009.

Data Sets

Minute Man National Historical Park Paleontological Archives
1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Minute Man National Historical Park Digital Bedrock Geologic Map
2009-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online.
http://science.nature.nps.gov/nrdata/datastore.cfm?ID=48346.

Minute Man National Historical Park Digital Surficial Geologic Map
2009-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online.
http://science.nature.nps.gov/nrdata/datastore.cfm?ID=48347.

Massachusetts Digital Geologic Map
1998-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by Boston College staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=MA.

Morristown National Historical Park

Morristown National Historical Park (MORR) was authorized March 2, 1933. The park preserves the setting of the Continental Army's winter quarters for January 1777 and 1779-1780. MORR's boundaries have changed several times: June 6, 1953; September 18, 1964; October 26, 1974; October 21, 1976; October 4, 1991; November 6, 1998, and August 23, 2003. It currently encompasses 692.30 ha (1,710.72 acres), all but 2.04 ha (5.03 acres) of which are under federal administration.

MORR is divided into four units: Fort Nonsense, Jockey Hollow Encampment Area, New Jersey Brigade Encampment Area, and Washington's Headquarters (or Ford Mansion). Most of the land area is in the Jockey Hollow Encampment Area and the New Jersey Brigade Encampment Area, which are adjacent on Tempe Wick Road. Fort Nonsense is about 2 km (1.25 miles) northeast of Jockey Hollow. Finally, Washington's Headquarters, the smallest unit, is 4.5 km (2.8 miles) northeast of Jockey Hollow.

Geologic Background

MORR is located in and around Morristown in south-central Morris County and northern Somerset County, New Jersey, near the center of the northern half of the state. Most of MORR's land is southwest of Morristown, with the exception of Washington's Headquarters. The Passaic River flows through the New Jersey Brigade Encampment Area, and the Whippany River circles north of the various units. Elongate ridges are found northwest and southeast of Morristown; those in the west are Proterozoic-age metamorphic and igneous rocks, and those in the east are basalts that formed at approximately the Triassic-Jurassic boundary (see the appendix for a geological time scale). Washington's Headquarters is in the Piedmont physiographic province, and the other three park units are in the Appalachian Highlands province (Eby 1976) (the New Jersey Highlands, fittingly). This division is rooted in the geology of the area (see below). Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held for MORR during July 2007. The geology of MORR was summarized in a geologic scoping summary by the National Park Service (2008), an internal NPS document.

Northern New Jersey is divided into two very different bedrock provinces. The New Jersey Highlands, composed of metamorphosed Proterozoic rocks, are northwest of a major fault zone called the Ramapo Fault. Southeast of the Ramapo Fault is the Newark Basin, a site of much younger Triassic and Jurassic rift basin deposition (Eby 1976; Sykes et al. 2008). The fault can be identified by its escarpment: there is an elevation difference of between 60 and 250 m (200 and 800 ft) on the two sides of the fault (NPS 2008).

The New Jersey Highlands are part of the Reading Prong, a physiographic province of the Appalachians that also includes the Hudson Highlands of New York and the Reading Hills of Pennsylvania. These areas have related Proterozoic bedrock affected by the Grenville Orogeny (mountain-building event) (Gunderson 1990). The basic components of the New Jersey Highlands bedrock include: metamorphosed igneous rocks known as the Losee Metamorphic Suite, which make up most of the bedrock of MORR; overlying metamorphosed sedimentary and volcanic rocks; and several groups of intrusive rocks, including the Byram Intrusive Suite, which underlies part of MORR (Volkert and Drake 1999; Volkert 2004). These rocks were formed and deformed during tectonic events associated with the lengthy Grenville Orogeny, one of the effects of the assembly of a supercontinent (Rodinia) (Levin 1999). For reference, there are two major stages to the Grenville Orogeny in northeastern North America, the Elzevirian Orogeny of approximately 1350 to 1185 Ma (million years ago) (McLelland et al. 1996), and the Ottawan Orogeny of approximately 1080 to 1030 Ma (Volkert et al. 2000). Also, in many geologic publications the ancient North American landmass is known as Laurentia, the technical term for the core of the continent (Levin 1999).

The Losee Metamorphic Suite represents the remains of a magmatic arc (an arc-shape area of igneous activity) formed largely between 1282 ± 7 Ma and 1248 ± 12 Ma. It was intruded by granites, including the Byram Intrusive Suite, between approximately 1200 and 1100 Ma, and was heavily metamorphosed between approximately 1025 and 990 Ma by the Ottawan Orogeny (Aleinikoff et al. 2007). Its rocks were

formed on a continental margin that was overriding another plate (Volkert 2004). The overlying metasedimentary and metavolcanic rocks were deposited sometime before 1174 Ma in a back-arc basin, a type of extensional basin formed in response to the presence of mountains (Volkert 2004). The Byram Intrusive Suite pushed into the older rocks about 1110 ± 25 Ma (Volkert 2004). Metamorphism continued for tens of millions of years, until roughly 875 Ma, as more continental pieces were added to Rodinia (Gates et al. 2004). Rodinia began to break up at about 760 Ma, leading to rift basins and intrusions of dikes (Volkert and Drake 1999), and the formation of the Iapetus Ocean (Sykes et al. 2008). This rifting finished by the early Cambrian (Volkert and Drake 1999), setting the stage for another round of continental collisions and supercontinent formation that would dominate the next 300 million years.

Three major orogenic events trace the formation of the supercontinent Pangaea in northeastern North America (Levin 1999), and their effects are visible at several other NETN parks. MORR and its surroundings provide a glimpse of what happened as Pangaea broke apart. The breakup of Pangaea began during the Triassic, creating a system of rift basins paralleling the Appalachian Mountains. The sediments deposited in these basins are grouped together as the Newark Supergroup. They are found from northern South Carolina to Nova Scotia and record 35 million years of continental rifting. The Newark Basin is one of the rift basins now filled with Newark Supergroup rocks (Olsen 1980a). The rocks of the Newark Supergroup are known for their cyclic deposits, shifting from rivers and floodplains to great rift lakes and back to terrestrial deposition (Olsen 1980b). These cycles in the rock record are evidence of ancient Milankovitch cycles in the Newark Supergroup; Milankovitch cycles are climate cycles that are keyed to various features of Earth's movement in space (Olsen and Whiteside 2008). Their modern durations can be used to establish internal chronologies in the rocks. Particularly notable among the rock cycles are Van Houten cycles, interpreted as representing the roughly 20,000-year cycle of the precession of the equinoxes (Cox and Niemitz 1997); thus, dry-wet-dry cycles have a periodicity of approximately 20,000 years (Malinconico 2000). Also prominent is a 405,000-year orbital eccentricity cycle (Olsen and Whiteside 2008). Other cycles, with periodicities of 100,000 years to several million years, are also known (Kerr 1991; Kominz et al. 1991; Metz 1993; Olsen and Whiteside 2008). During deposition, the Newark Basin was carried north on Pangaea, moving from approximately 5° N to 20° N (Kent and Tauxe 2005).

Flood basalts, faulting, and folding accompanied the rifting (Olsen 1980c). The eruption of the Newark Supergroup's flood basalts probably occurred over a time span of 580,000 years ± 100,000 years at approximately 201 Ma (Olsen et al. 1996), which is approximately the Triassic-Jurassic boundary. Note that recent dates for the Triassic-Jurassic boundary vary from 199.6 Ma to 201.6 Ma depending on the source, with the most recent work indicating an age of 201.4 Ma for the oldest basalts of the Newark Supergroup, including the Hartford Basin, and 201.3 Ma for the Triassic-Jurassic boundary (Schoene et al. 2010). This igneous event was part of the largest known eruptions on Earth, extending over much of central Pangaea from present-day France to eastern North America, West Africa, and southwestern Brazil, and eventually covering about 11,000,000 km^2 (4,200,000 $miles^2$). The volcanic rocks are now recognized as the Central Atlantic Magmatic Province (CAMP) (Marzoli et al. 1999).

While no large tectonic events have occurred on the east coast of North America since the Jurassic, earthquakes still occur occasionally on the Ramapo Fault system. The present system of stresses began during the middle Mesozoic, after the rifting (Sykes et al. 2008). Many of the land surfaces are fairly young. Valleys in the Piedmont were incised during the late Miocene and early Pleistocene in response to episodes of sea level dropping. Thus, the oldest preserved landforms on the Piedmont are no older than the late Miocene (Stanford et al. 2001). Landforms in both the highlands and Piedmont were resculpted by glacial activity during the Pleistocene.

Glaciers advanced during the Pleistocene at several times; at least three periods can be distinguished in New Jersey. The oldest episode of glaciation is unnamed. It advanced the farthest south, and at its maximum extent covered MORR. The following Illinoian glaciation did not go as far as MORR. The Wisconsinan, the last major glaciation, covered a similar area in New Jersey, also not reaching MORR (Stanford 1993). During this glaciation, the Ontario and Hudson-Champlain lobes of the Laurentide ice sheet pushed into New Jersey from New York (Cotter et al. 1986). The glaciers reached their maximum

extent between 22,000 and 20,000 years ago (Witte 1997). This is marked by a terminal moraine, the pile of unsorted debris left by a glacier along the line where it reached it greatest extent and then began retreating. Deglaciation proceeded in several steps, each leaving a moraine to mark the location of a temporary stop (Stanford 1993). Ice had retreated from New Jersey over 17,500 years ago (Witte 1997). Glacial retreat left behind 14 major glacial lakes or lake groups (Stanford 1993).

The presence of glacial lakes in New Jersey has been known for over a hundred years (Salisbury and Kuemmel 1895). One of the larger lakes, Glacial Lake Passaic, left lake bottom deposits in the MORR area east of the Ramapo Fault (Stone et al. 2002; Stanford 2006, 2007, 2009; Pristas 2007; NPS 2008). At its largest, Glacial Lake Passaic was 16 km (10 miles) by 48 km (30 miles) (Minard 1967) and 540 km^2 (208 $miles^2$) in area (Reimer et al. 1981), and averaged 50 to 60 m (160 to 200 ft) deep, up to 75 m (240 ft) deep (Minard 1967). The Great Swamp National Wildlife Refuge, 7 km (4 miles) south of Morristown, is one of its remnants (Minard 1967). Glacial Lake Passaic existed between approximately 20,000 and 17,000 radiocarbon years before present (similar to, but different than calendar years; see "Quaternary rocks and sediments" below for more information) (Uchupi et al. 2001). The Moggy Hollow stage of Glacial Lake Passaic, which affected the Morristown area (Stone et al. 2002; Stanford 2006, 2007, 2009; Pristas 2007), occurred at the same time as the terminal moraine (Stone et al. 1989). Humans arrived in the Hudson River/Long Island area before 11,500 years ago; the record of their presence is broken up by a lack of sediment deposition around the Pleistocene-Holocene boundary, which dates to approximately the same time (Thieme 2003).

The bedrock geology of MORR consists of middle Proterozoic metamorphic and igneous rocks, except for Washington's Headquarters, on the Mesozoic side of the Ramapo Fault. At the New Jersey Brigade Encampment Area, the bedrock is composed of three types of middle Proterozoic gneiss, and a somewhat younger granite. The Jockey Hollow Encampment Area has similar bedrock geology, with an additional primarily igneous unit and a mixed metamorphosed sedimentary and igneous unit. Fort Nonsense is underlain by gneiss and granite as well (Drake et al. 1996; Pristas 2004). The ancient metamorphics and igneous rocks can be ranked approximately by age, with the gneisses usually part of the older Losee Metamorphic Suite, the mixed metamorphics usually part of the formerly sedimentary sequence above the Losee Metamorphic Suite, and the granite belonging to the Byram Intrusive Suite, the youngest of the three (Volkert and Drake 1999). Because of their proximity to the Ramapo Fault, all of these MORR units are adjacent to much younger Early Jurassic rocks of the Newark Supergroup. Fort Nonsense is next to the Boonton Formation, and Jockey Hollow is across from older rocks of the Towaco Formation and overlying Hook Mountain Basalt. Finally, Washington's Headquarters itself is underlain by the Boonton Formation (Drake et al. 1996; Pristas 2004). Surficially, Jockey Hollow and New Jersey Brigade have deposits of alluvium, colluvium, and weathered bedrock residue. Fort Nonsense has surficial deposits of weathered gneiss. Again, Washington's Headquarters is different, as it has surficial beach deposits left by Glacial Lake Passaic (Stone et al. 2002; Stanford 2006, 2007, 2009; Pristas 2007).

For the purposes of this report, the most likely rock and sediment units for fossil finds are the Boonton Formation and the Quaternary rocks and sediments. The Towaco Formation will also be included because of its proximity. The gneisses, granites, and other Proterozoic bedrock units have practically no chance of fossils because they are either extremely deformed rocks or rocks that never would have had fossils, and because of their great age; the closest thing to a fossil in any of these is the possibility that some graphite deposits in gneiss may represent metamorphosed organic matter such as algal mats (Volkert et al. 2000). There is a report of stromatolites in the Franklin Marble, one of the metasedimentary rock units above the Losee Metamorphic Suite (Volkert and Aleinikoff 2007), but this unit is less deformed than the MORR bedrock.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within MORR. However, they are known to preserve fossils elsewhere, and future field investigations within the park may uncover fossils in them.

Towaco Formation (Upper Triassic or Lower Jurassic)

The Towaco Formation is adjacent to the Jockey Hollow Encampment Area, southeast of the Ramapo Fault, but is not mapped within MORR (Drake et al. 1996; Pristas 2004). This formation is included in this report because of its proximity.

The Towaco Formation is a combination of gray to black siltstones and red siltstones and sandstones (Olsen 1980b). It was named in 1980 as part of a larger redefinition of what had been known as the Brunswick Formation. Previously described as a single unit with three intervening basalt flows (the Watchung Basalts), the Brunswick Formation and Watchung Basalts were divided into seven units. From oldest to youngest, these are the Passaic Formation, Orange Mountain Basalt, Feltville Formation, Preakness Basalt, Towaco Formation, Hook Mountain Basalt, and Boonton Formation (Olsen 1980c). The deposition of the Towaco Formation occurred during a period of a few hundred thousand years at approximately 201 Ma (Olsen et al. 1996).

The Towaco Formation is composed of red, gray, and black sedimentary rocks, with minor amounts of volcaniclastics present as a thin brown layer near the top. It is roughly 340 m (1,115 ft) thick and is sandwiched by the Preakness Basalt below and Hook Mountain Basalt above. It is mostly made up of laterally continuous sedimentary cycles (Olsen 1980c). Sedimentary cycles in the Towaco Formation average 30 m (100 ft) thick, and are made up of four general divisions. The basal part is 1 to 5 m (3 to 16 ft) thick and composed of gray siltstone, sandstone, and sometimes conglomerate. It often has root trace-rich levels and reptile tracks, and represents a period when the Newark Basin's lake was expanding (transgressive sequence). The next part is 1 to 5 m (3 to 16 ft) of gray to black siltstone, often including a limy black varved section, and with underwater avalanche deposits (turbidites). This section represents a deep lake, and often has fish skeletons. Areas closer to the Ramapo Fault have thicker deep lake portions than areas farther away, indicating that the lakes were deeper there. Above the deep lake is 3 to 6 m (10 to 20 ft) of grey siltstone and sandstone, similar to the basal part; it represents the retreat of the lake (regressive sequence). Finally, representing the periods between lakes, are 20 to 30 m (66 to 100 ft) of red siltstone and sandstone. This portion has reptile tracks, root horizons, and bioturbation. There are smaller cycles within it of rivers giving way to floodplains and ephemeral lakes, followed by a return to rivers (Olsen 1980b). Dry-wet-dry cycles lasted roughly 20,000 years, dictated by climate factors following parameters of Earth's orbit (Malinconico 2000).

Fossils are most common in the black and gray deposits of the Towaco Formation (Olsen 1980a). The premier fossil location for the Towaco Formation is the Roseland Quarry, of the Walter Kidde Dinosaur Park (also known as the Riker Hill Fossil Site), approximately 16 km (10 miles) east-northeast of Morristown. From high in the formation, it is best known for its dinosaur tracks, but also has plant fossils, a beetle fragment, invertebrate traces, fish scales and skeletons, reptile bone fragments, and *Batrachopus* tracks (from terrestrial crocodile relatives) (Olsen 1980b; Gallagher 1983). Fossils of the Towaco Formation include stromatolites (around inundated trees; Whiteside and Olsen [2005]), pollen, spores, various plant remains (stems, twigs, limbs, carbonized compressions, and natural casts), root casts (Olsen 1980c), a beetle elytron (Huber et al. 2003), invertebrate burrows and traces, probably mostly from annelids and arthropods (Metz 1992), articulated fish skeletons and scales (Olsen 1980c), a possible vertebra from an early ornithischian (beaked) dinosaur (Olsen 1988), reptile bone fragments and tracks, and coprolites (fossil feces) (Olsen 1980c). Plant taxa represented include the horsetail *Equisetites*, ferns (including *Phlebopteris*), and conifers (*Brachyphyllum* and *Pagiophylum*) (Olsen 1980a). The most abundant fossils are skeletons of the fish *Semionotus*, and tracks of the trace genera *Anomoepus* (from ornithischian dinosaurs), *Batrachopus*, and *Grallator* (from theropod dinosaurs) (Olsen 1980a) (note that in most of his publications Olsen considers *Anchisauripus*, *Eubrontes*, and *Grallator* tracks to represent growth stages of *Grallator*; other authors may split them). Rarer track taxa include *Ameghinichnus* (from a mammal or early mammal relative) (Olsen 1988), and *Rhynchosauroides* (from either lizards or sphenodontians [tuataras]). Among the tracks are numerous tiny tracks (<3 cm or 1 in long) of *Anomoepus* and *Grallator*, possibly representing babies (Olsen 1980b). Pollen and spores are found in siltstone (Olsen 1980c), while the beetle fossil, *Ameghinichnus* tracks, and *Rhynchosauroides* tracks are

only present in the upper of the formation (Olsen 1980a, 1988). Tracks are abundant in the transgressive, regressive, and river/floodplain sections of the formation (Olsen 1980b).

The semionotid fish of the Towaco Formation are of interest for evolutionary studies because of the great resolution (resolution at the scale of a year is possible) and cyclic nature of the lake deposits (McCune et al. 1994). The semionotids of the formation were very diverse, with 21 species. Repeated lake formation and evaporation allowed much speciation and colonization (McCune 1989). Six of the species are thought to have originated in the Towaco Formation, eight are thought to be colonists that evolved in older formations, and seven have uncertain origins. Speciation was rapid, on the order of 5,000 to 8,000 years for a lake that lasted 21,000 to 24,000 years (McCune 1996).

Boonton Formation (Lower Jurassic)

The Boonton Formation underlies Washington's Headquarters, and is adjacent to Fort Nonsense on the opposite site of the Ramapo Fault (Drake et al. 1996; Pristas 2004). Like the Towaco Formation, it started as part of the Brunswick Formation; its rocks had been known as the Boonton and Whitehall beds. Underneath is the Hook Mountain Basalt (Olsen 1989c). The Boonton Formation is much thicker than the Towaco Formation, being composed of 500 m (1650 ft) of sedimentary rocks deposited cyclically, mostly as red lake deposits, with some gray to black lake deposits and minor red fluvial sandstones and alluvial fan conglomerates (Olsen 1989). The base of the formation has unusual rocks that lack cycling and may represent former evaporite deposits. The rest of the formation is composed of more typical cycles of red siltstone and sandstone (35 m [115 ft] thick on average) and thinner gray siltstones (2 m [7 ft] thick on average) (Olsen 1980c).

The Boonton Formation is slightly younger than the Towaco Formation, and dates to the early part of the Early Jurassic (approximately 199 Ma) (Olsen and McCune 1991; Olsen et al. 1996). Like the Towaco Formation, depositional settings cycled to and from lakes over ~20,000 year intervals (Metz 1993). The climate was more arid than that of the Towaco Formation (Fedosh and Smoot 1988), and was seasonal (Thomson and McCune 1984).

The fossil record of the Boonton Formation is similar to that of the Towaco Formation, except there are more fish genera and fewer track taxa known from the Boonton Formation. Also like the Towaco Formation, the Boonton Formation has a particularly fossiliferous locality in the vicinity of MORR. Near Boonton, 13 km (8 miles) northeast of Morristown, the upper meter (3 ft) of the formation is known as the Boonton Fish Bed, for its fish fossils (Olsen 1980c; Metz 1993). The Boonton Formation has yielded spores, pollen, roots, other plant fossils including *Equisetites* and the conifer *Brachyphyllum*, conchostracans (clam shrimp) (Olsen 1980a, 1980c), a variety of invertebrate traces (mostly produced by arthropods) (Metz 1993), fish skeletons, reptile tracks (Olsen 1980a, 1980c), and coprolites (Gilfillan and Olsen 2000). The most abundant fossils are conchostracans, the fish *Diplurus*, *Ptycholepis*, *Redfieldius*, and *Semionotus*, and the track genera *Anomoepus*, *Batrachopus*, and *Grallator* (Olsen 1980c). Coprolites are also abundant. The large feces were probably produced by the large coelacanth *Diplurus* (Gilfillan and Olsen 2000). As in the Towaco Formation, the semionotid fish of the Boonton Formation are diverse. Nine species are known, two of which are shared with the Towaco Formation (McCune 1987, 1989). Lake and shore deposits of the Boonton Formation have also produced plant fragments, invertebrate and reptile tracks (Metz 1993).

Quaternary rocks and sediments (Pleistocene-Holocene)

Quaternary rocks and sediments are present at all four MORR units, in the form of cobble- to silt-sized rock fragments. The most promising unit for Pleistocene fossils is probably the glacial lake beach deposits present at Washington's Headquarters. Jockey Hollow and New Jersey Brigade Encampment Areas and Fort Nonsense have mostly weathered gneiss for surficial deposits (Stone et al. 2002; Stanford 2006, 2007, 2009; Pristas 2007). Not having been deposited in settings associated with fossils, such as lakes or rivers, they are unlikely to have fossils, but isolated material is possible. Both Jockey Hollow and New Jersey Brigade Encampment Area do have alluvial deposits associated with drainage such as Primrose Brook (Stone et al. 2002; Stanford 2006, 2007, 2009; Pristas 2007); these deposits also have potential. Stream bed

localities may yield finds like ground sloths, giant beavers, stag moose, and caribous (Gallagher 1984). Glacial Lake Passaic may have even reached some distance on Primrose Brook (NPS 2008).

Quaternary fossils of New Jersey and adjacent areas of New York and Pennsylvania generally fall into two categories: mammal bones, especially those of large extinct mammals like mastodons; and material useful for paleoecological studies, such as pollen, spores, and algal and invertebrate microfossils. Both kinds tend to be associated with bodies of water, either extant or their marshy remnants. A number of sites of both types are found within approximately 100 km (60 miles) of MORR (Hartnagel and Bishop 1921; Hay 1923; Jepsen 1960; Newman 1977; Cotter et al. 1984).

The Quaternary mammal fossils of New Jersey have been described in a series of statewide surveys (Cope 1868; Hay 1923; Richards 1951; Jepsen 1960; Parris 1983). Terrestrial mammals definitely known from fossils in New Jersey include ground sloths (*Megalonyx* and *Erethmotherium* [formerly *Megatherium*]), muskrats (*Ondatra*), the extinct giant beaver (*Castoroides*), possibly two extinct species of horse (*Equus complicatus* and *E. fraternus*, only specimen now lost), deer (*Odocoileus*), elk (*Cervus*), caribou (*Rangifer*), the extinct stag moose or stag elk (*Cervalces*), an extinct musk ox (*Bootherium*, [formerly *Symbos*]), and two extinct species of proboscidean (*Mammut americanus*, the American mastodon, and *Mammuthus primigenius*, the woolly mammoth; *Mammuthus columbi*, the Columbian mammoth, may also be present). Note that this list may be incomplete because there is the possibility that Pleistocene specimens of extant animals have been discarded (Parris 1983). Possible finds include beavers (*Castor*), foxes (*Urocyon*), wolves (*Canis*, including a bone misidentified as from a bear in Richards [1951]), and raccoons (*Procyon*). Reports of bears, peccaries (*Mylohyus*), bison, and the musk ox *Ovibos* are either mistaken or cannot be confirmed (Parris 1983).

Among the best-known Pleistocene mammals of New Jersey are the mastodon and the stag moose (Parris 1983). Mastodon finds, usually consisting of teeth but sometimes including whole skeletons of multiple individuals, have been reported from New Jersey since the early 1800s. They are particularly common between northeastern Burlington County and northeastern Monmouth County, and on a line approximating the terminal moraine from Warren County to Union County (Jepsen 1960). Jepsen (1960) reported 31 localities that are within approximately 100 km (60 miles) of MORR, and Parris (1983) had records of another 10 discovered in the intervening two decades. A number of fossil sites are also known within this radius in southeastern New York and eastern Pennsylvania (Hartnagel and Bishop 1921; Hay 1923). The nearest find comes from Boonton, and was made sometime before 1903 (Jepsen 1960). The most notable of these finds is probably the discovery of five or six individuals halfway between Hackettstown and Vienna, 34 km (21 miles) west-northwest of Morristown in Warren County, in 1844 (Hay 1923; Jepsen 1960). The individuals came from three size classes, including a calf (Hay 1923). One skeleton was sent to Harvard University (Jepsen 1960), but not all of them fared so well; the bones of the largest and smallest disintegrated upon removal from the swampy pond in which they were found (Maxwell 1845). Later experience would show that the phenomenon of bones crumbling or turning to mushy blobs upon exposure is not uncommon in these well-watered coastal plain areas (Lockwood 1883; Daeschler et al. 1993). Finds of *Cervalces*, although rarer, include the type and best specimen of the genus, which was found in Hope Township, 43 km (27 miles) west-northwest of Morristown (Scott 1885; Parris 1983).

Paleoecological materials have been reported from fewer sites, but unlike mammal bones, there is a much greater potential of discovery. For example, organic material suitable for radiocarbon dating, along with fossil pollen and spores, can probably be found in the sediment of any lake, pond, or marsh of appropriate age. Organic debris, wood, and mollusk shells may be found in fluvial settings, such as the alluvial sediment associated with Primrose Brook. Summaries of pollen sites and radiocarbon sites in the vicinity of MORR have been published by Newman (1977; radiocarbon-specific) and Cotter et al. (1984; both pollen and radiocarbon). Newman (1977) shows ten radiocarbon sites within approximately 100 km (60 miles) of MORR, and Cotter et al. (1984) show ten pollen sites and four radiocarbon-only sites in that general radius within western New Jersey and Pennsylvania. The nearest of those cited by Cotter et al. (1984) is Budd Lake, 23 km (14 miles) west-northwest of Morristown. The oldest date at this site is 22,890

± 720 radiocarbon years before present (Stanford 1993) (note that radiocarbon dates are not the same as calendar dates, and that radiocarbon years require calibration to yield calendar years. Uncalibrated radiocarbon dates in publications are often denoted with "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. Therefore, dates that are not labeled with "calendar years" or something similar should be assumed to be uncalibrated radiocarbon dates. This date was too old to calibrate using Calib 5.0.2 [http://calib.qub.ac.uk/calib/], but would be older in calendar years). Holocene pollen has also been recovered from the Great Swamp, from a location about 7.4 km (4.6 miles) southeast of Jockey Hollow Encampment Area (Meyerson 1970). While pollen is the most common material used for paleoecological studies, other fossils have been used from some sites. Glovers Pond, 38 km (24 miles) west-northwest of Morristown, has fossils including an oribatid mite record that spans from the last glacial maximum to the present (Erickson 2005), and fossil midges (Erickson et al. 2008). Note that when dealing with publications predating the 1980s, radiocarbon dates used to calibrate deglaciation are often too young because they date the beginning of organic-rich sedimentation instead (Cotter et al. 1982, 1984).

Park Collections

There are no fossils in MORR museum collections (R. Masson, MORR biologist, pers. comm., November 2009).

Cultural Resource Contexts

Numerous archeological sites are known in the vicinity in New Jersey (Schrabisch 1917; Thieme 1998), although the age is sometimes overstated (Richards 1939). Paleoindian artifacts are fairly common in northern New Jersey, predating 11,500 years ago (Thieme 2003). Tools of bone, wood, and potentially fossiliferous stone like chert and flint are known, although the stone tools are more common. Charcoal, shells, and prey bones may also be found at sites (Schrabisch 1917). Thus, a human-fossil resource association would not be unexpected. To date, there are no reported examples of a fossil from a cultural resource context at MORR. 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

- The NPS Geologic Resources Division coordinated a geologic resource inventory scoping session for MORR during July 2007 (NPS 2008).
- Fossils are not presently known from MORR. The most likely potential sources for fossils at the park are the rocks of the Boonton Formation (present beneath Washington's Headquarters), glacial lake beach deposits (surface deposits at Washington's Headquarters), and Quaternary alluvial deposits associated with drainage (present at Jockey Hollow Encampment Area and New Jersey Brigade Encampment Area).
- Park staff should be encouraged to observe exposed sedimentary material for fossil material while conducting their usual duties. Staff should photodocument and potentially 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. 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).
- Future archeological excavations or infrastructure developments should consider scheduling site monitoring by a trained paleontologist in order to document and protect fossil resources.

- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

Literature Cited

Aleinikoff, J. N., R. A. Volkert, and C. M. Fanning. 2007. SHRIMP U-Pb geochronology of zircon and monazite from Ca. 1.3 Ga arc-related rocks, New Jersey Highlands. Abstracts with Programs - Geological Society of America **39**(1):37.

Cope, E. D. 1868. Synopsis of the extinct Mammalia of New Jersey. Pages 739-742 *in* Cook, G. H. Geology of New Jersey. New Jersey Geological Survey, Trenton, NJ. [full text available on Google Books]

Cotter, J. F. P., E. B. Evenson, L. A. Sirkin, and R. Stuckenrath. 1982. The radiometric age of the deglaciation of northeastern Pennsylvania and northwestern New Jersey. Abstracts with Programs - Geological Society of America **14**(7):468.

Cotter, J. F. P., E. B. Evenson, L. Sirkin, and R. Stuckenrath. 1984. The interpretation of "bog-bottom" radiocarbon dates in glacial chronologies. Pages 299-316 *in* Mahaney, W. C., editor. Correlation of Quaternary chronologies. GeoBooks, Norwich, United Kingdom.

Cotter, J. F. P., J. C. Ridge, E. B. Evenson, W. D. Sevon, L. Sirkin, and R. Stuckenrath. 1986. The Wisconsinan history of the Great Valley, Pennsylvania and New Jersey, and the age of the "terminal moraine". Pages 22-49 *in* Cadwell, D. H., editor. The Wisconsinan Stage of the First Geological District, eastern New York. New York State Museum and Science Service, Albany, NY. Bulletin 455.

Cox, J. W. and J. W. Niemitz. 1997. Geochemical comparison of Early Jurassic stratigraphy, Hartford and Newark basins: implications for paleoclimatic interpretations of Van Houten cycles. Abstracts with Programs - Geological Society of America **29**(1):38.

Daeschler, E., E. E. Spamer, and D. C. Parris. 1993. Review and new data on the Port Kennedy local fauna and flora (late Irvingtonian), Valley Forge National Historical Park, Montgomery County, Pennsylvania. The Mosasaur **5**:23-41.

Drake, A. A., R. A. Volkert, D. H. Monteverde, G. C. Herman, H. F. Houghton, R. A. Parker, and R. F. Dalton. 1996. Bedrock geologic map of northern New Jersey. U.S. Geological Survey, Reston, VA. Miscellaneous Investigations Map 2540-A. Scale 1:100,000.

Eby, C. F. 1976. Soil survey of Morris County, New Jersey. U.S. Department of Agriculture, Soils Conservation Service, Washington, DC.

Erickson, J. M. 2005. Fossil aquatic oribatid mites define paleoclimate intervals in lacustrine sediments: an example from Glovers Pond, NJ. Abstracts with Programs - Geological Society of America **37**(1):29.

Erickson, J. M., K. D. Zubin-Stathopoulos, M. J. Simmons. 2008. Paleotemperatures through the Younger Dryas interval at Glovers Pond, northern NJ, derived from fossil Chironomidae. Abstracts with Programs - Geological Society of America **40**(6):164.

Fedosh, M. S. and J. P. Smoot. 1988. A cored stratigraphic section through the northern Newark Basin, New Jersey. Pages 19-24 *in* Froelich, A. J. and G. R. Robinson Jr., editors. Studies of the early Mesozoic basins of the Eastern United States. U.S. Geological Survey, Reston, VA. Bulletin 1776. Online. http://pubs.er.usgs.gov/usgspubs/b/b1776. Accessed November 2009.

Gallagher, W. B. 1983. Paleoecology of the Delaware Valley region. The Mosasaur **1**:23-42.

Gallagher, W. B. 1984. Paleoecology of the Delaware Valley region: Part II, Cretaceous to Quaternary. The Mosasaur **2**:9-43.

Gates, A. E., D. W. Valentino, J. R. Chiarenzelli, G. S. Solar, and M. A. Hamilton. 2004. Exhumed Himalayan-type syntaxis in the Grenville Orogen, northeastern Laurentia. Journal of Geodynamics **37**(3-5):337-359.

Gilfillan, A. M. and P. E. Olsen. 2000. The coelacanth, *Diplurus longicaudatus* as the origin of the large coprolites occurring in the Triassic-Jurassic lacustrine strata of eastern North America. Abstracts with Programs - Geological Society of America **32**(1):A-20.

Gundersen, L. C. S. 1990. Geology of the Reading Prong, New York, and its application to predicting areas that have high radon potential. Pages 165-168 *in* Doe, B. R., editor. Proceedings of a U.S. Geological Survey workshop on Environmental geochemistry. U.S. Geological Survey, Reston, VA. Circular 1033. Online. http://pubs.er.usgs.gov/usgspubs/cir/cir1033. Accessed November 2009.

Hartnagel, C. A. and S. C. Bishop. 1921. The mastodons, mammoths and other Pleistocene mammals of New York State. New York State Museum and Science Service, Albany, NY. Bulletins 241 and 242. [full text available on Google Books]

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°. Carnegie Institution of Washington Publication 322. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/pleistoceneofnor00hayouoft]

Huber, P., N. G. McDonald, and P. E. Olsen. 2003. Early Jurassic insects from the Newark Supergroup, northeastern United States. Pages 206-233 *in* LeTourneau, P. M. and P. E. Olsen, editors. The great rift valleys of Pangea in eastern North America. Volume 2: Sedimentology, stratigraphy, and paleontology. Columbia University Press, New York, NY. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/huber_et_al_03.pdf. Accessed November 2009.

Jepsen, G. L. 1960 [1962 and 1964 editions as well]. A New Jersey mastodon. New Jersey State Museum, Trenton, NJ. Bulletin 6.

Kent, D. V. and L. Tauxe. 2005. Corrected Late Triassic latitudes for continents adjacent to the North Atlantic. Science **307**(5707):240-244. Online. http://magician.ucsd.edu/~ltauxe/CV/reprints/kent05.pdf. Accessed February 2010.

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* Lucas, S. G., 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, NM. Bulletin 34. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed September 2009.

Kerr, R. A. 1991. The stately cycles of ancient climate. Science **252**(5010):1254-1255.

Kominz, M. A., J. Beaven, G. C. Bond, and J. McManus. 1991. Are cyclic sediments periodic? Gamma analysis and spectral analysis of Newark Supergroup lacustrine strata. Pages 319-334 *in* Franseen, E. K., W. L. Watney, C .G. St. C. Kendall, and W. Ross, editors. Sedimentary modeling: computer simulations and methods for improved parameter definition. Kansas Geological Survey, Lawrence, KS. Bulletin 233.

Levin, H. L. 1999. The Earth through time (6th edition). Saunders College Publishing, Fort Worth, TX.

Lockwood, S. 1883. A *Mastodon americanus* in a beaver meadow. Proceedings of the American Association for the Advancement of Science **31**:365-366.

Malinconico, M. L. 2000. Patterns of organic sedimentation in lake cycles and sequences of the Mesozoic Newark and Richmond basins. Abstracts with Programs - Geological Society of America **32**(1):32, 57.

Marzoli, A., P. R. Renne, E. M. Piccirillo, M. Ernesto, G. Bellieni, and A. De Min. 1999. Extensive 200-million-year-old continental flood basalts of the Central Atlantic magmatic province. Science **284**(5414):616-618. Online. http://www.csam.montclair.edu/earth/eesweb/gorring/geos444/marzoli.99.pdf. Accessed February 2010.

Maxwell, J. B. 1845. [On the discovery of mastodon bones... near Hackettstown, New Jersey]. Proceedings of the American Philosophical Society **4**(32):118-121.

McCune, A. R. 1987. Lakes as laboratories of evolution: endemic fishes and environmental cyclicity. Palaios **2**(5):446-454.

McCune, A. R. 1989. Semionotid species flocks in the Newark Basin. Pages 94-96 *in* Olsen, P. E., R. W. Schlische, and P. J. W. Gore, editors. Sedimentation and basin analysis in siliciclastic rock sequences: Volume 2. Tectonic, depositional, and paleoecological history of early Mesozoic rift basins, eastern North America. Hanshaw, P. M., editor. Field trips for the 28th international geological congress. American Geophysical Union, Washington, DC.

McCune, A. R. 1996. Biogeographic and stratigraphic evidence for rapid speciation in semionotid fishes. Paleobiology **22**(1):34-48.

McCune, A. R., K. S. Thomson, and P. E. Olsen. 1984. Semionotid fishes from the Mesozoic Great Lakes of North America. Pages 27-44 *in* Echelle, A. A. and I. Kornfield, editors. Evolution of fish species flocks. University of Maine at Orono Press, Orono, ME. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/mccune_et_al_84_sm.pdf. Accessed November 2009.

McLelland, J., J. S. Daly, and J. M. McLelland. 1996. The Grenville orogenic cycle (ca. 1350-1000 Ma): an Adirondack perspective. Tectonophysics **265**(1-2):1-28.

Metz, R. 1992. Trace fossils from the Lower Jurassic nonmarine Towaco Formation, New Jersey. Northeastern Geology **14**(1):29-34.

Metz, R. 1993. Ichnology of the Boonton Formation (Early Jurassic), Rockaway River, Boonton, New Jersey. Northeastern Geology **15**(2):170-175.

Meyerson, A. L. 1970. Glacial Lake Passaic: palynological evidence for draining of the Great Swamp stage. New Jersey Academy of Science Bulletin **15**(1-2):10-12.

Minard, J. P. 1967. Summary report on the geology and mineral resources of the Great Swamp National Wildlife Refuge, New Jersey. U.S. Geological Survey, Reston, VA. Bulletin 1260-E. Online. http://pubs.er.usgs.gov/usgspubs/b/b1260E. Accessed November 2009.

National Park Service, Geologic Resources Division. 2008. Geologic resource evaluation scoping summary: Morristown National Historical Park. National Park Service, Geologic Resources Division, Denver, CO. Online.

http://www.nature.nps.gov/geology/inventory/publications/s_summaries/MORR_gre_scoping_summary_2008-0924.pdf. Accessed November 2009.

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, P. E. 1980a. Triassic and Jurassic formations of the Newark Basin. Pages 2-39 *in* Manspeizer, W., 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, NY. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_formations_80_sm.pdf. Accessed November 2009.

Olsen, P. E. 1980b. Fossil great lakes of the Newark Supergroup in New Jersey. Pages 352-398 *in* Manspeizer, W., 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, NY. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_gr_80_vsm.pdf. Accessed November 2009.

Olsen, P. E. 1980c. The latest Triassic and Early Jurassic formations of the Newark Basin (eastern North America, Newark Supergroup): stratigraphy, structure and correlation. New Jersey Academy of Science Bulletin **25**(2):25-51. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_njas_80_sm.pdf. Accessed November 2009.

Olsen, P. E. 1988. Paleontology and paleoecology of the Newark Supergroup (early Mesozoic, eastern North America). Pages 185-230 in Manspeizer, W., editor. Triassic-Jurassic rifting: continental breakup and the origin of the Atlantic Ocean and passive margins. Developments in Geotectonics **22**(Part A). Elsevier, Amsterdam, The Netherlands. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_88_sm3.pdf. Accessed November 2009.

Olsen, P. E. 1989. Newark Basin, Pennsylvania and New Jersey: stratigraphy. Pages 69-72 *in* Olsen, P. E., R. W. Schlische, and P. J. W. Gore, editors. Sedimentation and basin analysis in siliciclastic rock sequences: Volume 2. Tectonic, depositional, and paleoecological history of early Mesozoic rift basins, eastern North America. Hanshaw, P. M., editor. Field trips for the 28th international geological congress. American Geophysical Union, Washington, DC.

Olsen, P. E. and A. R. McCune. 1991. Morphology of the *Semionotus elegans* species group from the Early Jurassic part of the Newark Supergroup of eastern North America with comments on the family Semionotidae (Neopterygii). Journal of Vertebrate Paleontology **11**(3):269-292. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_mccune_91_sm.pdf. Accessed November 2009.

Olsen, P. E., and J. H. Whiteside. 2008. Pre-Quaternary Milankovitch cycles and climate variability. Pages 826-835 *in* Gornitz, V., editor. Encyclopedia of paleoclimatology and ancient environments. Encyclopedia of earth science. Kluwer Academic Publishers, Dordretch, the Netherlands. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_whiteside_2008_sm.pdf. Accessed November 2009.

Olsen, P. E., R. W. Schlische, and M. S. Fedosh. 1996. 580 ky duration of the Early Jurassic flood basalt event in eastern North America estimated using Milankovitch cyclostratigraphy. Pages 11-22 *in* Morales, M., editor. The continental Jurassic. Museum of Northern Arizona, Flagstaff, AZ. Bulletin 60. Online. http://geology.rutgers.edu/~schlisch/A16_1996_CAMP_duration.pdf. Accessed November 2009.

Parris, D. C. 1983. New and revised records of Pleistocene mammals of New Jersey. The Mosasaur **1**:1-21.

Pristas, R. P. 2004. Bedrock geology of New Jersey. New Jersey Geological Survey, Trenton, NJ. Digital Geodata Series 04-6. Scale 1:100,000. Online. http://www.state.nj.us/dep/njgs/geodata/dgs04-6.htm. Accessed November 2009.

Pristas, R. P. 2007. Surficial geology of New Jersey. New Jersey Geological Survey, Trenton, NJ. Digital Geodata Series 07-2. Scale 1:100,000. Online. http://www.nj.gov/dep/njgs/geodata/dgs07-2.htm. Accessed November 2009.

Reimer, G. E., G. M. Ashley, J. C. Liddicoat, M. J. Pavich, and B. D. Stone. 1981. Glacial Lake Passaic: preliminary coring, paleomagnetic and stratigraphic analysis. Abstracts with Programs - Geological Society of America **13**(3):171.

Richards, H. G. 1939. Reconsideration of the dating of the Abbott Farm site at Trenton, New Jersey. American Journal of Science **237**(5):345-354.

Richards, H. G. 1951. Some recent discoveries of Pleistocene mammals from New Jersey. New Jersey Department of Conservation, Trenton, NJ. Bulletin, Geological Series 60.

Salisbury, R. D. and H. B. Kuemmel. 1895. Lake Passaic, an extinct glacial lake. Journal of Geology **3**(5):533-560.

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

Schrabisch, M. 1917. Archaeology of Warren and Hunterdon counties. New Jersey Bureau of Geology and Topography, Trenton, NJ. Bulletin 18.

Schoene, B., J. Guex, A. Bartolini, U. Schaltegger, and T. J. Blackburn. 2010. A correlation between the Triassic-Jurassic boundary mass extinction and flood basalt eruption at the 100 ka-level using ID-TIMS U/Pb zircon geochronology. Geology (in press).

Scott, W. B. 1885. *Cervalces americanus*, a fossil moose, or elk, from the Quaternary of New Jersey. Proceedings of the Academy of Natural Sciences of Philadelphia **37**:181-202.

Stanford, S. D. 1993. Late Wisconsinan glacial geology of the New Jersey Highlands. Northeastern Geology **15**(3-4):210-223.

Stanford, S. D. 2006. Surficial geology of the Morristown quadrangle, Essex and Morris Counties, New Jersey. New Jersey Geological Survey, Trenton, NJ. Open-File Map 67. Scale 1:24,000. Online. http://www.state.nj.us/dep/njgs/pricelst/ofmap/ofm67.pdf. Accessed November 2009.

Stanford, S. D. 2007. Surficial geology of the Chatham quadrangle, Morris, Union, and Somerset counties, New Jersey. New Jersey Geological Survey, Trenton, NJ. Open-File Map 69. Scale 1:24,000. Online. http://www.state.nj.us/dep/njgs/pricelst/ofmap/ofm69.pdf. Accessed November 2009.

Stanford, S. D. 2009. Surficial geology of the Bernardsville quadrangle, Morris and Somerset counties, New Jersey. New Jersey Geological Survey, Trenton, NJ. Open-File Map 74. Scale 1:24.000. Online. http://www.state.nj.us/dep/njgs/pricelst/ofmap/ofm74.pdf. Accessed November 2009.

Stanford, S. D., G. M. Ashley, and G. J. Brenner. 2001. Late Cenozoic fluvial stratigraphy of the New Jersey Piedmont: a record of glacioeustasy, planation, and incision on a low-relief passive margin. Journal of Geology **109**(2):265-276.

Stone, B. D., G. E. Reimer, and R. R. Pardi. 1989. Revised stratigraphy and history of glacial Lake Passaic, New Jersey. Abstracts with Programs - Geological Society of America **21**(2):69.

Stone, B. D., S. D. Stanford, and R. W. Witte. 2002. Surficial geologic map of northern New Jersey. U.S. Geological Survey, Reston, VA. Miscellaneous Investigations Series Map 2540-C. Scale 1:100,000.

Sykes, L. R., J. G. Armbruster, W.-Y. Kim, and L. Seeber. 2008. Observations and tectonic setting of historic and instrumentally located earthquakes in the greater New York City-Philadelphia area. Bulletin of the Seismological Society of America **98**(4):1696-1719.

Thieme, D. 1998. Late Pleistocene through Holocene paleohydrology of the Hackensack and Passaic drainages and the potential for deeply buried archaeological sites. Abstracts with Programs - Geological Society of America **30**(1):78.

Thieme, D. M. 2003. Archaeological site formation in glaciated settings, New Jersey and southern New York. Pages 163-179 *in* Cremeens, D. L. and J. P. Hart, editors. Geoarchaeology of landscapes in the glaciated Northeast. New York State Museum and Science Service, Albany, NY. Bulletin 497.

Thomson, K. S. and A. R. McCune. 1984. Scale structure as evidence of growth patterns in fossil semionotid fishes. Journal of Vertebrate Paleontology **4**(3):422-429.

Uchupi, E., N. Driscoll, R. D. Ballard, and S.T. Bolmer, 2001. Drainage of late Wisconsin glacial lakes and the morphology and late Quaternary stratigraphy of the New Jersey-southern New England continental shelf and slope. Marine Geology **172**(1-2):117-145.

Volkert, R. A. 2004. Mesoproterozoic rocks of the New Jersey Highlands, north-central Appalachians: petrogenesis and tectonic history. Pages 697-728 *in* Tollo, R. P., L. Corriveau, J. McLelland, and M. J., editors. Proterozoic tectonic evolution of the Grenville Orogen in North America. Geological Society of America, Boulder, CO. Memoir 197.

Volkert, R. A. and J. N. Aleinikoff. 2007. 1.3 Ga continental-margin magmatic arc and back arc in the New Jersey Highlands and implications for the origin of zinc + iron deposits. Abstracts with Programs - Geological Society of America **39**(1):37.

Volkert, R. A. and A. A. Drake Jr. 1999. Geochemistry and stratigraphic relations of middle Proterozoic rocks of the New Jersey Highlands. U.S. Geological Survey, Reston, VA. Professional Paper 1565-C. Online. http://pubs.er.usgs.gov/usgspubs/pp/pp1565C. Accessed November 2009.

Volkert, R. A., C. A. Johnson, and A. V. Tamashausky. 2000. Mesoproterozoic graphite deposits, New Jersey Highlands: geologic and stable isotopic evidence for possible algal origins. Canadian Journal of Earth Sciences **37**(12):1665-1675.

Whiteside, J. H. and P. E. Olsen. 2005. Arboreal stromatolites from the Triassic and Jurassic of eastern North America: implications for environmental change. Abstracts with Programs - Geological Society of America **37**(1):8.

Witte, R. W. 1997. Late Wisconsinan glacial history of the upper part of Kittatinny Valley, Sussex and Warren counties, New Jersey. Northeastern Geology and Environmental Sciences **19**(3):155-169.

Additional References

Clarke, J. M. 1903. Mastodons of New York. Pages 921-933 *in* Merrill, F. J. H. and J. M. Clarke, editors. Report of the State Paleontologist 1902. New York State Museum and Science Service, Albany, NY. Bulletin 69.

Crowl, G. H. and R. Stuckenrath. Jr. 1977. Geological setting of the Shawnee-Minisink Paleoindian archeological site (36-Mr-43). Annals of the New York Academy of Sciences **288**:218-222.

Darton, H. 1885. Ancient bone cave in Pennsylvania. Scientific American Supplement **19**(472):7541-7542.

Dunning, G. R. and J. P. Hodych. 1990. U/Pb zircon and baddeleyite ages for the Palisades and Gettysburg sills of the northeastern United States: implications for the age of the Triassic/Jurassic boundary. Geology **18**(8):795-798.

Duty, D. W., M. J. Pavich, B. D. Stone, G. E. Reimer, and G. M. Ashley, investigators. 1982. Lake Passaic sediments and their implications as to geologic history. Pages 57-58 *in* Geological survey research. U.S. Geological Survey, Reston, VA. Professional Paper 1275. Online. http://pubs.er.usgs.gov/usgspubs/pp/pp1275. Accessed November 2009.

Holman, J. A. 1999. Appalachian Pleistocene herpetofaunas: general stasis in the epoch. Pages 145-153 *in* Eckerlin, R. P., editor. Proceedings of the Appalachian biogeography symposium. Virginia Museum of Natural History, Martinsville, VA. Special Publication 7.

Li, Y.-X., Z. Yu, and K. P. Kodama. 2007. Sensitive moisture response to Holocene millennial-scale climate variations in the Mid-Atlantic region, USA. The Holocene **17**(1):3-8.

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

McNett, C. W. Jr., B. A. McMillan, and S. B. Marshall. 1977. The Shawnee-Minisink Site. Annals of the New York Academy of Sciences **288**:282-296.

Mercer, H. C. 1894. Re-exploration of Hartman's Cave, near Stroudsburg, Pennsylvania, in 1893. Proceedings of the Academy of Natural Sciences of Philadelphia **46**:96-104.

Metz, R. 1991. Trace fossils, including a rare occurrence of ancient scratch circles, from the Towaco Formation (Lower Jurassic) of New Jersey. Abstracts with Programs - Geological Society of America **23**(1):104.

National Park Service. 2009. Morristown National Historical Park: ancillary map information document. National Park Service Natural Resource Program Center, Fort Collins, CO.

Olsen, P. E. 1995. Paleontology and paleoenvironments of Early Jurassic age strata in the Walter Kidde Dinosaur Park (New Jersey, USA). Pages 156-190 *in* Baker, J. E. B., 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, Trenton, NJ. Annual Field Conference 12.

Olsen, P. C., A. R. McCune, and K. S. Thomson. 1982. Correlation of the early Mesozoic Newark Supergroup by vertebrates, principally fishes. American Journal of Science **282**:1-44. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_mccune_thomson_sm.pdf. Accessed November 2009.

Oshchudlak, M. E. and J. F. Hubert. 1988. Petrology of Mesozoic sandstones in the Newark Basin, central New Jersey and adjacent New York. Pages 333-352 in Manspeizer, W., editor. Triassic-Jurassic rifting: continental breakup and the origin of the Atlantic Ocean and passive margins. Developments in Geotectonics **22**(Part A). Elsevier, Amsterdam, The Netherlands.

Puffer, J. H. and J. J. Student. 1992. Volcanic structures, eruptive style, and posteruptive deformation and chemical alteration of the Watchung flood basalts, New Jersey. Pages 261-277 *in* Puffer, J. H. and P. C. Ragland, editors. Eastern North American Mesozoic magmatism. Geological Society of America, Boulder, CO. Special Paper 268.

Ray, C. E. 1966. The identity of *Bison appalachicolus*. Notulae Naturae of the Academy of Natural Sciences of Philadelphia 384.

Schaeffer, B. 1948. A study of *Diplurus longicaudatus* with notes on the body form and locomotion of the Coelacanthini. American Museum Novitates 1378. Online. http://digitallibrary.amnh.org/dspace/bitstream/2246/2333/1/N1378.pdf. Accessed November 2009.

Stewart, T. P. 1828. Mammoth near Schooley's Mountain, New Jersey. American Journal of Science **14**(1):188-189.

Stone, B. D., M. J. Pavich, G. E. Reimer, J. C. Liddicoat, investigators. 1983. Glacial Lake Passaic. Page 163 *in* Geological research 1982. U.S. Geological Survey, Reston, VA. Professional Paper 1375.

Thompson, L. 1994. Discovery of the American mastodon (*Mammut americanum*) in New York State: 1921-1994. Thesis. University of Rochester, Rochester, NY.

Tucci, H. J. 1986. Archaeological investigations of Durham Cave. Current Research in the Pleistocene **3**:25-26.

Van Houten, F. B. 1980. Late Triassic part of Newark Supergroup, Delaware River section, west-central New Jersey. Pages 264-276 *in* Manspeizer, W., 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, NY.

Volkert, R. A. 1988. Geologic map of the Mendham Quadrangle, Morris County, New Jersey. New Jersey Geological Survey, Trenton, NJ. Geologic Map Series 88-3. Scale 1:24,000.

Volkert, R. A. 1988. Provisional geologic map of the Proterozoic Rocks of the Morristown Quadrangle, New Jersey. New Jersey Geological Survey, Trenton, NJ. Geologic Map Series 88-4. Scale 1:24,000.

Volkert, R. A. and J. H. Puffer. 1995. Late Proterozoic diabase dikes of the New Jersey Highlands: a remnant of Iapetan rifting in the north-central Appalachians. U.S. Geological Survey, Reston, VA. Professional Paper 1565-A.

Volkert, R. A., M. D. Feigenson, L. C. Patino, J. S. Delaney, and A. A. Drake Jr. 2000. Sr and Nd isotopic compositions, age and petrogenesis of A-type granitoids of the Vernon Supersuite, New Jersey Highlands, USA. Lithos **50**(4):325-347.

Weishampel, D. B. and L. Young. 1996. Dinosaurs of the East Coast. Johns Hopkins University Press, Baltimore, MA.

Data Sets

Morristown National Historical Park Paleontological Archives
1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Morristown National Historical Park Digital Bedrock Geologic Map
2009-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online.
http://science.nature.nps.gov/nrdata/datastore.cfm?ID=48356.

Morristown National Historical Park Digital Surficial Geologic Map
2009-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online.
http://science.nature.nps.gov/nrdata/datastore.cfm?ID=48355.

New Jersey Digital Geologic Map
1999-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by New Jersey Geological Survey staff; status: Active. Online.
http://tin.er.usgs.gov/geology/state/state.php?state=NJ.

Roosevelt-Vanderbilt National Historic Sites

Three parks in and around Hyde Park, New York are administered together as the Roosevelt-Vanderbilt National Historic Sites (ROVA). The parks include Eleanor Roosevelt National Historic Site (ELRO), Home of Franklin D. Roosevelt National Historic Site (HOFR), and Vanderbilt Mansion National Historic Site (VAMA).

ELRO was established to protect Val-Kill, the home of First Lady Eleanor Roosevelt. It was authorized May 26, 1977, and encompasses 73.05 ha (180.50 acres), all under federal administration.

HOFR protects Springwood, the birthplace and longtime residence of President Franklin D. Roosevelt, as well as the gravesites of the President and First Lady Eleanor. HOFR was designated January 15, 1944. Its boundaries have changed multiple times: October 23, 1952; November 2, 1964; January 23, 1974; March 3, 1975; May 31, 1984; March 29, 1989; November 10, 1998; January 5, 2007; and May 10, 2009. It encompasses 323.74 ha (799.98 acres), 155.51 ha (384.27 acres) of which are under federal administration.

VAMA was established to preserve the 19th century mansion of Frederick W. Vanderbilt. It was designated December 18, 1940, and encompasses 85.65 ha (211.65 acres), all of which are under federal administration.

Although Martin Van Buren National Historic Site (MAVA) is not officially included in the Northeast Temperate Network, nor is it one of the ROVA units, it is mentioned here due to its proximity and geologic similarity to the ROVA parks. MAVA is located 66 km (41 miles) north-northeast of VAMA, and was established to preserve Lindenwald, the retirement home of President Martin Van Buren. It was authorized October 26, 1974, and encompasses 16.01 ha (39.55 acres), all but 0.10 ha (0.24 acres) of which are under federal administration. However, an expansion to 121 ha (300 acres) has been approved for 2009, which would include much more of the original farm site.

Geologic Background

The ROVA units are located in western Dutchess County, New York, in and around Hyde Park. This area is within the Hudson Valley. VAMA is farthest north and is situated on the east bank of the Hudson River. It is about 1.6 km (1 mile) north of HOFR, also on the Hudson River. ELRO shares its western border with the main portion of HOFR, and detached units of HOFR border it on its north and east. Several small streams run through the park units. Poughkeepsie is 6.5 km (4 miles) south of HOFR and ELRO. To the west are the Catskill and Shawangunk Mountains, and to the east are the Taconic Mountains. MAVA, in northwestern Columbia County, New York, is farther from the river (6.8 km [4.2 miles] east). The ROVA parks are in the Valley and Ridge physiographic province (Faber 2002), while MAVA is in the Hudson-Mohawk Valley province (Case 1989). Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held for the ROVA parks during July 2007. The geology of the ROVA parks was described in a geologic scoping summary by the National Park Service (2008), an internal NPS document.

The rocks underlying the ROVA parks and MAVA began as Ordovician sediments (see the appendix for a geological time scale) that were faulted onto rocks to the west during one of the collisions that led to the formation of the supercontinent Pangaea. Eastern New York was near the boundary of the North American continent at the beginning of the Paleozoic, shortly before the deposition and disruption of the ROVA/MAVA bedrock. Prior continental rifting left a passive plate boundary (D. W. Fisher and Warthin 1976; Karabinos et al. 1999), similar to today's, where the continental crust leads into an ocean basin that is part of the same tectonic plate. This margin persisted until the Cambrian, when landmasses began colliding with North America. The collision that most affected eastern New York occurred during the Ordovician-age mountain-building event known as the Taconic Orogeny. The North American landmass of this time is known as Laurentia, the technical term for the core of the continent; this name commonly appears in scientific publications (Levin 1999).

The Taconic Orogeny of the northeastern United States has long been a source of controversy among geologists, even leading to court cases, criminal accusations, and expulsions (Friedman 2008). While the name might imply otherwise, it was not a simple single-stage occurrence, but a series of episodes (Rodgers 1971). In the New York region, the effects of the orogeny became apparent beginning approximately 458 Ma (million years ago) (Hurowitz and McLennan 2005). Exactly what happened during the orogeny is debated, and models with one or two subduction zones and the collision of one or two volcanic arcs have been proposed (Karabinos et al. 2003). The approach of the arc(s) was preceded by volcanic activity recorded as altered ash beds and similar deposits in sedimentary rocks forming to the west (Rodgers 1971; Rowley et al. 1979). Deformation and metamorphism increase from west to east (Rowley et al. 1979). Much of New York east of the Hudson River is made up of the Taconic Allochthon, a controversial area of displaced rocks.

The Taconic Allochthon is the general term for a series of fault blocks and slices found on either side of the immediate vicinity of New York's eastern border. Its component thrust sheets include upper Proterozoic and Cambrian rocks from the rift period and overlying Cambrian-Ordovician rocks from the continental rise that formed after the rift. The various thrust sheets have led to much confusion about the definitions of the rock formations (Kidd et al. 1995). One Taconic Allochthon thrust sheet, the Livingston Slice, is present just south of the ROVA parks (Goodwin et al. 2003). MAVA probably overlies the large Giddings Brook Slice (Rowley et al. 1979; Rowley and Kidd 1981). "Allochthon" is the term for a block or slice of rocks that have been transported from its original setting. The adjective "allochthonous" also describes this property, and is commonly used in geology. Similarly, "autochthon" and "autochthonous" refer to rocks that have remained where they were first deposited or formed. Some other terms, including "parautochthonous" and "neoautochthonous," refer to rocks that have only moved a short distance, intermediate between allochthony and autochthony. These last terms are sometimes used in reference to the Austin Glen Formation (see below).

The basic model for the creation of the Taconic Allochthon is as west-moving low angle thrust sheets traveling across the floor of a foreland basin (foreland basins are basins formed in response to adjacent mountain ranges). Some associated formations, such as the Austin Glen Formation, were deposited throughout the faulting process, before, during, and after movement (Sanders 1995). The various thrust sheets originally formed a deepwater continental rise. As part of the Taconic Orogeny's compressional activity, the rise was faulted onto the continental shelf (Hurowitz and McLennan 2005). The foreland basin subsided due to the addition of the thrust sheets and other sediment. This led to the sinking of the wide shallow marine platform to the west (Lehmann et al. 1994). The thrust sheets of the Allochthon were moved a substantial distance, perhaps 200 km (120 miles) (Hurowitz and McLennan 2005) to 1,000 km (620 miles) (Stanley and Ratcliffe 1985). Thus, much of the rock east of the Hudson River in New York actually formed some distance to the east.

Extensional stresses set in between the Taconic Orogeny and the later Acadian Orogeny, with some igneous activity (Fisher and Warthin 1976). Tectonic collisions after the Taconic Orogeny did not affect eastern New York as extensively, because the continental margin had moved farther east. The Acadian Orogeny contributed some folding, cleavage, and other deformation to eastern New York (Toots 1976). The later Alleghenian Orogeny, when Africa and South America collided with North America, had most of its effects outside of the ROVA/MAVA region, although the continental breakup that followed produced a few faults in Dutchess County and igneous activity to the south in Rockland County, dating to approximately 185 Ma (D. W. Fisher and Warthin 1976).

More recently, glacial activity during the Pleistocene (between 2.59 Ma and approximately 12,000 years ago) scoured and reworked the preexisting topography. There were four major periods of glaciation, but only the last (Wisconsinan) is evident at the surface in New York. Dutchess County was completely covered by ice (Faber 2002). The most recent glacial advance of the area was represented by the Hudson-Champlain lobe of the Laurentide Ice Sheet (Connally 1983). It overprinted previous glacial activity and left a great quantity of loose sediments during its retreat. Deglaciation was underway 20,000 years ago (Robinson et al. 2005). The glacial retreat left numerous recessional moraines (piles of glacial debris

deposited at standstills during retreat), including the Hyde Park Moraine that runs from Hyde Park to Salt Point (Faber 2002). This moraine is probably over 17,000 years old. It formed a delta into Glacial Lake Albany (see below); Hyde Park is now built on this delta (Connally and Sirkin 1986). The Hyde Park mastodon was found in sediment derived from the Hyde Park Moraine (Miller and Nester 2006).

As the ice sheet retreated, vast lakes of glacial meltwater formed in valleys that were blocked by ice and sediment dams. Major glacial lakes in New York included Glacial Lake Albany in the Hudson Valley (which inundated the Hyde Park area; Dineen 1986), Glacial Lake Iroquois in the Lake Ontario-St. Lawrence lowlands west of the Adirondacks, and Glacial Lake Vermont in the Champlain Valley. Glacial Lake Iroquois initially drained into the Hudson Valley through the Mohawk Valley, but it switched to draining into Glacial Lake Vermont as the ice margin retreated. This caused Glacial Lake Iroquois to fail catastrophically, followed by Glacial Lake Vermont (Rayburn et al. 2002). This catastrophic drainage of glacial lakes Albany, Iroquois, and Vermont took place approximately 13,350 years ago, sending a massive freshwater pulse into the Atlantic through the Hudson Valley. The freshwater pulse was a possible trigger for a short cold period (Donnelly et al. 2004; Thieler et al. 2007).

Glacial Lake Albany is also a collective term for a series of named stages corresponding to extended periods of stable lake level, progressively lower over time. From oldest to youngest, these are the Lake Albany, Lake Quaker Springs, Lake Coveville, and Lake Fort Ann stages. Together, they existed for a few thousand years, disappearing over 11,000 years ago (Dineen and Miller 2006). The history of Glacial Lake Albany and its successor lakes is described in detail by Dineen and Rogers (1979). Megafauna expanded into the Hudson Valley as the Wisconsinan ice sheet retreated, but went extinct in a few millennia or less (Robinson et al. 2000). By approximately 10,000 years ago most of the megafauna was extinct. Humans probably arrived around 12,500 years ago (Funk 1977).

The bedrock geology of the ROVA units consists of Ordovician-age sedimentary rocks. From oldest to youngest, these include the Stuyvesant Falls Formation, Indian River Formation, Mount Merino Formation, Austin Glen Formation, and Taconic mélange. The Hyde Park area is largely underlain by the Austin Glen Formation, with a fault-bounded lens of older rock that is divided in part between ELRO and HOFR. ELRO is mostly over the Austin Glen Formation, with the southwestern section of the park over a combination of the Indian River and Mount Merino formations in the fault slice, and the southeast section over a Taconic mélange (a rock unit composed of large rock fragments [up to km scale] in a fine-grained matrix, formed at convergent plate boundaries). HOFR is mostly underlain by the Austin Glen Formation, with the Stuyvesant Falls Formation present under the central and eastern sections of the main unit, and possibly some mélange under the southern part of the eastern detached unit. The Stuyvesant Falls stratigraphic interval has several names, but Stuyvesant Falls Formation will be retained here to reduce confusion when referring to the New York state geological map (D. W. Fisher et al. 1970a, b). This issue will be discussed further below. Finally, VAMA is entirely underlain by the Austin Glen Formation (D. W. Fisher et al. 1970a). Before expansion, MAVA was entirely underlain by the Stuyvesant Falls Formation, but the expansion will probably include the undivided Indian River and Mount Merino formations, and the Austin Glen Formation (D. W. Fisher et al. 1970b). The surficial geology of the ROVA units and MAVA consists of a combination of bedrock outcrops, Pleistocene glacial deposits, post-glacial lake and river deposits, and modern soils (Cadwell et al. 1987, 1989). The fossils of the ROVA units are limited to isolated shell imprints in rock of unknown provenance (D. Hayes, ROVA natural resource program manager, pers. comm., October 2009).

Sources of Paleontological Resources

The fossils of the ROVA parks and MAVA present opportunities for education, interpretation, and continued or future scientific research in the park. As noted, shell imprints are known at the ROVA parks, but they are undescribed.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within the ROVA parks. However, they are known to preserve fossils elsewhere, and future field investigations within the parks may uncover fossils in them. Mappable bedrock outcrops are present at HOFR and VAMA (Cadwell et al. 1989).

Stuyvesant Falls Formation (Lower-Middle Ordovician)

The Stuyvesant Falls Formation is only mapped under HOFR among the ROVA units (D. W. Fisher et al. 1970a). It is also present under MAVA (D. W. Fisher et al. 1970b). The stratigraphic interval here called the Stuyvesant Falls Formation has gone under several names. Landing (1988) notes that the Deepkill (or Deep Kill) Formation, Poultney Slate, Schaghticoke Shale, and Stuyvesant Falls Formation are synonyms. The Stuyvesant Falls Formation is the most recent of the names for the interval, coined in 1962 (D. W. Fisher 1962). Because the Stuyvesant Falls Formation was used on the state geological map (D. W. Fisher et al. 1970a), it is used here. However, it seems the use of this name is out of favor now, replaced by the Deepkill Formation (Landings 1988; Landing and Bartowski 1996) or Poultney Formation (Hurowitz and McLennan 2005). Regardless of the name, the rocks are part of the allochthonous Taconic slices (Fisher and Warthin 1976). The upper boundary with the Indian River Formation is conformable (Theokritoff 1964).

The Stuyvesant Falls Formation is mostly composed of shale, with some interbedded dolomite and quartzite beds, bedded gray-green chert, thin black shale seams, and black chert. This formation is interpreted as a distal slope and oceanic basin deposit (D. W. Fisher and Warthin 1976), forming under low energy conditions (D. W. Fisher 1977). It is at least 120 m (400 ft) thick (D. W. Fisher 1962). The age of the unit is Early Ordovician in part, with graptolites (a type of extinct free-floating colonial animal useful for establishing relative dates) indicating deposition between at least 479 and 472 Ma (the upper and lower boundaries are uncertain) (D. W. Fisher and Warthin 1976). The dates of the other units vary from this; the Deepkill Formation can be extended somewhat farther back, to between approximately 483 and 472 Ma (Landing 1988), and the Poultney Formation has been dated to between approximately 488 and 472 Ma (Hurowitz and McLennan 2005). The significance of these differences is debatable, given the diversity of opinions concerning Taconic geology and which rocks make up each unit.

The other units named for this interval are similar combinations of fine-grained rocks (slate and shale), carbonates (limestone and dolomite), and quartzite (Theokritoff 1964; Baldwin and Raiford 1988; 270 Landing 1988). A notable characteristic of the interval is the presence of alternating greenish rocks and dark rocks. The greenish units are interpreted as coming from more oxygen-rich periods, while the black units are interpreted as representing expansions of a long-term anoxic slope environment (Landing 1988).

Fossils are rare in the Stuyvesant Falls Formation. They include graptolites in the shale, and trace fossils on quartzite beds (D. W. Fisher 1977). The Deepkill Formation has a more diverse fossil record, including radiolarians (amoeba-like microorganisms that secrete outer coverings of silica) and sponge fragments in chert (Ruedemann 1942), crustaceans, graptolites (Berry 1962), and conodonts (eel-like extinct chordates) (D. W. Fisher 1988). Conodonts are present in conglomerate that marks the base of the Deepkill Formation, and in the green shales (D. W. Fisher 1988). Graptolites are present in the Poultney Formation (Theokritoff 1964).

Indian River Formation (Middle Ordovician)

Undivided Indian River/Mount Merino Formation rocks are mapped only at ELRO among the ROVA parks (D. W. Fisher et al. 1970a). The Indian River Formation (also Slate) is a colorful fine-grained unit. It is sometimes assigned to the Normanskill Formation or Group (D. W. Fisher 1962; D. W. Fisher and Warthin 1976). The unit is composed of red, blue-green, and purple slates (Landing 1988), maroon to bright red and pale green shale, red and green chert, limestone lenses that may represent turbidites (underwater sediment avalanche deposits) (D. W. Fisher and Warthin 1976), and some rare coarser material (Landing 1988). The red color is unusual for its time and place, and helped make the Indian

River Formation important to the early New York slate industry (Landing 1988). The formation is only about 50 m (160 ft) thick (Landing 1988). The lower boundary with the Stuyvesant Falls interval is conformable, as is the upper boundary with the Mount Merino Formation (Berry 1962), albeit abrupt (Landing 1988). It also grades laterally into the Mount Merino Formation (D. W. Fisher 1962), and the two are often mapped together (D. W. Fisher et al. 1970a). A good exposure of the Indian River Formation is located 14.1 km (8.75 miles) east of Hyde Park (Berry 1962).

The Indian River Formation is interpreted as a distal slope and oceanic basin deposit (D. W. Fisher and Warthin 1976), accumulating on trough slopes (McLelland and D. W. Fisher 1976) under low-energy conditions (D. W. Fisher 1977). Flint-rich horizons in the middle and upper parts are thought to be altered volcanic tuff beds (Rowley et al. 1979). The formation dates to the late Middle Ordovician, between approximately 464 and 461 Ma (*Nemagraptus gracilis* graptolite zone) (Landing 1988), and is interpreted as marking the onset of the Taconic Orogeny (Landing 2000).

Fossils are very rare in the Indian River Formation. Radiolarians are present in the chert, and graptolites in the shale. Benthic (bottom-dwelling) organisms are absent (D. W. Fisher and Warthin 1976; D. W. Fisher 1977).

Mount Merino Formation (Middle and/or Upper Ordovician)

Undivided Indian River/Mount Merino Formation rocks are mapped only at ELRO among the ROVA parks (D. W. Fisher et al. 1970a). The Mount Merino Formation (also Shale, or Member) is another of the formations in the Taconic Allochthon (D. W. Fisher and Warthin 1976). It is sometimes included in the Normanskill Formation or Group (D. W. Fisher 1962; Zen 1964; D. W. Fisher and Warthin 1976). The Mount Merino Formation is usually a greenish-gray shale with thin intervals of coarser quartz-rich material, lithologically similar to the Stuyvesant Falls interval (see above) (Landing 1988). There are minor quantities of carbonates, quartzites, and siltstones (Zen 1967). The lower portion is composed of shale, chert, and siltstones, and the upper portion is composed of shale, siltstone, conglomeratic carbonates, and thin carbonate lenses (Goodwin et al. 2003). Silt increases toward the top, perhaps due to increasing turbidity currents (Landing 1988). The two portions are sometimes informally known as the Lower Chert Member (lower) and the Stoddard Road Member (upper) (Rowley et al. 1979). Overall, the formation is only about 50 m (160 ft) thick (Landing 1988). The age of the formation is approximately 462 to 456 Ma, based on graptolite zones (*Nemagraptus gracilis* to *Climacograptus bicornis* zones; Rowley et al. 1979; Landing 1988).

The underlying Indian River Formation grades into the Mount Merino Formation (Berry 1962), albeit abruptly (Landing 1988); the two units are also laterally gradational (D. W. Fisher 1962). Above is the Austin Glen Formation. This contact is marked by quartz-rich beds in dark shale (Landing 1988). Per the contentious Taconic geology in general, this contact is interpreted as gradational (Berry 1962) or unconformable (Sanders 1995; Goodwin et al. 2003); more recent descriptions favor an unconformable contact. The formation's depositional environment is interpreted as the continental rise (Hurowitz and McLennan 2005), with low energy (D. W. Fisher 1977). It accumulated on trough slopes (McLelland and D. W. Fisher 1976), and formed from arc-related sediments (Landing and Bartowski 1996) eroded during the Taconic Orogeny (Hurowitz and McLennan 2000).

Fossils are rare in the Mount Merino Formation (D. W. Fisher and Warthin 1976; D. W. Fisher 1977). There are radiolarians in the chert of the lower portion, and graptolites in the shale of the upper portion (Landing 1988). Benthic organisms are absent (D. W. Fisher and Warthin 1976; D. W. Fisher 1977). The graptolites are useful for strain analyses of the Taconic Orogeny; in these studies, the shapes of metamorphosed graptolites are compared to those of unmetamorphosed graptolites (Goldstein et al. 1998).

Austin Glen Formation (Middle and/or Upper Ordovician)

The Austin Glen Formation (or Graywacke or Member) is widespread in the Hyde Park area, underlying all of the ROVA units (D. W. Fisher et al. 1970a). The Austin Glen Formation is a flysch (a rock unit

composed of cycles of sediment that become finer upward, deposited by turbidity currents in a foreland basin in advance of a continental collision) of the Taconic Orogeny (Bock et al. 1998). It is sometimes included in the Normanskill Formation or Group as its upper unit (D. W. Fisher 1962; Zen 1964; D. W. Fisher and Warthin 1976). However, the Austin Glen Formation is now regarded as forming not only with the older Normanskill units, but also during and after the thrust faulting that formed the Taconic Allochthon, which makes it distinct from the older units (Rowley et al. 1979; Sanders 1995; Goldstein et al. 1998). It was deposited and lithified in time to become part of Taconic mélange (D. W. Fisher and Warthin 1976), although it was not completely lithified during folding (Toots 1976). The lower part of the formation is composed of graywacke (dark, hard, poorly sorted sandstone with angular grains) and more typical sandstone interbedded with bluish dark shale, while the upper part is composed of graywacke, conglomerate, and shale beds (D. W. Fisher and Warthin 1976). The Austin Glen Formation is much thicker than the older units covered here, at 120 to 150 m (400 to 500 ft) thick in Columbia County. Various units mapped as the Snake Hill Formation or Shale overlie it (Berry 1962, although see below). As noted above, the contact with the underlying Mount Merino Formation has been interpreted as gradational (Berry 1962) or unconformable (Sanders 1995; Goodwin et al. 2003), with more recent descriptions favoring an unconformable contact. Based on graptolite zones, the Austin Glen Formation dates to either between approximately 462 and 456 Ma (*Nemagraptus gracilis* and *Climacograptus bicornis* zones; Bock et al. 1998) or between approximately 460 and 450 Ma (*Climacograptus bicornis* and *Orthograptus truncatus* var. *intermedius* zone; Landing 1988).

The Austin Glen Formation may or may not be the same as several other units. It is equivalent to the Pawlet Formation (Zen 1964, 1967; Kidd et al. 1995). "Austin Glen" is more commonly used in the central and southern Taconic region, while "Pawlet" is more commonly used in the northern Taconic region (Rowley and Kidd 1981; Landing 1988). The Snake Hill Formation is sometimes considered synonymous with the Austin Glen Formation (Berry 1963; Kidd et al. 1995), or equivalent to it (Zen 1967), although it is regarded as distinct by English et al. (2006), at least at its type locality on Saratoga Lake, 135 km (85 miles) north of VAMA. Some authors consider the Austin Glen Formation, Pawlet Formation, and Snake Hill Shale identical, and advocate abandonment of the Normanskill concept and the Snake Hill Shale, with restriction of the Austin Glen Formation to the folded part of the graywacke and shale (Kidd et al. 1995).

The Austin Glen Formation was deposited rapidly on the unstable continental slope (D. W. Fisher and Warthin 1976). The graywacke and graywacke conglomerates represent turbidites, while the finer-grained rocks probably represent periods of time with fewer turbidites (D. W. Fisher 1977). Between Albany and Poughkeepsie the Austin Glen Formation is mostly represented by submarine channels and interchannel depositional areas (McCarthy and Lash 1985). Both the Austin Glen and Pawlet formations are composed of turbidites that formed from sediment eroded from areas to the east (Rowley and Kidd 1981). The sequence may have begun with turbidites being deposited on outer and inner trench slopes. Then, after the Taconic Allochthon was thrust onto the continental margin, Austin Glen and Pawlet deposition spread out as a sediment blanket across the margin as well (Landing 1988).

The fossils of the Austin Glen and Pawlet formations are not diverse, with graptolites the most commonly cited fossil organisms (D. W. Fisher and Warthin 1976; Rowley et al. 1979). Pyritized worm burrows have also been reported from the Austin Glen Formation (Bock et al. 1998). Graptolites are found in the shale but are rare in the graywacke beds (D. W. Fisher 1977).

Taconic mélange (Upper Ordovician)

Of the ROVA parks, ELRO and possibly the eastern detached section of HOFR overlie what can be described as Taconic mélange (D. W. Fisher et al. 1970a). One of the effects of the Taconic Orogeny was the formation of "block in shale" or mélange units. The blocks are not necessarily small, as in common conglomerates; entire stratigraphic units, such as the Rysedorph Hill Conglomerate, the Stark's Knob basalts (Kidd et al. 1995), and the Snake Hill Formation (English et al. 2006), may be "blocks in shale". Mélange is found around and beneath the large thrust sheets of the Taconic Allochthon, and formed at the same time as the thrusts (Landing 1988). Because of how it formed, the mélange is not a conventional layer-cake stratigraphic unit (Kidd et al. 1995). There is not one type of mélange, either (Sanders 1994;

Kidd et al. 1995; Sanders and Guo 1995); each area of mélange varies depending on the rocks that went into it, and the processes that formed it.

The mélange formed as a sort of super-conglomerate. Blocks of rock were shed by various preexisting units, either as a result of submarine gravity slides, or from falling off of the leading edge of thrust-faulted segments of formations. These loose blocks would then enter basins where mudrocks were being formed, and become incorporated into the new units (Berry 1962; D. W. Fisher and Warthin 1976). Some may represent soft-sediment slumps on deep water marine deltas (Sanders 1994). Most of the rock pieces are graywacke, probably derived from the Austin Glen Formation (D. W. Fisher and Warthin 1976) or similar units (Sanders 1994). The result is well-expressed under the old term "blocks in shale." To further confuse matters, smaller-scale slumps and distortions are present in the Austin Glen Formation (Sanders and Guo 1995), including outcrops described as Poughkeepsie Mélange immediately south of the ROVA parks (Goodwin et al. 2003). Graptolites in the shale show that deposition occurred approximately 452 to 450 Ma (*Climacograptus spiniferus* zone; English et al. 2005).

Given the variable composition and origin, these rocks have been assigned several names, including the Bald Mountain Limestone, Forbes Hill Conglomerate, Poetskill Breccia, Rysedorph Conglomerate (D. W. Fisher et al. 1971), Whipstock Breccia (Landing 1988), Poughkeepsie Mélange, and, most recently, Cohoes Mélange (Kidd et al. 1995). Aside from "blocks in shale" or mélange, wildflysch (Baldwin and Raiford 1988) and diamictite (Sanders 1994, 1995; Sanders and Guo 1995) have also been used to more broadly describe the rocks. For simplicity, it has been opted here to simply identify it as Taconic mélange, following the New York state geologic map (D. W. Fisher et al. 1970a). Even "mélange" may be a misnomer. This term originated as a description for a type of rock unit formed in an accretionary wedge, having been scraped off of a plate at a subduction zone. At least some authors (Sanders 1994, 1995; Sanders and Guo 1995) have argued that there is no evidence for a subduction zone in the area and the mélange should be called "diamictite" instead, as a more general term that does not have tectonic connotations.

Taconic mélange is fossiliferous, and includes both fossils of organisms that lived in the same time and place as the formation of the mélange, and fossils from the shed blocks of older units. Fossils in the shale matrix, which pertain to the deposition of the mélange, include graptolites (Berry 1962, 1963; Landing 1988; Kidd et al. 1995; English et al. 2005). Older fossils from the exotic blocks represent a variety of marine organisms, including bryozoans (Baldwin and Raiford 1988), brachiopods, trilobites, ostracodes (Kidd et al. 1995; Sanders 1995), pelmatozoans (stalked echinoderms such as crinoids) (Baldwin and Raiford 1988), and graptolites (Kidd et al. 1995; Sanders 1995). Chert from the Mount Merino Formation, known to contain radiolarians (D. W. Fisher and Warthin 1976), is also present (Kidd et al. 1995). Limestone pebbles in mélange have yielded brachiopods, trilobites, and ostracodes, sometimes as old as the early Cambrian (Sanders 1995).

Quaternary rocks and sediments (Pleistocene-Holocene)

The Quaternary rocks and sediments of the ROVA units and MAVA are mostly derived from the actions of glaciers and postglacial lakes and rivers. Significant units at ELRO include outwash sand and gravel, and, in the east and southeast, thin till with bedrock within 1 to 3 m (3 to 10 ft) of the surface. HOFR surficial geology includes exposed bedrock, lake delta deposits in the central part of the park, outwash sand and gravel in the eastern part, and possibly thin till in the eastern detached unit. VAMA includes bedrock outcrops, lake sand deposits in the north, and two bodies of lake delta deposits, in the south and southeast (Cadwell et al. 1989). Pre-expansion, MAVA surficial geology is composed of lake delta deposits (Cadwell et al. 1987).

Fossils are known from a number of different sources in the Quaternary deposits, including lesser-known sources such as much older fossils in rocks eroded by the glaciers and left in till deposits (Ries 1891; Kay 1953), and potential root traces in clay (Ries 1891). Most finds, though, are either bones of Quaternary vertebrates, or pollen and other plant material used for paleoecological studies.

Southeast New York has abundant Quaternary megafaunal fossils (Robinson et al. 2001), particularly of mastodons (Clarke 1903; Hartnagel and Bishop 1921; D. W. Fisher and Reilly 1969; Robinson et al. 2005). By 1921 the area including Columbia, Dutchess, Greene, Rockland, Sullivan, Ulster, and especially Orange County boasted 42 mastodon finds. Among them are several historically notable specimens. The oldest record of mastodon fossils from North America is a tooth and several bones found in 1705 from the Claverack area, 50 km (31 miles) northeast of VAMA (and 16 km [10 miles] south of MAVA). The bones quickly disintegrated for the most part, but the tooth was brought to wider attention in 1714 by Cotton Mather, who interpreted the fossils as coming from an antediluvian ("pre-Flood") giant. This was followed in 1706 by a tooth from the Coxsackie area, 64 km (40 miles) north of VAMA. Continuing with the presidential theme of the ROVA parks and MAVA, Thomas Jefferson obtained the skull and jaws of a mastodon found in 1800 at Shawangunk, 26 km (16 miles) southwest of HOFR (paleontology being one of his numerous scholarly interests). The Newburgh area of Orange County, 32 km (20 miles) south-southwest of HOFR, has yielded numerous mastodon specimens, including several of note for their completeness or historical background (information per Hartnagel and Bishop [1921] except where noted): the Peale mastodon, excavated under the direction of Charles Willson Peale in 1801 from John Masten's farm at Newburgh, 32 km (20 miles) south-southwest of HOFR (Boxer 1985), and unfortunately appears to have later been lost or destroyed by fire; a specimen found in 1829 and described as the first example of *Tetracaulodon mastodontoideum* (Godman 1830), now known to be a mastodon but previously part of a long taxonomic argument; the Shawangunk Head, found in 1844 in Scotchtown; the Warren mastodon, found in 1845 and now at the American Museum of Natural History; the Whitfield skeleton, found in 1879 near Little Britain; the Schaffer skeleton, found in 1899; and the Temple Hill mastodon, found in 1921. Also of note, but not from Newburgh, is the Otisville or Marsh mastodon, found in 1872 east of the town, 58 km (36 miles) southwest of HOFR (Hartnagel and Bishop 1921; Robinson et al. 2005).

The most important mastodon and megafaunal find for the ROVA parks is the Hyde Park mastodon, from just north of ELRO and HOFR on Haviland Road (between 0.31 km [0.19 miles] and 1.6 km (1.0 miles] north to northeast of ELRO and HOFR detached units). It was found in 1999 during work on a small recreational pond (Lozier Pond) (D. C. Fisher and Sherpa 2003), and was excavated in 2000 from what is interpreted as a small oxbow wetland deposit; the animal was probably mired in the former pond. The skeleton was semiarticulated, and is between 84% and 91% complete, lacking only some of the tail and feet. It dates to between 13,425 and 13,234 calendar years before present (11,480 ± 50 radiocarbon years before present) (Miller and Nester 2006) (note that radiocarbon dates are not the same as calendar dates, and that radiocarbon years require calibration to yield calendar years. Uncalibrated radiocarbon dates in publications are often denoted with "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. Therefore, dates that are not labeled with "calendar years" or something similar should be assumed to be uncalibrated radiocarbon dates. Dates here were calibrated using Calib 5.0.2 [http://calib.qub.ac.uk/calib/] where the data permit). The individual was male, and is estimated to have been between 29 and 39 years old at death. It shows no evidence for Paleoindian butchering, but does show signs of injuries suffered from other mastodons (D. C. Fisher and Sherpa 2003). Plant fossils in the wetland date from between 15,613 to 15,058 calendar years before present (12,970 ± 40 radiocarbon years before present) to 13,238 to 13,020 calendar years before present (11,230 ± 50 radiocarbon years before present) (Miller and Nester 2006). The site has many other types of fossils, including diatoms (Allmon et al. 2001; Sokal and Hall 2003), peat, pollen, plant macrofossils (leaves, needles, twigs, seeds, fruits, cones, and megaspores from aquatic, wetland, and other plants), bivalves, gastropods, ostracodes (Miller and Nester 2006), and several types of beetles (Nelson et al. 2002).

A few other mastodon or mammoth finds are known from the Hyde Park area. Two mastodon finds were made in Poughkeepsie prior to 1855 (one in a shelly marl bed), and mastodon or mammoth fossils were found on the "Hyde Park road" in 1899. This Hyde Park material was found 4.5 m (15 ft) below the surface at a location identified as a "swamp on the old Macpherson place, in the Hyde Park road, near the country homes of Frederick W. Vanderbilt and other prominent New York persons." Bone fragments

and part of a tusk were recovered, with at least some of it sent to Vassar College (Hartnagel and Bishop 1921).

Other extinct megafauna are also represented in the area, especially from the Wallkill lowland to the southwest; the lowland may have been a Pleistocene migration route (D. W. Fisher and Reilly 1969). A stag moose or moose-elk (*Cervalces*) is known from the Newburgh-Montgomery area (Dewey Parr site), found with turtle and dog bones, and beaver-gnawed wood (Funk et al. 1970). Another stag moose is known from Pine Island (Pawelski Farm), 70 km (43 miles) southwest of HOFR (Robinson et al. 2001, 2005). A mammoth is reported from east of Ossining, 69 km (43 miles) south of HOFR, in marl flooring a peat bog (D. W. Fisher and Reilly 1969). The same site that yielded the Monroe mastodon, recovered between 1888 and 1901, 55 km (34 miles) south-southwest of HOFR, also had bear and horse fossils (Hartnagel and Bishop 1921). The Dutchess Quarry Caves, near Florida, 56 km (35 miles) southwest of HOFR, have the most diverse assemblage of these sites, including pollen, plant macrofossils, fish, amphibians, reptiles, birds, and mammals, mostly in caves 1 and 8. The bones were probably brought in by nonhuman predators or scavengers, and have been disturbed by cryoturbation (frost churning) and bioturbation. Taxa no longer living in the area include extinct flat-headed peccary and giant beaver, and caribou, which have emigrated elsewhere. The bones of the now-absent megafauna date from between 16,894 to 16,097 calendar years before present (13,840 ± 80 radiocarbon years before present) to 13,703 to 13,357 calendar years before present (11,670 ± 70 radiocarbon years before present) (Steadman et al. 1997). Among them are bones of caribou, from the lowest layer. A Cumberland-type point was found in the same layer (Guilday 1968). However, the bones cannot be definitely associated with human artifacts (Steadman et al. 1997). The higher levels are between 6,000 and 700 years old, based on associated artifacts (Funk et al. 1970). Ground sloths and American bison are also known from the Hudson Valley (D. W. Fisher and Reilly 1969).

While not as eye-catching, pollen, plant macrofossils, and invertebrates are widely distributed as well. They are often used for determining chronologies and examining paleoecology. Numerous sites from New York have organic materials that have been submitted for radiocarbon dating. The materials include peat, charcoal, wood, twigs, leaves, shells, bone, and unspecified organic debris (Muller and Calkin 1993). The nearest described pollen site is Eagle Hill Camp Bog in Columbia County, 25 km (16 miles) north of VAMA. Its pollen and organics are perhaps as old as approximately 13,890 radiocarbon years before present (Connally and Sirkin 1986). Other specific sites within approximately 100 km (60 miles) include: Heart's Content Bog, a pollen site 50 km (31 miles) north of VAMA (Ibe and Pardi 1985); Binnewater Pond, 64 km (40 miles) southwest of HOFR, which has pollen, spores, plant macrofossils, and charcoal (Robinson et al. 2005); Spruce Pond, 65 km (40 miles) southwest of HOFR, which has pollen, plant macrofossils, and charcoal (Maenza-Gmelch 1997); Burden Lake and a peat bog at West Sand Lake, pollen sites 88 km (55 miles) northeast of VAMA (Gaudreau 1982); Great Bear Swamp, a pollen site roughly 100 km (60 miles) northwest of VAMA; and Meadowdale Bog, a pollen site near Albany (Dineen 1986). As with the Hyde Park mastodon, megafaunal sites often also have useful material for paleoecological studies (Robinson et al. 2005). Additional information on pollen sites can be found on the National Oceanic and Atmospheric Administration's online Global Pollen Database (http://www.ncdc.noaa.gov/paleo/gpd.html).

Park Collections

The ROVA parks have no paleontological material in their collections to date.

Cultural Resource Contexts

Humans have been present in southeastern New York for over 10,000 years, so a human-fossil resource association would not be unexpected. In the vicinity of the ROVA parks and MAVA, Paleoindian and Archaic sites are known along the Hudson River, including ancient quarry sites where flint was taken for tools. Two sites, at Kings Road and West Athens Hill, are across the Hudson River from MAVA (Funk 1977). Paleoindian artifacts have also been found at Dutchess Quarry Cave (Guilday 1968). People may

have been hunting caribou, stag moose, and mastodon (Funk et al. 1970). Artifacts and human bones are known in the western part of the Millbrook quadrangle, east of Hyde Park (Murray 1976). Shell middens with occasional animal bones are present in the lower Hudson valley (south of Bear Mountain, 51 km [32 miles] south of HOFR). Human bones are very rare and habitations are not elaborate. The evidence suggests brief occupations to gather oysters on the river when other food sources were unavailable, particularly in late winter and early spring (Brennan 1977). To date, neither the ROVA parks nor MAVA have reported paleontological material from cultural resource contexts. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

In addition to surficial outcrops, many of the buildings and walls at ROVA use local stone, including the FDR Home and Library, Stone Cottage, and Top Cottage (D. Hayes, pers. comm., October 2009). While not known to be fossiliferous, these provide additional architectural "outcrops" of local geology, tying together natural history and human history.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division coordinated a geologic resource inventory scoping session for the ROVA parks during July 2007, which includes a discussion on paleontological resources (NPS 2008).
- Documented paleontological resources at the ROVA parks to date consist of isolated shell impressions.
- Park staff should be encouraged to observe exposed sedimentary material for fossil material while conducting their usual duties. Staff should photodocument and potentially 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. 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).
- Future archeological excavations or infrastructure developments should consider scheduling site monitoring by a trained paleontologist in order to document and protect fossil resources.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

Literature Cited

Allmon, W. D., P. L. Nester, J. Sherpa, J. J. Chiment, A. J. Erwin, N. Russell, and C. B. Griggs. 2001. Preliminary paleoenvironmental, paleoecological, and taphonomic comparison of two new Mastodon skeletons from the late Pleistocene of New York State. Abstracts with Programs - Geological Society of America **33**(1):84.

Baldwin, B. and A. V. Raiford. 1988. Taconic geology near Fair Haven, Vermont. Vermont Geology **5**:G1-G13.

Berry, W. B. N. 1962. Stratigraphy, zonation, and age of Schaghticoke, Deepkill, and Normanskill shales, eastern New York. Geological Society of America Bulletin **73**(6):695-718.

Berry, W. B. N. 1963. On the 'Snake Hill Shale'. American Journal of Science **261**(8):731-737.

Bock, B., S. M. McLennan, and G. N. Hanson. 1994. Does redistribution of rare earth elements in turbidites of the Appalachian foreland basin compromise provenance information? Mineralogical Magazine **58A**(A-K):103-104.

Bock, B., S. M. McLennan, and G. N. Hanson. 1998. Geochemistry and provenance of the Middle Ordovician Austin Glen Member (Normanskill Formation) and the Taconian Orogeny in New England. Sedimentology **45**(4):635-655.

Boxer, S. 1985. They broke the great beast's skull: America's first scientific expedition was a crude, if ingenious, affair. The Sciences **25**(2):58-59.

Brennan, L. A. 1977. The lower Hudson: the Archaic. Annals of the New York Academy of Sciences **288**:411-430.

Cadwell, D. H., R. J. Dineen, G. G. Connally, P. J. Fleisher, and J. L. Rich. 1987. Surficial geologic map of New York: Hudson-Mohawk sheet. New York State Museum and Science Service, Albany, NY. Map and Chart Series 40. Scale 1:250,000.

Cadwell, D. H., G. G. Connally, R. J. Dineen, P. J. Fleisher, M. L. Fuller, L. Sirkin, and G. C. Wiles. 1989. Surficial geologic map of New York: Lower Hudson sheet. New York State Museum and Science Service, Albany, NY. Map and Chart Series 40. Scale 1:250,000.

Case, R. J. 1989. Soil survey of Columbia County, New York. U.S. Department of Agriculture, Soils Conservation Service, Washington, DC.

Clarke, J. M. 1903. Mastodons of New York. Pages 921-933 *in* Merrill, F. J. H. and J. M. Clarke, editors. Report of the State Paleontologist 1902. New York State Museum and Science Service, Albany, NY. Bulletin 69.

Connally, G. G. 1983. Wisconsinan time-, rock-, and morpho-stratigraphy of the mid-Hudson Valley, New York. Abstracts with Programs - Geological Society of America **15**(3):133.

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 and Science Service, Albany, NY. Bulletin 455.

Dineen, R. J. 1986. Deglaciation of the Hudson Valley between Hyde Park and Albany, New York. Pages 89-108 *in* Cadwell, D. H., editor. The Wisconsinan Stage of the First Geological District, eastern New York. New York State Museum and Science Service, Albany, NY. Bulletin 455.

Dineen, R. J. and N. G. Miller. 2006. Age and paleoecology of plant fossils associated with the Quaker Springs stage of Lake Albany, and a chronology of deglacial events in the Hudson-Champlain Lowlands, New York. Abstracts with Programs - Geological Society of America **38**(2):8-9.

Dineen, R. J. and W. B. Rogers. 1979. Sedimentary environments in glacial Lake Albany in the Albany section of the Hudson-Champlain Lowlands. Pages 87-119 (Trip A-3) *in* Friedman, G. M., editor. Joint annual meeting of New York State Geological Association, 51st annual meeting and New England intercollegiate geological conference, 71st annual meeting. New York State Geological Association, Staten Island, NY.

Donnelly, J. P., N. Driscoll, E. Uchupi, L. Keigwin, W. Schwab, E. Thieler, and S. Swift. 2004. Catastrophic drainage of glacial Lake Iroquois down the Hudson River valley: a potential trigger for the intra-Allerod cold period. Eos **85**(supplement to 47):F1155. Abstract PP31A-0900.

English, A. M., E. Landing, and G. C. Baird. 2005. Snake Hill Formation – syntectonic facies of the easternmost Taconic foreland basin in eastern New York. Abstracts with Programs - Geological Society of America **37**(1):18.

English, A. M., E. Landing, and G. C. Baird. 2006. Snake Hill Formation – reconstructing eastern Taconic foreland basin litho- and biofacies from a giant mélange block in eastern New York, USA. Palaeogeography, Palaeoclimatology, Palaeoecology **242**(3-4):201-213.

Faber, M. 2002. Soil survey of Dutchess County, New York. U.S. Department of Agriculture, Soils Conservation Service, Washington, DC.

Fisher, D. C. and J. M. Sherpa. 2003. The Hyde Park mastodon: osteology and taphonomy. Abstracts with Programs - Geological Society of America **35**(3):75.

Fisher, D. W. 1962. Correlation of the Ordovician rocks in New York State. New York State Museum and Science Service, Albany, NY. Map and Chart Series 3.

Fisher, D. W. 1977. Correlation of the Hadrynian, Cambrian and Ordovician rocks in New York State. New York State Museum and Science Service, Albany, NY. Map and Chart Series 25.

Fisher, D. W. and E. M. Reilly Jr. 1969. New discoveries of late Pleistocene mammals in the Hudson valley. Abstracts with Programs - Geological Society of America **1**(1):18.

Fisher, D. W. and A. S. Warthin Jr. 1976. Stratigraphic and structural geology in western Dutchess County, New York. Trip B-6 *in* Johnsen, J. H., editor. Guidebook to field excursions at the 48th annual meeting of the New York State Geological Association. New York State Geological Association, Staten Island, NY.

Fisher, D. W., Y. W. Isachsen, and L. V. Rickard. 1970a. Geologic map of New York: Lower Hudson sheet. New York State Museum and Science Service, Albany, NY. Map and Chart Series 15. Scale 1:250,000.

Fisher, D. W., Y. W. Isachsen, and L. V. Rickard. 1970b. Geologic map of New York: Hudson-Mohawk sheet. New York State Museum and Science Service, Albany, NY. Map and Chart Series 15. Scale 1:250,000.

Fisher, D. W., Y. W. Isachsen, and L. V. Rickard. 1971. Generalized tectonic-metamorphic map of New York. New York Museum and Science Service, Albany, NY. Map and Chart Series 15.

Friedman, G. M. 2008. Explosive bolide impact designates the Cambrian explosion, terminating the Cambrian event in New York. Northeastern Geology and Environmental Sciences **30**(1):61-68.

Funk, R. E. 1977. Early cultures in the Hudson drainage basin. Annals of the New York Academy of Sciences **288**:316-332.

Funk, R. E., D. W. Fisher, and E. M. Reilly Jr. 1970. Caribou and Paleo-Indian in New York state: a presumed association. American Journal of Science **268**(2):181-186.

Gaudreau, D. C. 1982. Holocene vegetational history of central New England and the Hudson River valley. Program and Abstracts - American Quaternary Association **7**:93.

Godman, J. D. 1830. Description of a new genus and new species of extinct mammiferous quadruped. Transactions of the American Philosophical Society (Series 2) **3**(19):478-485.

Goldstein, A., J. Knight, and K. Kimball. 1998. Deformed graptolites, finite strain and volume loss during cleavage formation in rocks of the Taconic slate belt, New York and Vermont, U.S.A. Journal of Structural Geology **20**(12):1769-1782.

Goodwin, B. P., R. H. Waines, and J. H. MacDonald. 2003. Preliminary stratigraphy and structure of a medial Ordovician Mount Merino inlier within the Livingston Taconic tectonic thrust slice in west-central Dutchess County, mid-Hudson Valley, New York. Abstracts with Programs - Geological Society of America **35**(3):94-95.

Guilday, J. E. 1968. Archaeological evidence of caribou from New York and Massachusetts. Journal of Mammalogy **49**(2):344-345.

Hartnagel, C. A. and S. C. Bishop. 1921. The mastodons, mammoths and other Pleistocene mammals of New York State. New York State Museum and Science Service, Albany, NY. Bulletins 241 and 242.

Hurowitz, J. A. and S. M. McLennan. 2000. Neodymium isotopic evolution of the eastern margin of Laurentia: from rifting to the Taconian Orogeny. Abstracts with Programs - Geological Society of America **32**(1):25-26.

Hurowitz, J. A. and S. M. McLennan. 2005. Geochemistry of Cambro-Ordovician sedimentary rocks of the northeastern United States: changes in sediment sources at the onset of Taconian orogenesis. The Journal of Geology **113**(5):571-587.

Ibe, R. A. and R. R. Pardi. 1985. A radiocarbon-dated pollen diagram for Heart's Content Bog, Green County, New York. Northeastern Geology **7**(3-4):201-208.

Karabinos, P., J. N. Aleinikoff, and C. M. Fanning. 1999. Distinguishing Grenvillian basement from pre-Taconian cover rocks in the Northern Appalachians. American Journal of Science **299**(6):502-515.

Karabinos, P., H. M. Stoll, and J. C. Hepburn. 2003. The Shelburne Falls arc – lost arc of the Taconic orogeny. Pages B3-1-B3-17 *in* Brady, J. and J. Chaney, editors. New England Intercollegiate Geologic Conference, Amherst, MA.

Kay, G. M. 1953. Geology of the Utica Quadrangle, New York. New York State Museum and Science Service, Albany, NY. Bulletin 347.

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* Lucas, S. G., 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, NM. Bulletin 34. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed September 2009.

Kidd, W. S. F., A. Plesch, and F. W. Vollmer. 1995. Lithofacies and structure of the Taconic flysch, melange, and allochthon, in the New York Capital District. Pages 57-80 (Trip A-4) *in* Garver, J. I. and J. A. Smith, editors. Field trip guidebook for the 67th annual meeting of the New York State Geological Association. New York State Geological Association, Staten Island, NY.

Landing, E. 1988. Depositional tectonics and biostratigraphy of the western portion of the Taconic Allochthon, eastern New York State. Pages 96-110 *in* Landing, E., editor. Sesquicentennial celebration of the New York State Geological Survey: proceedings of meeting. New York State Museum and Science Service, Albany, NY. Bulletin 462.

Landing, E. 2000. Lower Paleozoic of the East Laurentian continental slope: eustatic/climate controls on macro- and microscale mudstone alternations. Abstracts with Programs - Geological Society of America **33**(1):16.

Landing, E. and K. E. Bartowski. 1996. Oldest shelly fossils from the Taconic Allochthon and late Early Cambrian sea-levels in eastern Laurentia. Journal of Paleontology **70**(5):741-761.

Lehmann, D., C. E. Brett, and R. Cole. 1994. Tectonic and eustatic influences upon the sedimentary environments of the Upper Ordovician strata of New York and Ontario. Concepts in Sedimentology and Paleontology **4**:181-201.

Levin, H. L. 1999. The Earth through time (6th edition). Saunders College Publishing, Fort Worth, TX.

Maenza-Gmelch, T. E. 1997. Vegetation, climate, and fire during the late-glacial-Holocene transition at Spruce Pond, Hudson Highlands, southeastern New York, USA. Journal of Quaternary Science **12**(1):15-24.

McCarthy, B. and G. G. Lash. 1985. Turbidite sedimentology of the Austin Glen Graywacke (Middle Ordovician) of eastern New York. Abstracts with Programs - Geological Society of America **17**(1):53.

McLelland, J. M. and D. W. Fisher. 1976. Stratigraphy and structural geology in the Harlem Valley, S.E. Dutchess County, New York. Trip C-7 *in* Johnsen, J. H., editor. Guidebook to field excursions at the 48th annual meeting of the New York State Geological Association. New York State Geological Association, Staten Island, NY.

Miller, N. G. and P. L. Nester. 2006. Paleoecology of a late Pleistocene wetland and associated mastodon remains in the Hudson Valley, southeastern New York State. Pages 291-304 *in* Greb, S. F. and W. A. DiMichele. Wetlands through time. Geological Society of America, Boulder, CO. Special Paper 399.

Muller, E. H. and P. E. Calkin. 1993. Timing of Pleistocene glacial events in New York State. Canadian Journal of Earth Science **30**(9):1829-1845.

Murray, D. J. 1976. Pleistocene history of the Millbrook, New York region. Trip B-5 *in* Johnsen, J. H., editor. Guidebook to field excursions at the 48th annual meeting of the New York State Geological Association. New York State Geological Association, Staten Island, NY.

National Park Service, Geologic Resources Division. 2008. Geologic resource evaluation scoping summary: Saratoga National Historical Park & Roosevelt-Vanderbilt National Historic Sites. National Park Service, Geologic Resources Division, Denver, CO. Online. http://www.nature.nps.gov/geology/inventory/publications/s_summaries/ROVA-SARA_gre_scoping_summary_2008-0924.pdf. Accessed September 2009.

Nelson, R. E., S. H. Lubkin, and P. Nester. 2002. Paleoenvironments of the Hyde Park, New York, Mastodon site, based on subfossil coleopteran remains. Abstracts with Programs - Geological Society of America **34**(6):547.

Rayburn, J. A., D. A. Franzi, and P. L. K. Knuepfer. 2002. A large late glacial breakout flood through the Champlain and Hudson Lowlands, New York. Abstracts with Programs - Geological Society of America **34**(6):475.

Ries, H. 1891. Quaternary deposits of the Hudson River valley between Croton and Albany, with notes on the brick clays and the manufacture of brick. New York State Geologist Annual Report **10**:110-155.

Robinson, G., D. A. Burney, and L. P. Burney, L. P. 2000. Megafaunal fossil sites of the lower Hudson Valley region. New York State Museum and Science Service, Albany, NY. Circular 62:41.

Robinson, G., D. A. Burney, and L. P. Burney, L. P. 2001. Landscape paleoecology and late Quaternary extinctions in the Hudson Valley. Abstracts with Programs - Geological Society of America **33**(1):63.

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.

Rodgers, J. 1971. The Taconic Orogeny. Geological Society of America Bulletin **82**(5):1141-1178.

Rogers, W. B., Y. W. Isachsen, T. D. Mock, and R. E. Nyahay. 1990. New York State geological highway map. New York State Museum and Science Service, Albany, NY. Educational Leaflet 33.

Rowley, D. B. and W. S. F. Kidd. 1981. Stratigraphic relationships and detrital composition of the medial Ordovician flysch of western New England: implications for the tectonic evolution of the Taconic Orogeny. Journal of Geology **89**(2):199-218.

Rowley, D. B., W. S. F. Kidd, and L. L. Delano. 1979. Detailed stratigraphic and structural features of the Giddings Brook slice of the Taconic Allochthon in the Granville area. Pages 186-242 (Trip A-8) *in* Friedman, G. M., editor. Joint annual meeting of New York State Geological Association, 51st annual meeting and New England intercollegiate geological conference, 71st annual meeting. New York State Geological Association, Staten Island, NY.

Ruedemann, R. 1942. Notes on Ordovician plankton and radiolarian chert of New York. Pages 45-71 *in* Paleontology and geology. New York State Museum and Science Service, Albany, NY. Bulletin 327.

Sanders, J. E. 1994. Poughkeepsie "Mélange": a geologic misnomer for a deep-water delta deposit in the Northern Appalachian Ordovician foreland basin, Dutchess County, NY. Northeastern Geology **16**(1):40.

Sanders, J. E. 1995. Lower Paleozoic carbonate-clast diamictites: relationship to thrust sheets that advanced across the floor of the northern Appalachian Ordovician foreland basin. Northeastern Geology and Environmental Sciences **17**(1):23-45.

Sanders, J. E. and B. Guo. 1995. Poughkeepsie "Mélange": a monomict quartzite block diamictite in the Northern Appalachian Ordovician Foreland Basin, Dutchess County, NY. Northeastern Geology and Environmental Sciences **17**(1):46-60.

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

Sokal, M. A. and R. I. Hall. 2003. Use of sedimentary diatom assemblages to assess environmental changes during the late Pleistocene at a mastodon site in Hyde Park, New York State. Abstracts with Programs - Geological Society of America **35**(3):76.

Stanley, R. S. and N. M. Ratcliffe. 1985. Tectonic synthesis of the Taconian orogeny in western New England. Geological Society of America Bulletin **96**(10):1227-1250.

Steadman, D. W., T. W. Stafford Jr., and R. E. Funk. 1997. Nonassociation of paleoindians with AMS-dated late Pleistocene mammals from the Dutchess Quarry caves, New York. Quaternary Research **47**(1):105-116.

Theokritoff, G. 1964. Taconic stratigraphy in northern Washington County, New York. Geological Society of America Bulletin **75**(3):171-190.

Thieler, E. R., B. Butman, W. C. Schwab, M. A. Allison, N. W. Driscoll, J. P. Donnelly, and E. Uchupi. 2007. A catastrophic meltwater flood event and the formation of the Hudson Shelf valley. Palaeogeography, Palaeoclimatology, Palaeoecology **246**(1):120-136.

Toots, H. 1976. Structural geology of the Taconic unconformity. Trip B-2 *in* Johnsen, J. H., editor. Guidebook to field excursions at the 48th annual meeting of the New York State Geological Association. New York State Geological Association, Staten Island, NY.

Zen, E-an. 1964. Taconic stratigraphic names: definitions and synonymies. U.S. Geological Survey, Reston, VA. Bulletin 1174. Online. http://pubs.er.usgs.gov/usgspubs/b/b1174. Accessed October 2009.

Zen, E-an. 1967. Time and space relationships of the Taconic allochthon and autochthon. Geological Society of America, Boulder, CO. Special Paper 97.

Additional References

Berry, W. B. N. 1977. Ecology and age of graptolites from graywackes in eastern New York. Journal of Paleontology **51**(6):1102-1107.

Cole, R. B., K. D. Ridgway, and D. F. Lehmann. 1994. Synorogenic petrofacies of a forearc to foreland and basin transition during the Middle Ordovician Taconic Orogeny, New York. Abstracts with Programs - Geological Society of America **26**(7):A-196.

Connally, G. C. and L. A. Sirkin. 1971. Luzerne Readvance near Glens Falls, New York. Geological Society of America Bulletin **82**(4):989-1008.

Connally, G. G. and L. A. Sirkin. 1973. Wisconsinan history of the Hudson-Champlain Lobe. Pages 47-69 *in* Black, R. F., R. P. Goldthwait, and H. B. Willman, editors. The Wisconsinan Stage. Geological Society of America, Boulder, CO. Memoir 136.

De Simone, D. J. 2008. Field evidence for readvances: the Luzerne example. Abstracts with Programs - Geological Society of America **40**(2):69.

Dineen, R. J. 1979. Stratigraphy of glacial Lake Albany and its successors in the Albany area, New York. Abstracts with Programs - Geological Society of America **11**(1):10.

Dudley, J. 1814. Letter from Governour Dudley to the Reverend Cotton Mather: Roxbury, 10 July, 1706. Collections of the Massachusetts Historical Society **2**:263-264.

Feingold, B. J., K. D. Bedient, K. M. Menking, J. S. Schneiderman, W. D. Allmon, and P. L. Nester. 2001. Post-glacial environmental history of Hyde Park Mastodon site, Dutchess County, NY. Abstracts with Programs - Geological Society of America **33**(1):63.

Fisher, D. C. 2005. Osteology, taphonomy, and life history of two late Pleistocene American mastodons (*Mammut americanum*). Short Papers and Abstracts - World of Elephants Congress **2**:44-46.

Goldman, D., K. T. Barrett, and S. M. Bergstrom. 2000. Working toward a standard Upper Ordovician graptolite zonation: correlation of the Mt. Merino and Utica shales in New York State. Abstracts with Programs - Geological Society of America **32**(4):A-15.

Griggs, C. B. 2003. ^{14}C dates and dendrochronology in the late Pleistocene: the first warm period partially covered by tree-ring chronologies from upstate New York. Abstracts with Programs - Geological Society of America **35**(3):75.

Kidd, W. S. F., L. L. Delano, and D. B. Rowley. 1981. Depositional history of the Taconic continental rise compared with equivalent sequences along the Northern Appalachians. Abstracts with Programs - Geological Society of America **13**(3):141.

Lake, T. R. and J. J. Chiment. 2003. First nations and last elephants. Abstracts with Programs - Geological Society of America **35**(3):75.

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

Menking, K. M., J. S. Schneiderman, K. M. Bedient, B. C. Collins, B. J. Feingold, W. D. Allmon, and P. L. Nester. 2001. Sedimentological and pollen analysis of the Hyde Park Mastodon site, Dutchess County, NY. Abstracts with Programs - Geological Society of America **33**(6):21.

Miklus, N. M., A. J. Smith, D. F. Palmer, and P. L. Nester. 2003. Ostracodes as indicators of a Younger Dryas environment at three fossil mastodon sites in New York. Abstracts with Programs - Geological Society of America **35**(3):76.

Miller, N. G. 2003. Contemporary and prior environments of the Hyde Park, New York, mastodon on the basis of associated plant macrofossils. Abstracts with Programs - Geological Society of America **35**(3):75.

Nester, P. L. and L. Brown. 2003. Three dimensional geometry of a late-Pleistocene basin, Hyde Park, New York, integrating field observation techniques and ground penetrating radar. Abstracts with Programs - Geological Society of America **35**(3):75.

Nester, P. L., K. M. Menking, J. S. Schneiderman, B. J. Feingold, and K. D. Bedient. 2001. Quantitative analysis of microscopic charcoal from sediments of a late Pleistocene lake, Dutchess County, New York. Abstracts with Programs - Geological Society of America **33**(6):442.

Paleontological Research Institution. No date. The Hyde Park Mastodon. Online. http://www.priweb.org/mastodon/HP_mast/HP_mast_main.html. Accessed November 2009.

Rayburn, J. A., P. L. K. Knuepfer, and D. A. Franzi. 2005. A series of large, late Wisconsinan meltwater floods through the Champlain and Hudson Valleys, New York State, USA. Quaternary Science Reviews **24**(22):2410-2419.

Rayburn, J. A., D. A. Franzi, and P. L. K. Knuepfer. 2007. Evidence from the Lake Champlain Valley for a later onset of the Champlain Sea and implications for late glacial meltwater routing to the North Atlantic. Palaeogeography, Palaeoclimatology, Palaeoecology **246**(1):62-74.

Robinson, G., D. A. Burney, L. P. Burney. 2003. Megafaunal population collapse and extinction in lower New York State. Abstracts with Programs - Geological Society of America **35**(3):75.

Thompson, L. 1994. Discovery of the American mastodon (*Mammut americanum*) in New York State: 1921-1994. Thesis. University of Rochester, Rochester, NY.

Thomson, K. S. 2008. The legacy of the mastodon: the golden age of fossils in America. Yale University, New Haven, CT.

Data Sets

Eleanor Roosevelt National Historic Site Paleontological Archives
1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Home of Franklin D. Roosevelt National Historic Site Paleontological Archives
1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Vanderbilt Mansion National Historic Site Paleontological Archives
1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Roosevelt-Vanderbilt National Historic Sites Paleontological Archives
1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Martin Van Buren National Historic Site Paleontological Archives
1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

New York Digital Geologic Map
1999-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by New York State Museum staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=NY.

Saint-Gaudens National Historic Site

Saint-Gaudens National Historic Site (SAGA) was established August 31, 1964. SAGA preserves the home, studio, and gardens of noted sculptor Augustus Saint-Gaudens, who worked in the late 19th and early 20th centuries. Its boundaries were changed October 31, 1976, November 9, 2000, and March 31, 2010. SAGA encompasses 77.19 ha (190.75 acres), all of which are under federal administration. The addition of the Blow-Me-Down Farm parcel in March 2010 does not add any additional rock units to the geology of SAGA, but does improve the chances of finding fossil material.

Geological Background

SAGA is located on the western border of New Hampshire in Sullivan County, adjacent to the Connecticut River on the west and across the river from Windsor, Vermont. It is about 14 km (9 miles) north of Claremont, New Hampshire, and 18 km (11 miles) south-southwest of Lebanon, New Hampshire. Marsh-Billings-Rockefeller National Historical Park (MABI), with similar geology, is about 17 km (11 miles) northwest of SAGA (see the MABI summary in this report for more information). Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held during July 2007. The geology of SAGA and MABI was described in a geologic scoping summary by the National Park Service (2008), an internal NPS document.

The geologic history of northern New England has been a source of controversy due to the complex geology arising from several large events. New England was only assembled during the Paleozoic, a relatively recent few hundred million years ago (see the appendix for a geological time scale), as part of the formation of the supercontinent Pangaea. Shortly after it was assembled it was subjected to the stresses that separated eastern North America from Africa and Europe, forming the Atlantic Ocean. These events greatly distorted the preexisting geology.

The rocks underlying SAGA began as Paleozoic marine sediments that were deformed during the Acadian Orogeny (mountain building event), one of several tectonic events leading to the formation of Pangaea, but rocks in the vicinity record more ancient events. West of SAGA in central Vermont is the Green Mountain Massif and other rocks of the Grenville Province, an area uplifted and metamorphosed by the earlier (over 1.03 Ga, or billion years old) Grenville Orogeny (Karabinos et al. 1999). Approximately 590 Ma (million years ago), continental rifting in the area began to open an ocean basin (the Iapetus Ocean), causing the Grenville Province to become what would now be the eastern margin of the North American continent. This margin persisted until approximately 510 Ma, when the local tectonic system shifted from spreading to convergence (Kim and Wunsch 2009). The North American landmass of this time is known as Laurentia, the technical term for the core of the continent; this name commonly appears in scientific publications.

The underlying geology of the Connecticut River Valley in New Hampshire and Vermont is composed of the Connecticut Valley-Gaspé Trough, a middle Paleozoic structural low sandwiched by the Shelburne Falls volcanic arc on the west and the Bronson Hill Arc on the east (Karabinos et al. 2003; Rankin et al. 2007). The Shelburne Falls Arc formed between approximately 485 and 470 Ma, and the Bronson Hill Arc was active between approximately 455 and 440 Ma; the Connecticut Valley-Gaspé Trough formed between them shortly afterward (Karabinos et al. 2003). All three reached their present positions as a result of the Taconic (or Taconian) and Acadian orogenies.

The Taconic Orogeny began during the Ordovician, during the same period that the volcanic arcs were active (Kim and Wunsch 2009). Exactly what happened during the orogeny is debated, and models with one or two subduction zones and continental collision with one or two volcanic arcs have been proposed (Karabinos et al. 2003). The net effects were that much of the Iapetus Ocean was destroyed, the ocean basin sediments were disrupted and in some cases forced long distances to the west, and slivers of land that formed elsewhere were sutured to Laurentia (including the Shelburne Falls and Bronson Hill arcs), moving the margin of the continent east and causing the formation of a mountain range (Doolan 1996;

Kim and Wunsch 2009). The Connecticut Valley-Gaspé Trough formed between the Shelburne Falls and Bronson Hill arcs during the Silurian as a result of temporary extensional forces between periods of collisions (Doolan 1996; Karabinos et al. 2003), and was the setting for the deposition of SAGA's bedrock. At the time, the trough supported a seaway, and the sedimentary rocks deposited in it began as turbidites (underwater sediment avalanche units) (Naylor 1989).

Collision occurred along the margin again beginning around 375 Ma, at the onset of the Acadian Orogeny (Karabinos et al. 1999). During this event, the great forces deformed and folded the Connecticut Valley-Gaspé Trough sediments. The Acadian Orogeny was responsible for the final assembly of the various small continental blocks that make up New England (Doolan 1996). The later Alleghenian Orogeny, when the African part of Gondwana collided with North America, had most of its effects elsewhere, but the rifting that pulled Africa from North America during the Triassic and Jurassic produced faults in the vicinity (J. Thompson et al. 1993). The MABI-SAGA area of Vermont and New Hampshire then became geologically quiet, with the exception of igneous rocks that intruded approximately 122 Ma and were later exposed by erosion as nearby Mount Ascutney (Schniederman 1989; J. Thompson et al. 1993).

More recently, glacial activity during the Pleistocene (between 2.59 Ma and approximately 12,000 years ago) scoured and reworked the preexisting topography of New England. The most recent glacial advance of the area was represented by the Hudson-Champlain lobe of the Laurentide Ice Sheet (NPS 2008). It overprinted previous glacial activity and left a great quantity of loose sediments. As the ice sheet retreated, vast lakes of glacial meltwater formed in valleys that were blocked by ice and sediment dams. The largest of these in New England was Glacial Lake Hitchcock, which was present in what is now the Connecticut River Valley and adjoining tributary valleys. First appearing about 17,900 years ago in the lower valley, it extended north as the ice sheets continued retreating and persisted after the ice was gone, lasting until about 12,600 years ago. The SAGA area was not deglaciated until after 14,700 years ago (Benner et al. 2009), and was subsequently inundated by the lake (NPS 2008). The history of Glacial Lake Hitchcock has been studied through the use of varves (annual sediment layers) that allow for a very detailed chronology of events (Ridge and Larsen 1990; Ridge et al. 1999). Humans first appeared in New England over ten thousand years ago (Curran and Dincauze 1977).

From oldest to youngest, the bedrock and surficial geology at SAGA include the Gile Mountain Formation (Devonian) and Quaternary glacial and glacial lake deposits (Lyons et al. 1997; Fullerton et al. 2003; Bennett et al. 2006). To date, there are no fossils associated with SAGA (S. Walasewicz, pers. comm., September 2009). The Quaternary units are the most likely potential sources for fossils at SAGA; the Gile Mountain Formation is a possible source, but is metamorphosed and known for being generally unfossiliferous. It is not exposed at the surface at SAGA in outcrops large enough to map (Fullerton et al. 2003), but outcrops are present along Blow-Me-Up Brook and New Hampshire Route 12A (S. Walasewicz, pers. comm., October 2009). There are also architectural "outcrops" of local stone on SAGA property, including a historic stone arch bridge, the foundation of the adjacent grist mill, and a small dam (S. Walasewicz, pers. comm., October 2009).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within SAGA. However, they are known to preserve fossils elsewhere, and future field investigations within the park may uncover fossils in them.

Gile Mountain Formation (Devonian)

The Gile Mountain Formation is a metamorphosed sedimentary rock unit. It is quite similar to the underlying Waits River Formation, and the two are often discussed together. Both formations include abundant schist and some marble or related rocks (Hatch et al. 1988). Both formations are interpreted as representing turbidites, and the contact between the two units appears to be gradational (Hueber et al. 1990). They differ in that the Gile Mountain Formation has a significant proportion of quartzite, and less marble (Hatch et al. 1988). The subunit Meetinghouse Slate Member is mostly composed of dark pelites

(metamorphosed mudstones/shales) (Rankin et al. 2007). It is present east and north of SAGA (Lyons et al. 1997; Bennett et al. 2006). As per the general difficulties surrounding these units, the Meetinghouse Slate Member has been interpreted as at the base of the Gile Mountain Formation (the older interpretation, still in use; Rankin et al. 2007), or at the top of the unit (Hatch 1988; Hueber et al. 1990). The Gile Mountain Formation of the SAGA area is composed of a variety of metasedimentary rocks, such as slate, phyllite, and schist, which are types of rocks on a continuum of metamorphic intensity affecting fine-grained rocks like shale and mudstone (increasing intensity from slate to schist). Minor quantities of quartzite (began as sandstone) and marble (began as limestone) are also present (Lyons et al. 1997; Bennett et al. 2006). The metamorphism of the formation in the SAGA area is in the chlorite zone (Lyons 1955), which is a low grade of metamorphism.

The age of the Gile Mountain Formation and underlying Waits River Formation have historically been a matter of some controversy. A Silurian date for the Waits River Formation and Devonian date for the Gile Mountain Formation are currently accepted (Walsh et al. 2009); more precise dating has been elusive. As of late, the Gile Mountain Formation has been dated to the Emsian stage of the Early Devonian (407 to 398 Ma) based on correlation with the Compton Formation of Quebec, which has plant fossils of that age. However, the Waits River Formation is dated as older than 423 ± 4 Ma (Hueber et al. 1990). Barring some error, such as an incorrect date, or mistaken Gile Mountain-Compton Formation correlation (Moench et al. 1995), or the presence of a significant heretofore-undiscovered unconformity or unconformities between or within the Waits River and Gile Mountain formations (Aleinikoff and Karabinos 1990; Hueber et al. 1990), the dates imply a long period of continuous deposition. This is inconsistent with some assessments of the deposition (Aleinikoff and Karabinos 1990), but Hueber et al. (1990) note that the time between the individual turbidity currents is unknown.

Fossils are extremely rare in the Gile Mountain Formation. Doll (1984) reported that corals, trilobites, and crinoids were present in a unit he identified as the Westmore-Giles Mountain Formation of the Westmore area, 140 km (85 miles) north of SAGA (the Westmore Formation is an old name for a subdivision of the Waits River Formation thought to be equivalent to the Gile Mountain Formation [Lyons 1955; Murthy 1958]). Hueber et al. (1990) reported remains of *Prototaxites* (a giant fungus) from a site on Indian Stream, far northern New Hampshire, 190 km (120 miles) northeast of SAGA. No fossils have been reported from this unit at SAGA.

Quaternary rocks and sediments (Pleistocene-Holocene)

The Quaternary rocks and sediments of SAGA include lacustrine (associated with lakes) clay and silt and glacial deposits (Fullerton et al. 2003). The lacustrine material was left by Glacial Lake Hitchcock. It is possible that lake delta deposits are present in the upper parts of SAGA, farther from the river. Additionally, varve deposits may be found in steep ravines, and eolian deposits may have draped SAGA's landscapes after the lake drained. Mapping is needed to test for the presence of these possible deposits (NPS 2008). If varve deposits are present, they would be good locations to look for fossils, such as plant body fossils and fish body and trace fossils (NPS 2008).

To date, no fossils have been reported from the Quaternary rocks and deposits of SAGA. Quaternary fossils are generally uncommon in Vermont and New Hampshire (Curran and Dincauze 1977), with the exception of the area associated with Glacial Lake Hitchcock. A variety of fossils are known from deposits of the lake along the Connecticut River Valley. These include remains of spores, plants (Knecht et al. 2009), snails (Ridge et al. 2009), crustaceans (Knecht et al. 2009), midges, and ostracodes, a single bone from a dace-like fish, and trace fossils from worm-like invertebrates, tadpole shrimp, and at least two types of fish, one a large fish (possibly brook trout), the other a sculpin (Benner et al. 2009). The nearest trace fossil sites are in the Walpole area, 45 km (30 miles) south of SAGA, the Canoe Brook area, 60 km (35 miles) southwest of SAGA, and the South Newbury area, 65 km (40 miles) northeast of SAGA (Benner et al. 2008, 2009). Canoe Brook and South Newbury are also plant fossil sites. Plant fossils range from organic muck (gyttja) to leaves, twigs, and wood (Ridge et al. 1999). Tufts University (Medford, MA) hosts a glacial varve database (Ridge 2009; http://ase.tufts.edu/geology/varves/).

Postglacial ponds and bogs are also known to be fossiliferous, yielding plant fossils (Hollick 1931) and freshwater bivalves and gastropods (Z. Thompson 1853). Fossiliferous Holocene-age marl (lime-rich mudstone) deposited in lakes and ponds in neighboring Vermont is best developed in lakes and ponds over the Waits River Formation. The marl is often called shell marl, because of the great quantity of mollusk shells. It was valued as a fertilizer (Z. Thompson 1853). Marl beds are often found under peat; as a water body fills and shallows, mosses begin to encroach over it, forming peat layers (Hitchcock et al. 1861). Marl from a former bog at nearby MABI is known to be fossiliferous. A few fossils are currently in MABI collections and include imprints of veined leaves, twigs, and grass stems (L. Anderson, MABI museum curator, pers. comm., September 2009).

Terrestrial vertebrate fossils are rare, but one find has been made from central Vermont, where large bones were found in 1848 near Mount Holly, 36 km (22 miles) west of SAGA and identified as mammoth bones by Louis Agassiz (possibly mastodon instead) (Johnson 1998).

Park Collections

SAGA has no paleontological material in its collections to date.

Cultural Resource Contexts

SAGA has no paleontological material reported from cultural resource contexts to date. 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

- The NPS Geologic Resources Division coordinated a geologic resource inventory scoping session for SAGA and MABI during July 2007 (NPS 2008). The participants of the scoping meetings developed a series of recommendations for future work.
- No paleontological resources are known for SAGA to date, although there is potential for fossils to be found in the deposits associated with Glacial Lake Hitchcock.
- Park staff should be encouraged to observe exposed sedimentary material for fossil material while conducting their usual duties. Staff should photodocument and potentially 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. 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).
- Future archeological excavations or infrastructure developments should consider scheduling site monitoring by a trained paleontologist in order to document and protect fossil resources.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

References Cited

Aleinikoff, J. N. and P. Karabinos. 1990. Zircon U-Pb data for the Moretown and Barnard volcanic members of the Missisquoi Formation and a dike cutting the Standing Pond Volcanics, southeastern Vermont. Pages D1-D10 *in* Slack, J. F., editor. Summary results of the Glens Falls CUSMAP project, New York, Vermont, and New Hampshire. U.S. Geological Survey, Reston, VA. Bulletin 1887. Online. http://pubs.er.usgs.gov/usgspubs/b/b1887. Accessed October 2009.

Benner, J. S., J. C. Ridge, and N. K. Taft. 2008. Late Pleistocene freshwater fish (Cottidae) trackways from New England (USA) glacial lakes and a reinterpretation of the ichnogenus *Broomichnium* Kuhn. Palaeogeography, Palaeoclimatology, Palaeoecology **260**(3-4):375-388.

Benner, J. S., J. C. Ridge, and R. J. Knecht. 2009. Timing of post-glacial reinhabitation and ecological development of two New England, USA, drainages based on trace fossil evidence. Palaeogeography, Palaeoclimatology, Palaeoecology **272**(3-4):212-231.

Bennett, D. S., C. A. Wittkop, and C. L. Dicken. 2006. Bedrock geologic map of New Hampshire - a digital representation of the Lyons and others 1997 map and ancillary files. U.S. Geological Survey, Reston, VA. Data Series 215. Scale 1:250,000. CD-ROM.

Curran, M. L. and D. F. Dincauze. 1977. Paleoindians and paleo-lakes: new data from the Connecticut drainage. Annals of the New York Academy of Sciences **288**:333-348.

Doll, C. G. 1984. Fossils from the metamorphic rocks of the Silurian-Devonian Magog Belt in northern Vermont. Vermont Geology 3.

Doolan, B. 1996. The geology of Vermont. Rocks & Minerals **71**(4):218-225. Online. http://www.anr.state.vt.us/dec/geo/pdfdocs/VermontGeoWebDoolan.pdf. Accessed February 2010.

Fullerton, D. S., C. A. Bush, and J. N. Pennell. 2003. Map of surficial deposits and materials in the eastern and central United States (east of 102 degrees west longitude). U.S. Geological Survey, Reston, VA. Geologic Investigations Series Map 2789. Scale 1:2,500,000. Online. http://pubs.er.usgs.gov/usgspubs/i/i2789. Accessed October 2009.

Hatch, N. L. Jr. 1988. Some revisions to the stratigraphy and structure of the Connecticut Valley trough, eastern Vermont. American Journal of Science **288**(10):1041-1059.

Hitchcock, E., E. Hitchcock Jr., A. D. Hager, and C. H. Hitchcock. 1861. Report on the geology of Vermont: descriptive, theoretical, economical, and scenographical; Volume I. State of Vermont, Proctorville, VT. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/reportongeologyo00vermrich]

Hollick, C. A. 1931. Plant remains from a Pleistocene lake deposit in the upper Connecticut River Valley. Brittonia **1**(1):35-55.

Hueber, F. M., W. A. Bothner, N. L. Hatch Jr., S. C. Finney, and J. N. Aleinikoff. 1990. Devonian plants from southern Quebec and northern New Hampshire and the age of the Connecticut Valley trough. American Journal of Science **290**(4):360-395.

Johnson, C. W. 1998. The nature of Vermont: introduction and guide to a New England environment. University Press of New England, Hanover, NH.

Karabinos, P., S. D. Samson, J. C. Hepburn, and H. M Stoll. 1998. Taconian Orogeny in the New England Appalachians: collision between Laurentia and the Shelburne Falls Arc. Geology **26**(3):215-218.

Karabinos, P., J. N. Aleinikoff, and C. M. Fanning. 1999. Distinguishing Grenvillian basement from pre-Taconian cover rocks in the Northern Appalachians. American Journal of Science **299**(6):502-515.

Karabinos, P., H. M. Stoll, and J. C. Hepburn. 2003. The Shelburne Falls arc – lost arc of the Taconic orogeny. Pages B3-1-B3-17 *in* Brady, J. and J. Chaney, editors. New England Intercollegiate Geologic Conference, Amherst, MA.

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* Lucas, S. G., 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, NM. Bulletin 34. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed September 2009.

Kim, J. and D. Wunsch. 2009. Physiography and bedrock geology. Pages 5-11*in* Brown, R. A., editor. Where the great river rises: an atlas of the Connecticut River watershed in Vermont and New Hampshire. Dartmouth College Press, Lebanon, NH.

Knecht, R. J., J. S. Benner, D. C. Rogers, and J. C. Ridge. 2009. *Surculichnus bifurcauda* n. igen., n. isp., a trace fossil from late Pleistocene glaciolacustrine varves of the Connecticut River valley, USA, attributed to notostracan crustaceans based on neoichnological experimentation. Palaeogeography, Palaeoclimatology, Palaeoecology **272**(3-4):232-239.

Lyons, J. B. 1955. Geology of the Hanover Quadrangle, New Hampshire-Vermont. Geological Society of America Bulletin **66**(1):105-145.

Lyons, J. B., W. A. Bothner, R. H. Moench, and J. B. Thompson Jr. 1997. Bedrock geologic map of New Hampshire. U.S. Geological Survey, Reston, VA. Special Map. Scale 1:250,000.

Moench, R. H., G. M. Boone, W. A. Bothner, E. L. Boudette, N. L. Hatch Jr., A. M. Hussey III, R. G. Marvinney, and J. N. Aleinikoff. 1995. Geologic map of the Sherbrooke-Lewiston area, Maine, New Hampshire, and Vermont, United States, and Quebec, Canada. U.S. Geological Survey, Reston, VA. Miscellaneous Investigations Series Map 1898-D. Scale 1:250,000.

Murthy, V. R. 1958. A revision of the lower Paleozoic stratigraphy in eastern Vermont. Journal of Geology **66**(3):276-287.

National Park Service, Geologic Resources Division. 2008. Geologic resource evaluation scoping summary: Marsh-Billings-Rockefeller National Historical Park & Saint-Gaudens National Historic Site. National Park Service, Geologic Resources Division, Denver, CO. Online. http://www.nature.nps.gov/geology/inventory/publications/s_summaries/MABI-SAGA_gre_scoping_summary_2008-0924.pdf. Accessed September 2009.

Naylor, R. S. 1989. Role of the Connecticut Valley Gaspé Trough in the Acadian Orogeny. Abstracts with Programs - Geological Society of America **21**(2):54.

Rankin, D. W., R. A. Coish, R. D. Tucker, Z. X. Peng, S. A. Wilson, and A. A. Rouff. 2007. Silurian extension in the upper Connecticut Valley, United States and the origin of middle Paleozoic basins in the Quebec Embayment. American Journal of Science **307**(1):216-264.

Ridge, J. C. 2009 (most recent year). North American Glacial Varve Project. Tufts University, Medford, MA. Online. http://ase.tufts.edu/geology/varves/. Accessed October 2009.

Ridge, J. C. and F. D. Larsen. 1990. Re-evaluation of Antevs' New England varve chronology and new radiocarbon dates of sediments from glacial Lake Hitchcock. Geological Society of America Bulletin **102**(7):889-899.

Ridge, J. C., M. R. Besonen, M. Brochu, S. L. Brown, J. W. Callahan, G. J. Cook, R. S. Nicholson, and N. J. Toll. 1999. Varve, paleomagnetic, and ^{14}C chronologies for late Pleistocene events in New Hampshire and Vermont (U.S.A.). Geographie Physique et Quaternaire **53**(1):79-107.

Ridge, J. C., C. C. Beck, E. B. Voytek, R. L. Bayless, and J. L. Dean. 2009. Calibration of a unified New England varve chronology: deglaciation rates and moraine building in the Connecticut Valley of New Hampshire and Vermont. Abstracts with Programs - Geological Society of America **41**(3):36.

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

Schneiderman, J. S. 1989. The Ascutney Mountain Breccia: field and petrologic evidence for an overlapping relationship between Vermont sequence and New Hampshire sequence rocks. American Journal of Science **289**(6):771-811.

Thompson, J. B. Jr., J. L. Rosenfeld, and C. P. Chamberlain. 1993. Sequence and correlation of tectonic and metamorphic events in southeastern Vermont. Pages B.1-B.26 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(1).

Thompson, Z. 1853. Appendix to the history of Vermont, natural, civil and statistical. Published by the author, Burlington, VT. [full text available on Google Books]

Walsh, G. J., J. Kim, and M. H. Gale. 2009. Bedrock geology of the Montpelier area, central Vermont. Annual Meeting - New England Intercollegiate Geological Conference 101. Trip C4.

Additional References

Curran, K. and D. F. Dincauze. 1999. Archaeological chronometry for Connecticut River valley surfaces. Abstracts with Programs - Geological Society of America **31**(2):A-11.

Fisher, G. W. and P. Karabinos. 1980. Stratigraphic sequence of the Gile Mountain and Waits River formations near Royalton, Vermont. Geological Society of America Bulletin **91**(5):282-286.

Hatch, N. L. Jr. 1988. Some revisions to the stratigraphy and structure of the Connecticut Valley trough, eastern Vermont. American Journal of Science **288**(10):1041-1059.

Hatch, N. L. Jr. 1989. Day 3: The Connecticut Valley Trough. Pages 39-43 *in* Lyons, J. B., W. A. Bothner, B. L. Doolan, N. L. Hatch Jr., R. H. Moench, and R. S. Stanley, leaders. Metamorphism and tectonics of eastern and central North America: Volume 2, a transect through the New England Appalachians. Hanshaw, P. M., editor. Field trips for the 28th International Geological Congress. American Geophysical Union, Washington, DC.

Hatch, N. L. Jr. 1991. Revisions to the stratigraphy of the Connecticut Valley trough, eastern Vermont. Pages 5-7 *in* Stratigraphic notes, 1989-90. U.S. Geological Survey, Reston, VA. Bulletin 1935. Online. http://pubs.er.usgs.gov/usgspubs/b/b1935. Accessed October 2009.

Karabinos, P. 2006. Accretion of northern Appalachian arc terranes. Abstracts with Programs - Geological Society of America **38**(3):20.

Karabinos, P. and J. C. Hepburn. 2006. Silurian subduction under the Laurentian margin in the New England Appalachians. Abstracts with Programs - Geological Society of America **38**(2):32-33.

Koteff, C., J. R. Stone, F. D. Larsen, and J. H. Hartshorn. 1987. Glacial Lake Hitchcock and postglacial uplift. U.S. Geological Survey, Reston, VA. Open-File Report 87-329. Online. http://pubs.er.usgs.gov/usgspubs/ofr/ofr87329. Accessed October 2009.

Levin, H. L. 1999. The Earth through time (6th edition). Saunders College Publishing, Fort Worth, TX.

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

Nicholas, G. P. III. 1982. Former glacial-lake basins and early postglacial settlement. Program and Abstracts - American Quaternary Association. Conference **7**:148.

Nicholson, S.W., C. L. Dicken, J. D. Horton, M. P. Foose, J. A. L. Mueller, and R. Hon. 2006. Preliminary integrated geologic map databases for the United States: Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, Rhode Island, and Vermont. U.S. Geological Survey, Reston, VA. Open-File Report 2006-1272. Online. http://pubs.usgs.gov/of/2006/1272/. Accessed September 2009.

Ratcliffe, N. M., J. N. Aleinikoff, T. R. Armstrong, G. J. Walsh, and W. E. Hames. 2001. Intrusive relations and isotopic ages of Devonian granites in southern and central Vermont: evidence for a prolonged Acadian Orogeny and partitioning of compressional strain. Abstracts with Programs - Geological Society of America **33**(6):81.

Rittenour, T. M., J. Brigham-Grette, and M. E. Mann. 2000. El Nino-like climate teleconnections in New England during the late Pleistocene. Science **288**(5468):1039-1042.

Shook, R. A. Jr. 1983. Soil survey of Sullivan County, New Hampshire. U.S. Department of Agriculture, Soils Conservation Service, Washington, DC.

Stone, B. D. and J. R. Stone. 2009. A deep glacial varve record from the Hadley Basin, Glacial Lake Hitchcock, Sunderland, Massachusetts. Abstracts with Programs - Geological Society of America **41**(3):36.

Thorson, R. M. and C. A. Schile. 1995. Deglacial eolian regimes in New England. Geological Society of America Bulletin **107**(7):751-761.

Walsh, G. J., T. R. Armstrong, and N. M. Ratcliffe. 1996. Digital bedrock geologic map of the Vermont part of the 7.5 X 15 minute Mount Ascutney and Springfield quadrangles, Vermont. U.S. Geological Survey, Reston, VA. Open-File Report 96-733-A. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_18694.htm. Accessed October 2009.

Westerman, D. S. 2007. The tectonic origins of Devonian magmatism in northeastern Vermont: a speculative model. Abstracts with Programs - Geological Society of America **39**(1):53.

Data Sets

Saint-Gaudens National Historic Site Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

New Hampshire Digital Geologic Map
2006-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by U.S. Geological Survey staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=NH.

Vermont Digital Geologic Map
2006-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by U.S. Geological Survey and Vermont Geological Survey staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=VT.

Saratoga National Historical Park

Saratoga National Historical Park (SARA) was authorized June 1, 1938. It preserves the Saratoga battlefield, the site of the turning point in the American Revolution where in two battles (September 18 and October 7, 1777) Continental forces defeated and forced the surrender of a British army. SARA has two units: the main unit with the battlefield, and the Old Saratoga unit in and around Schuylerville, 10.9 km (6.8 miles) to the north, which includes Major General Phillip Schuyler's home, the Saratoga Monument, and Victory Woods. SARA's boundaries changed January 12, 1983. It encompasses 1,372.86 ha (3,392.42 acres), all but 205.39 ha (507.54 acres) of which are under federal administration.

Fort Stanwix National Monument (FOST), 145 km (90 miles) west-northwest of SARA, was authorized August 21, 1935. It hosts a reconstruction of the original Fort Stanwix, site of a siege in August 1777 and the signings of several treaties, including a British-Iroquois treaty November 5, 1768. Although FOST is not officially included in the Northeast Temperate Network, it is mentioned here for completeness and because its geology shares some features with SARA. FOST encompasses 6.28 ha (15.52 acres), all of which are under federal administration.

Geologic Background

SARA is located in eastern Saratoga County, New York. Stretches of the main unit's eastern border are on the west bank of the Hudson River. Saratoga Lake is a little over 5.6 km (3.5 miles) west of the main unit, and Saratoga Springs lies 13 km (8 miles) northwest. Troy, the nearest of the three large cities of the Capitol District, is about 28 km (17 miles) south of SARA. The Adirondack Mountains rise to the north and northwest. FOST is located in the south-central section of the city of Rome, in central Oneida County, New York. The Mohawk River runs east and south of FOST, joining the Erie Canal about 1 km (0.6 miles) south of the park. SARA is in the Hudson-Mohawk lowlands physiographic province (Silverman 2004), while FOST is in the Ontario (Oneida) Lake Plain province (Stein et al. 2008). Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held for SARA during July 2007. The geology of SARA was described in a geologic scoping summary by the National Park Service (2008), an internal NPS document.

The rocks underlying SARA and FOST began as Ordovician sediments (see the appendix for a geological time scale) deposited during one of the collisions that led to the formation of the supercontinent Pangaea. Eastern New York was near the boundary of the North American continent at the beginning of the Paleozoic, shortly before the deposition of the SARA/FOST bedrock. SARA is underlain by folded and faulted continental shelf rocks deformed by the Taconic and Acadian orogenies (mountain building events) (Fisher et al. 1971), and FOST is located on what had been a stable platform with little deformation (Fisher et al. 1971; Rogers et al. 1990). Prior continental rifting left a passive plate boundary (Fisher and Warthin 1976; Karabinos et al. 1999), similar to today's, where the continental crust leads into an ocean basin that is part of the same tectonic plate. This margin persisted until the Cambrian, when landmasses began colliding with North America. The collision that most affected eastern New York occurred during the Ordovician-age mountain-building event known as the Taconic Orogeny. The North American landmass of this time is known as Laurentia, the technical term for the core of the continent; this name commonly appears in scientific publications (Levin 1999). Early life left its traces in the vicinity; Petrified Sea Gardens, 18 km (11 miles) northwest of the main SARA unit, preserves Cambrian-age stromatolites (layered structures formed by algae trapping sediment); it is from this location that stromatolites were first recognized as organic structures, by James Hall in 1883 (Kluessendorf 1998).

The Taconic Orogeny of the northeastern United States has long been a source of controversy among geologists, even leading to court cases, criminal accusations, and expulsions (Friedman 2008). While the name might imply otherwise, it was not a simple single-stage occurrence, but a series of episodes (Rodgers 1971). In the New York region, the effects of the orogeny became apparent beginning approximately 458 Ma (million years ago) (Hurowitz and McLennan 2005). Exactly what happened during the orogeny is

debated, and models with one or two subduction zones and the collision of one or two volcanic arcs have been proposed (Karabinos et al. 2003). The approach of the arc(s) was preceded by volcanic activity recorded as altered ash beds and similar deposits in sedimentary rocks forming to the west (Rodgers 1971; Rowley et al. 1979). Deformation and metamorphism increase from west to east (Rowley et al. 1979). Much of New York east of the Hudson River is made up of the Taconic Allochthon, a controversial area of displaced rocks.

The Taconic Allochthon is the general term for a series of fault blocks and slices found on either side of the immediate vicinity of New York's eastern border. Its component thrust sheets include upper Proterozoic and Cambrian rocks from the rift period and overlying Cambrian-Ordovician rocks from the continental rise that formed after the rift. The various thrust sheets have led to much confusion about the definitions of the rock formations (Kidd et al. 1995). One Taconic Allochthon thrust sheet, the large Giddings Brook Slice, is just east of SARA (Rowley et al. 1979). "Allochthon" is the term for a block or slice of rocks that have been transported from its original setting. The adjective "allochthonous" also describes this property, and is commonly used in geology. Similarly, "autochthon" and "autochthonous" refer to rocks that have remained where they were first deposited or formed. Some other terms, including "parautochthonous" and "neoautochthonous," refer to rocks that have only moved a short distance, intermediate between allochthony and autochthony. These last terms are sometimes used in reference to the Austin Glen Formation (see below).

The basic model for the creation of the Taconic Allochthon is as west-moving low angle thrust sheets traveling across the floor of a foreland basin (foreland basins are basins formed in response to adjacent mountain ranges). Some associated formations, such as the Austin Glen Formation, were deposited throughout the faulting process, before, during, and after movement (Sanders 1995). The various thrust sheets originally formed a deepwater continental rise. As part of the Taconic Orogeny's compressional activity, the rise was faulted onto the continental shelf (Hurowitz and McLennan 2005). The thrust sheets of the Allochthon were moved a substantial distance, perhaps 200 km (120 miles) (Hurowitz and McLennan 2005) to 1,000 km (620 miles) (Stanley and Ratcliffe 1985). The foreland basin subsided due to the addition of the thrust sheets and other sediment. This led to the sinking of the wide shallow marine platform to the west (Lehmann et al. 1994). At the time, the marine body over the area was on the order of 500 to 900 km (310 to 560 miles) wide, between Laurentia and an incoming island arc. Black shales like the Utica Shale represent the deep water part of the closing ocean basin (Rigby 1993). The subsidence, in combination with sea level rise, allowed the deep basinal units to spread (Lehmann et al. 1994; Brett and Baird 2002a), advancing across the northeastern United States and southeastern Canada (Bergström and Mitchell 1992).

Extensional stresses set in between the Taconic Orogeny and the later Acadian Orogeny, with some igneous activity (Fisher and Warthin 1976). Tectonic collisions after the Taconic Orogeny did not affect eastern New York as extensively, because the continental margin had moved farther east. The Acadian Orogeny contributed some folding, cleavage, and other deformation to eastern New York (Toots 1976). The later Alleghenian Orogeny, when Africa and South America collided with North America, had most of its effects outside of the SARA/FOST region, although the continental breakup that followed produced a few faults in Dutchess County and igneous activity in Rockland County, dating to approximately 185 Ma (Fisher and Warthin 1976).

More recently, glacial activity during the Pleistocene (between 2.59 Ma and approximately 12,000 years ago) scoured and reworked the preexisting topography. There were four major periods of glaciation, but only the last (Wisconsinan) is evident at the surface in New York (Silverman 2004). The most recent glacial advance in the Saratoga area was represented by the Hudson-Champlain lobe of the Laurentide Ice Sheet (Connally 1983). It overprinted previous glacial activity and left a great quantity of loose sediments during its retreat (Robinson et al. 2005). Ice covered even the Adirondacks, but broke up into smaller lobes on the mountains as it thinned and receded (Muller et al. 1983; Gurrieri and Musiker 1990). Deglaciation was underway approximately 20,000 years ago (Robinson et al. 2005), and the Saratoga area was deglaciated a few thousand years later (Connally and Sirkin 1971). A few brief readvances occurred

during deglaciation (Ibe and Pardi 1985). To the west of SARA, FOST is in an area where two lobes (the Mohawk and Ontario lobes) affected the setting (Krall 1977). The Mohawk Lobe arrived from the southeast, and the Ontario Lobe from the northwest. FOST was most affected by the Oneida Sublobe of the Ontario Lobe (Ridge et al. 1991).

As the ice sheet retreated, vast lakes of glacial meltwater formed in valleys that were blocked by ice and sediment dams. Major glacial lakes in New York included Glacial Lake Albany, associated with the Hudson Valley (this lake inundated the SARA area), Glacial Lake Iroquois in the Lake Ontario-St. Lawrence lowlands west of the Adirondacks (which inundated the FOST area), and Glacial Lake Vermont in the Champlain Valley. Glacial Lake Iroquois initially drained into the Hudson Valley through the Mohawk Valley, but it switched to draining into Glacial Lake Vermont as the ice margin retreated. This caused Glacial Lake Iroquois to fail catastrophically, followed by Glacial Lake Vermont (Rayburn et al. 2002). This catastrophic drainage of glacial lakes Albany, Iroquois, and Vermont took place approximately 13,350 years ago, sending a massive freshwater pulse into the Atlantic through the Hudson Valley. The freshwater pulse was a possible trigger for a short cold period (Donnelly et al. 2004; Thieler et al. 2007). Oneida Lake is a remnant of Lake Iroquois (Stein et al. 2008).

Glacial Lake Albany is also a collective term for a series of named stages corresponding to extended periods of stable lake level, progressively lower over time. From oldest to youngest, these are the Lake Albany, Lake Quaker Springs, Lake Coveville, and Lake Fort Ann stages. Together, they existed for a few thousand years, disappearing over 11,000 years ago (Dineen and Miller 2006). The history of Glacial Lake Albany and its successor lakes is described in detail by Dineen and Rogers (1979), including lake levels as recorded in the Saratoga Lake area. Megafauna expanded into the Hudson Valley as the Wisconsinan ice sheet retreated, but went extinct in a few millennia or less (Robinson et al. 2000). By 10,000 years ago most of the megafauna was extinct. Humans probably arrived around 12,500 years ago (Funk 1977).

The bedrock geology of SARA and FOST consist of Ordovician-age sedimentary rocks. From oldest to youngest, these include the Indian River Formation, Mount Merino Formation, Austin Glen Formation, and Utica Shale (including the Canajoharie Shale; see below). The main unit of SARA is mostly underlain by the portion of the Utica Shale previously known as the Canajoharie Shale, with some undivided Indian River and Mount Merino Formation rocks in the west and some Austin Glen Formation rocks in the northwest. The Saratoga Unit parcels overlie undivided Indian River and Mount Merino Formation rocks. FOST overlies the Utica Shale (Fisher et al. 1970). The surficial geology of SARA and FOST consists of a combination of deposits dominated by post-glacial lake and river deposits and Pleistocene glacial deposits (Cadwell et al. 1987).

It should be noted that there is an alternative method of mapping the bedrock of the SARA area that omits formations in favor of units related to the complex fault- and tectonics-influenced stratigraphy, as used by Kidd et al. (1995), Landing et al. (2003), and English et al. (2006). In this method, the bedrock becomes a combination of mélange (a rock unit composed of large rock fragments [up to km scale] in a fine-grained matrix, formed at convergent plate boundaries), flysch (a deep marine rock unit composed of repetitive coarse-to-fine sediment layers, deposited by underwater avalanches in advance of a continental collision) dominated by graywacke (dark, hard, poorly sorted sandstone with angular grains), and shale-dominated flysch. This report will retain the older formational names to maintain consistency with the ROVA-SARA scoping summary. Using either formations or non-formational units does not change the fact that the primary fossil resource of the rocks is graptolites (a type of extinct colonial animal usually found in free-floating colonies, and useful for establishing relative dating), with other, rarer marine invertebrates.

Documented fossil resources at SARA consist of a shell and horn coral catalogued in the park collections (C. Robinson Valosin, SARA curator, pers. comm., November 2009). However, there is apparently a fossiliferous site at SARA as shown on an old map, but its precise location is unknown. Additionally, a cut bank at Schuyler House has exposed fossils (NPS 2008). Three fossiliferous locations have been identified on maps (Cushing and Ruedemann 1914; Ruedemann 1930), probably including the two scoping summary locations (see below).

Sources of Paleontological Resources

The fossils of SARA present opportunities for education, interpretation, and continued or future scientific research in the park. Three fossil sites have been reported from SARA units, and several other fossil sites are known from the immediate vicinity, including one just south of the main unit in Bemis Heights (Cushing and Ruedemann 1914; Ruedemann 1930). However, detail is lacking for these sites, and they are described as coming from geologic units that have since been superseded or heavily redefined. The sites include: a location at what is now the northwestern corner of the Schuyler House unit, in the Normanskill Shale (Cushing and Ruedemann 1914); a location in the Snake Hill Shale in the northeastern part of the main unit just north of Kroma (or Kromma) Kill, in an area where the bedrock is obscured by Pleistocene deposits (Cushing and Ruedemann 1914); and a location in the Snake Hill Shale, in the eastern central part of the main unit south of Mill Creek, near a small hill (Ruedemann 1930). The Schuyler House site is probably the cut bank site of the scoping summary (C. Robinson Valosin, pers. comm., November 2009), and the Kroma Kill site is probably the old map site of the scoping summary, as it is on the same map. The sites were probably explored by Cushing and/or Ruedemann circa 1909. Unfortunately, no collections have been located, and it may be that only field observations or collections were made, without any specimens being deposited in museum collections. Based on the geology, any specimens found would probably have been graptolites, most likely from the *Climacograptus spiniferous zone*, dating to approximately 450 Ma. The rocks were probably black mudstone, in mixed flysch deposited during the Taconic Orogeny that is now part of the mélange (E. Landing, New York state paleontologist, New York State Museum, pers. comm., November 2009 and January 2010).

According to the state geological map for this area, the Schuyler House site overlies undivided Indian River and Mount Merino formations, and the two sites in the main unit overlie the Canajoharie Shale (modern Utica Shale) (Fisher et al. 1970); thus, these formations are included under this section instead of "Potential Sources of Paleontological Resources." Relocating these sites and establishing their geology is a high priority for SARA fossil resource management. Fossils have not yet been documented from FOST.

Indian River Formation (Middle Ordovician)

The Indian River Formation (also Slate) is a colorful fine-grained unit. It is sometimes assigned to the Normanskill Formation or Group (Fisher 1962; Fisher and Warthin 1976). This formation is present under SARA (Fisher et al. 1970). The unit is composed of red, blue-green, and purple slates (Landing 1988), maroon to bright red and pale green shale, red and green chert, limestone lenses that may represent turbidites (underwater sediment avalanche deposits) (Fisher and Warthin 1976), and some rare coarser material (Landing 1988). The red color is unusual for its time and place, and helped make the Indian River Formation important to the early New York slate industry (Landing 1988). The formation is only about 50 m (160 ft) thick (Landing 1988). The lower boundary with the Stuyvesant Falls interval is conformable, as is the upper boundary with the Mount Merino Formation (Berry 1962), albeit abrupt (Landing 1988). It also grades laterally into the Mount Merino Formation (Fisher 1962), and the two are often mapped together (Fisher et al. 1970).

The Indian River Formation is interpreted as a distal slope and oceanic basin deposit (Fisher and Warthin 1976), accumulating on trough slopes (McLelland and Fisher 1976) under low-energy conditions (Fisher 1977). Flint-rich horizons in the middle and upper parts are thought to be altered volcanic tuff beds (Rowley et al. 1979). The formation dates to the late Middle Ordovician, between approximately 464 and 461 Ma (*Nemagraptus gracilis* graptolite zone) (Landing 1988), and is interpreted as marking the onset of the Taconic Orogeny (Landing 2000).

Fossils are very rare in the Indian River Formation. Radiolarians are present in the chert, and graptolites in the shale. Benthic (bottom-dwelling) organisms are absent (Fisher and Warthin 1976; Fisher 1977).

Mount Merino Formation (Middle and/or Upper Ordovician)

The Mount Merino Formation (also Shale, or Member) is another of the formations in the Taconic Allochthon (Fisher and Warthin 1976). This formation is present under SARA (Fisher et al. 1970). It is

sometimes included in the Normanskill Formation or Group (Fisher 1962; Zen 1964; Fisher and Warthin 1976). The Mount Merino Formation is usually a greenish-gray shale with thin intervals of coarser quartz-rich material. There are minor quantities of carbonates, quartzites, and siltstones (Zen 1967). The lower portion is composed of shale, chert, and siltstones, and the upper portion is composed of shale, siltstone, conglomeratic carbonates, and thin carbonate lenses (Goodwin et al. 2003). Silt increases toward the top, perhaps due to increasing turbidity currents (Landing 1988). The two portions are sometimes informally known as the Lower Chert Member (lower) and the Stoddard Road Member (upper) (Rowley et al. 1979). Overall, the formation is only about 50 m (160 ft) thick (Landing 1988). The age of the formation is approximately 462 to 456 Ma, based on graptolite zones (*Nemagraptus gracilis* to *Climacograptus bicornis* zones; Rowley et al. 1979; Landing 1988).

The underlying Indian River Formation grades into the Mount Merino Formation (Berry 1962), albeit abruptly (Landing 1988); the two units are also laterally gradational (Fisher 1962). Above is the Austin Glen Formation. This contact is marked by quartz-rich beds in dark shale (Landing 1988). Per the contentious Taconic geology in general, this contact is interpreted as gradational (Berry 1962) or unconformable (Sanders 1995; Goodwin et al. 2003); more recent descriptions favor an unconformable contact. The formation's depositional environment is interpreted as the continental rise (Hurowitz and McLennan 2005), with low energy (Fisher 1977). It accumulated on trough slopes (McLelland and Fisher 1976), and formed from arc-related sediments (Landing and Bartowski 1996) eroded during the Taconic Orogeny (Hurowitz and McLennan 2000).

Fossils are rare in the Mount Merino Formation (Fisher and Warthin 1976; Fisher 1977). There are radiolarians in the chert of the lower portion, and graptolites in the shale of the upper portion (Landing 1988). Benthic organisms are absent (Fisher and Warthin 1976; Fisher 1977). The graptolites are useful for strain analyses of the Taconic Orogeny; in these studies, the shapes of metamorphosed graptolites are compared to those of unmetamorphosed graptolites (Goldstein et al. 1998).

Utica Shale (including the Canajoharie Shale) (Upper Ordovician)

The Utica Shale is one of the oldest and most widespread black (organic-rich) shales (Martin 2005), present across the northeastern United States and southeastern Canada (Bergström and Mitchell 1992). The Canajoharie Shale was named for a similar shale, but it is now usually abandoned for the Flat Creek Member of the Utica Shale, which is the basal member of the formation (Goldman et al. 1994; Brett and Baird 2002a). The Canajoharie Shale is one of several Ordovician-age units in eastern New York, originally based on fossil content, which have fallen out of favor recently. It still has some use as a biostratigraphic label, in recognition of the fact that the base of the Utica Shale is older in the east than the west (Fisher 1977), and is occasionally still used (Lehmann et al. 1995). Goldman et al. (1994) replaced the name Canajoharie Shale with the Flat Creek Member of the Utica Shale, which is divided from the upper part of the Utica Shale (named the Indian Castle Member) by a sandy unit called the Dolgeville Formation. (Increasing the complexity, Brett and Baird [2002b] raised the Indian Castle and Flat Creek members to formations). The Dolgeville Formation also interfingers with the Flat Creek Member (Goldman et al. 1994). The Utica Shale is undivided east of the Dolgeville Formation, and its lower boundary is unconformable over carbonate rocks of the Trenton Group, which had been part of a shelf area (Goldman 1995). Some older references divide the Canajoharie and Utica shales into several members by the organisms present. In this scheme, the Canajoharie Shale is split into a lower Minaville and upper Fairfield members, and the Utica Shale is divided into the lower Nowadaga Member, middle Loyal Creek Member, and upper Holland Patent Member (Kay 1937). The Snake Hill Formation, discussed above, has sometimes been interpreted as a sandy depositional environment of the Canajoharie Shale (Zen 1967), or as gradational with the Utica Shale (Fisher 1977).

The Canajoharie section of the Utica Shale has a more limy composition than the upper Utica Shale, but both are dominantly black shales (Fisher et al. 1971). Numerous bentonite layers are found throughout the Utica Shale, and can be used to establish the unit's chronology independently of its graptolites (Goldman et al. 1994). The formation is known as a hydrocarbon producer, including oil and natural gas (Martin 2005). In accordance with the unit becoming younger at the base from east to west, the lower

section of the Utica Shale is present in the Saratoga Springs/SARA area (Fisher et al. 1970), while the upper part is present in the Utica/FOST area (Ruedemann 1925a). The Utica Shale is up to 300 m (1,000 ft) thick in eastern New York (Martin 2005). It is only 68 m (223 ft) thick in the Ballston Spa area, 16 km (10 miles) west of SARA (Roloson et al. 2008), but is about 210 m (700 ft) thick around Utica (Ruedemann 1925a; this predates the synonymization of the Canajoharie Shale with the Utica Shale, but the Canajoharie Shale as described was only present in eastern New York). Based on graptolites, the Utica Shale dates to between approximately 454 and 447 Ma (*Corynoides americanum* to *Geniculograptus pygmaeus* zones; Goldman 1995; Goldman et al. 2000).

The Utica Shale is part of a transgressive sequence (seas advancing over land) that formed in response to subsidence of the foreland basin (Goldman 1995). It transgressed to the west over shelf units in multiple pulses, in concert with subsidence and sea level rise (Mitchell et al. 1992; Goldman et al. 1994, 1999). Within the Utica Shale are smaller transgressive and regressive (retreating seas) episodes: the Flat Creek Member has a transgressional section followed by a regressional section, and the Indian Castle Member records a basin-wide deepening (Goldman et al. 1995). The Utica Shale was deposited in a deep marine basin with a subsiding north-south trough. As the basin filled in eastern New York, deposition spread to the west (Martin 2005). Sediment came from the Taconic highlands to the east (Bergström and Mitchell 1992). The environment is considered low energy and quiet water. Bioturbation was low. Shells were concentrated by east-moving currents and then buried by west-moving turbidity currents (Lehmann et al. 1990). In the Mohawk Valley, deposition was under great water depth, perhaps more than several hundred meters or feet, but water depth was shallower elsewhere (Bergström and Mitchell 1992).

Utica Shale fossils are common (Fisher 1977), and the bottom conditions must have been more favorable to life than earlier dark shales (see the shaly units described above for examples) (Ruedemann 1925a). Shelly layers alternate with sparsely fossiliferous clays (Lehmann et al. 1990). A diverse assemblage has been described from the Utica Shale, including problematics, possible algal traces or impressions (or invertebrate trace fossils), conulatans (shelled jellyfish), sponges, apparent nematomorph worms (horsehair worms), bryozoans, brachiopods, bivalves, cephalopods, gastropods, tentaculites (ribbed conical mollusks), machaeridians (armored annelids, first described as possible barnacles), ostracodes, crustaceans, eurypterids (sea scorpions), trilobites (Ruedemann 1925a, b, 1926), conodonts (Bergström and Goldman 1994), graptolites, and polychaete worm tubes (Ruedemann 1925a, b, 1926). Fossils assigned specifically to the Canajoharie Shale (modern lower Utica Shale) include brachiopods, polychaete worm tubes, bivalves, cephalopods, gastropods, hyolithids (extinct possible mollusks with conical shells), ostracodes, trilobites, and graptolites (Ruedemann 1912, 1916a, 1925a; Cushing and Ruedemann 1914). A phosphatic fossil hash is present at the base of the upper Utica Shale section, and sometimes between the "Loyal Creek" and "Holland Patent" members. These fossils include tube-like pieces resembling conulatan fragments (Lehmann et al. 1995).

There are some fossiliferous outcrops in the vicinities of SARA and FOST. Graptolites are present in the Utica Shale of Ballston Spa. They are most abundant in the lowest 7 m (23 ft) (Roloson et al. 2008). Notable fossiliferous outcrops are also known around Glens Falls (32 km [20 miles] north of SARA; Ruedemann 1912) and Albany (Beecher 1883; Ruedemann 1912). Trilobites have been found in the Utica Shale in and around Rome, New York. Some have been replaced with pyrite and are very well preserved, including soft tissue (Stürmer and Bergström 1973). Utica Shale outcrops in the Rome area also have preserved sponges, bryozoans, brachiopods, worms (Stürmer and Bergström 1973), eurypterids (Ruedemann 1916b), and trilobites (Stürmer and Bergström 1973). The uppermost Utica Shale level ("Holland Patent Member") in the Holland Patent area, 16.5 km (10.3 miles) northeast of FOST, has an assemblage including algae, sponges, bryozoans, brachiopods, worm tubes, bivalves, cephalopods, gastropods, tentaculites, trilobites, ostracodes, eurypterids, and graptolites, with sponges, cephalopods, trilobites, and graptolites being most abundant (Kay 1953).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within SARA and FOST. However, they are known to preserve fossils elsewhere, and future field investigations within the parks may uncover fossils in them.

Austin Glen Formation (Middle and/or Upper Ordovician)

The Austin Glen Formation (or Graywacke or Member) is a flysch of the Taconic Orogeny (Bock et al. 1998). This formation is present under SARA (Fisher et al. 1970). It is sometimes included in the Normanskill Formation or Group as its upper unit (Fisher 1962; Zen 1964; Fisher and Warthin 1976). However, the Austin Glen Formation is now regarded as forming not only with the older Normanskill units, but also during and after the thrust faulting that formed the Taconic Allochthon, which makes it distinct from the older units (Rowley et al. 1979; Sanders 1995; Goldstein et al. 1998). The lower part of the formation is composed of graywacke and more typical sandstone interbedded with bluish dark shale, while the upper part is composed of graywacke, conglomerate, and shale beds (Fisher and Warthin 1976). The Austin Glen Formation is much thicker than the older units covered here, at 120 to 150 m (400 to 500 ft) thick in Columbia County. Various units mapped as the Snake Hill Formation or Shale overlie it (Berry 1962). As noted above, the contact with the underlying Mount Merino Formation has been interpreted as gradational (Berry 1962) or unconformable (Sanders 1995; Goodwin et al. 2003), with more recent descriptions favoring an unconformable contact. Based on graptolite zones, the Austin Glen Formation dates to either between approximately 462 and 456 Ma (*Nemagraptus gracilis* and *Climacograptus bicornis* zones; Bock et al. 1998) or between approximately 460 and 450 Ma (*Climacograptus bicornis* and *Orthograptus truncatus* var. *intermedius* zone; Landing 1988).

The Austin Glen Formation may or may not be the same as several other units. It is equivalent to the Pawlet Formation (Zen 1964, 1967; Kidd et al. 1995). "Austin Glen" is more commonly used in the central and southern Taconic region, while "Pawlet" is more commonly used in the northern Taconic region (Rowley and Kidd 1981; Landing 1988). The Snake Hill Formation is sometimes considered synonymous with the Austin Glen Formation (Berry 1963; Kidd et al. 1995), or equivalent to it (Zen 1967), although it is regarded as distinct by English et al. (2006), at least at its type locality on Saratoga Lake. Some authors consider the Austin Glen Formation, Pawlet Formation, and Snake Hill Shale identical, and advocate abandonment of the Normanskill concept and the Snake Hill Shale, with restriction of the Austin Glen Formation to the folded part of the graywacke and shale (Kidd et al. 1995; although see the "Utica Shale" section below for another interpretation of the Snake Hill unit).

The Austin Glen Formation was deposited rapidly on the unstable continental slope (Fisher and Warthin 1976). The graywacke and graywacke conglomerates represent turbidites, while the finer-grained rocks probably represent periods of time with fewer turbidites (Fisher 1977). Both the Austin Glen and Pawlet formations are composed of turbidites that formed from sediment eroded from areas to the east (Rowley and Kidd 1981). The sequence may have begun with turbidites being deposited on outer and inner trench slopes. Then, after the Taconic Allochthon was thrust onto the continental margin, Austin Glen and Pawlet deposition spread out as a sediment blanket across the margin as well (Landing 1988).

The fossils of the Austin Glen and Pawlet formations are not diverse, with graptolites the most commonly cited fossil organisms (Fisher and Warthin 1976; Rowley et al. 1979). Pyritized worm burrows have also been reported from the Austin Glen Formation (Bock et al. 1998). Graptolites are found in the shale but are rare in the graywacke beds (Fisher 1977). For reference, if the Snake Hill Formation is based on an Austin Glen Formation outcrop, then a diverse benthic fauna can be added to the Austin Glen Formation, but it must be rare. Snake Hill Formation fossils include bryozoans, brachiopods, bivalves, gastropods, trilobites, crinoids, crinoid-like cystoids, graptolites (Ruedemann 1912; Cushing and Ruedemann 1914), and trace fossils (English et al. 2005).

Quaternary rocks and sediments (Pleistocene-Holocene)

The Quaternary rocks and sediments of SARA and FOST are mostly derived from the actions of glaciers and postglacial lakes and rivers. At the main SARA unit, most of the surficial geology is made up of limy silt and clay from glacial lakes. Also present are recent alluvium along the river, till on the western and southwestern borders, and glacial lake sand in the northwestern corner. Bedrock outcrops large enough to map are exposed at the surface just southeast of the park. Saratoga Monument rests on lacustrine sand. Schuyler House is over a combination of thin till with bedrock within 1 to 3 m (3 to 10 ft) of the surface (west), bedrock (southwest), and glacial lake silt and clay (east). Victory Woods is situated upon a combination of glacial lake silt and clay (southwest), lake sand (northwest), and modern alluvium (east) (Cadwell et al. 1987). Some postglacial dunes are also present (NPS 2008). FOST overlies outwash sand and gravel left by glacial rivers, with some modern colluvium possibly present on its east border (Cadwell et al. 1987).

Fossils are known from a number of different sources in the Quaternary deposits, including lesser-known sources such as much older fossils in rocks eroded by the glaciers and left in till deposits (Ries 1891; Kay 1953), and potential root traces in clay (Ries 1891). Most finds, though, are either bones of Quaternary vertebrates, or pollen and other plant material used for paleoecological studies. To date, the fossils in SARA collections appear to have derived from Quaternary deposits (see the "Park Collections" section below for more information).

Mastodons and, to a lesser extent, mammoths are iconic and common Quaternary fossils in New York. More than a half-dozen mastodon finds have been made within roughly 100 km (60 miles) of SARA (information per Hartnagel and Bishop [1921] except where noted), but the only one of any great completeness is the Cohoes mastodon, found in 1866 from Cohoes, 36 km (22 miles) south of SARA. Several finds were associated with shell marls. Of historical interest are two specimens found south of SARA. The oldest record of mastodon fossils from North America is a tooth and several bones found in 1705 from the Claverack area, 86 km (53 miles) south of SARA. The bones quickly disintegrated for the most part, but the tooth was brought to wider attention in 1714 by Cotton Mather, who interpreted the fossils as coming from an antediluvian ("pre-Flood") giant. This was followed in 1706 by a tooth from the Coxsackie area, 71 km (44 miles) south of SARA. At least two mammoth finds are known, from Queensbury, 41 km (25 miles) north of SARA, and from Mount Holly, 80 km (50 miles) northeast of SARA and identified as mammoth bones by Louis Agassiz (possibly mastodon instead) (Johnson 1998). Two mastodon finds are known from 100 km (60 miles) of FOST: a partial skeleton from Canastota, 28 km (17 miles) southwest of the park; and a tusk from Copenhagen (possibly from a mammoth instead), over 75 km (47 miles) north-northwest of the park. Three mammoth finds are also known: at Chittenango, 39 km (24 miles) southwest of FOST, associated with the Erie Canal; at Minoa, 48 km (30 miles) west-southwest of FOST; and at Salina, 60 km (37 miles) west-southwest of FOST (Hartnagel and Bishop 1921). Of other megafauna, ground sloths, caribou, and American bison are also known from the Hudson Valley, to the south of SARA (Fisher and Reilly 1969) (see the Roosevelt-Vanderbilt National Historic Sites summary in this document for further information).

While not as eye-catching, pollen, plant macrofossils, and invertebrates are widely distributed as well. They are often used for determining chronologies and examining paleoecology. Numerous sites from New York have organic materials that have been submitted for radiocarbon dating. The materials include peat, charcoal, wood, twigs, leaves, shells, bone, and unspecified organic debris (Muller and Calkin 1993). Sites are usually lakes, ponds, bogs, swamps, or areas that had formerly been one of these. A particular topic of interest for lakes in the Adirondacks is histories of acidification, although in most of these cases the studied period of time is very short, on the order of a few hundred years (Smol and Dixit 1990; Uutala 1990; Dixit et al. 1993). Material of interest for acidification studies include scales of mallmonadacean or chrysophycean algae (golden algae) (Smol et al. 1984; Christie and Smol 1986), diatoms (Dixit et al. 1993), and mandibles of larval phantom midges (*Chaoborus*) (Uutala 1990). Wetland areas of former dune fields have also been studied for pollen, such as within the Colonie Dune Field between Albany and Schenectady to the south and southwest of SARA, where bogs formed between dunes during the time shortly before and after the beginning of the Holocene (Dineen et al. 1978).

Ballston Lake is the nearest published pollen site to SARA, 16 km (10 miles) to the west-southwest. Ballston Lake formed near the beginning of the Younger Dryas cold period. At the time, the Mohawk River flowed in the Ballston Lake basin (Garrand et al. 2000). The base of one sediment core from the lake dates to 13,233 to 13,063 calendar years before present (11,240 ± 40 radiocarbon years before present). Note that radiocarbon dates are not the same as calendar dates, and that radiocarbon years require calibration to yield calendar years. Uncalibrated radiocarbon dates in publications are often denoted with "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. Therefore, dates that are not labeled with "calendar years" or something similar should be assumed to be uncalibrated radiocarbon dates. Dates here were calibrated using Calib 5.0.2 (http://calib.qub.ac.uk/calib/) where the data permit. Much organic matter is present in the lake's southern basin because of anoxic conditions (Daigle and Rodbell 2005). Other sites within approximately 100 km (60 miles) of SARA include: Heart's Content Bog, a pollen site 25 km (16 miles) south of SARA (Ibe and Pardi 1985); Meadowdale Bog, a pollen site near Albany, 39 km (24 miles) south of SARA (Dineen 1986); Burden Lake and a peat bog at West Sand Lake, pollen sites 43 km (27 miles) south-southeast of SARA (Gaudreau 1982); Great Bear Swamp, a pollen site roughly 70 km (45 miles) southwest of SARA (Dineen 1986); and Eagle Hill Camp Bog in Columbia County, 102 km (63 miles) south of SARA (Connally and Sirkin 1986). Megafaunal sites often also have useful material for paleoecological studies (Robinson et al. 2005). A number of pollen sites have been studied in the Adirondacks as well (Overpeck 1985; Jackson 1989; Jackson and Whitehead 1991). Additional information on pollen sites can be found on the National Oceanic and Atmospheric Administration's online Global Pollen Database (http://www.ncdc.noaa.gov/paleo/gpd.html).

Most Quaternary fossil reports from the vicinity of FOST, other than the mastodons and mammoths discussed above, are associated with lakes. These include Oneida Lake, as near as 22 km (14 miles) west of FOST (Fadem 2001); Green Lake, 45 km (28 miles) southwest of FOST (Smith et al. 2007); Onondaga Lake, 60 km (37 miles) west-southwest of FOST (Dean and Eggleston 1978; Rowell 1996; Mullins and Lyons 2005); and Otsego Lake, 65 km (40 miles) southeast of FOST (Yuretich and Leclair 1980). Lake deposits may include organic debris, peat, wood (Mullins and Lyons 2005), pollen, diatoms (Rowell 1996), stromatolites (Yuretich and Leclair 1980), bivalves, gastropods (Mullins and Lyons 2005), and ostracodes (Smith et al. 2007). River deposits may have datable organic debris, charcoal, and wood (Scully and Arnold 1981).

Park Collections

Christine Robinson Valosin (pers. comm., November 2009) reported two items cataloged as fossils in SARA collections. SARA-2531 is a horn coral (cataloged as an animal tooth) found somewhere near the Neilson House. SARA-15735 is a bivalve shell recovered during an archeological investigation of the American Headquarters site (Woodworth Farm). The two localities are near each other. Further investigation may yield additional provenance information for these fossils and suggest potential for continued discoveries. There are no fossils currently known from FOST museum collections.

As discussed above, the fossil localities included on maps by Cushing and Ruedemann (1914) and Ruedemann (1930) were probably based on field collections and/or observations, with apparently no specimens to be found in the collections of the New York State Museum. Records about the field activities of Cushing, Ruedemann, and other associated researchers are kept at the New York State Museum; however, again no records were found for field work in the area of the future park (E. Landing, pers. comm., November 2009 and January 2010).

Cultural Resource Contexts

Humans have been present in New York for over 10,000 years, and there are artifacts of Middle Archaic (8,000-6,000 years ago) and Late Archaic (6,000-3,000 years ago) age at Victory Woods of SARA, as well as Middle Archaic shell middens and evidence of camps as old as 8,500 years at Saratoga Lake, indicating occupation and utilization of the SARA area for the last 7,500 years (Stevens et al. 2007). Thus, a human-

fossil resource association would not be unexpected. To date, there is one reported example of a fossil that could be considered as associated with a cultural resource context at SARA or FOST: SARA-15735, which was recovered during an archeological investigation as mentioned above. 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

- The NPS Geologic Resources Division coordinated a geologic resource inventory scoping session for SARA during July 2007, which includes a discussion on paleontological resources (NPS 2008).
- Documented paleontological resources at SARA to date consist of a shell and horn coral in park collections. Further investigation of their provenance may lead to additional finds.
- Three fossiliferous sites are within SARA units per maps included in Cushing and Ruedemann (1914) and Ruedemann (1930). Relocating these sites and establishing their geology (many of the units used in these maps have been superseded or redefined) is a high priority for SARA fossil resource management.
- Park staff should be encouraged to observe exposed sedimentary material for fossil material while conducting their usual duties. Staff should photodocument and potentially 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. 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).
- Future archeological excavations or infrastructure developments should consider scheduling site monitoring by a trained paleontologist in order to document and protect fossil resources.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

Literature Cited

Beecher, C. E. 1883. List of species of fossils from an exposure of the Utica slate and associated rocks, within the limits of the City of Albany. Page 78 *in* Annual Report of the Regents. New York State Museum and Science Service, Albany, NY. Annual Report 36.

Bergström, S. M. and C. E. Mitchell. 1992. The Ordovician Utica Shale in the eastern Midcontinent region: age, lithofacies, and regional relationships. Pages 67-89 *in* Chaplin, J. R. and J. E. Barrick, editors. Special papers in paleontology and stratigraphy: a tribute to Thomas W. Amsden. Oklahoma Geological Survey, Norman, OK. Bulletin 145.

Bergström, S. M. and D. Goldman. 1994. Conodont biostratigraphy and biofacies of the Jacques Cartier River Ordovician section, Quebec. Pages 1-4 *in* Landing, E., editor. Studies in stratigraphy and paleontology in honor of Donald W. Fisher. New York State Museum and Science Service, Albany, NY. Bulletin 481.

Berry, W. B. N. 1962. Stratigraphy, zonation, and age of Schaghticoke, Deepkill, and Normanskill shales, eastern New York. Geological Society of America Bulletin **73**(6):695-718.

Berry, W. B. N. 1963. On the 'Snake Hill Shale'. American Journal of Science **261**(8):731-737.

Bock, B., S. M. McLennan, and G. N. Hanson. 1994. Does redistribution of rare earth elements in turbidites of the Appalachian foreland basin compromise provenance information? Mineralogical Magazine **58A**(A-K):103-104.

Bock, B., S. M. McLennan, and G. N. Hanson. 1998. Geochemistry and provenance of the Middle Ordovician Austin Glen Member (Normanskill Formation) and the Taconian Orogeny in New England. Sedimentology **45**(4):635-655.

Brett, C. E. and G. C. Baird. 2002a. Revised stratigraphy of the Trenton Group in its type area, central New York State: sedimentology and tectonics of a Middle Ordovician shelf-to-basin succession. Physics and Chemistry of the Earth **27**(1-3):231-263.

Brett, G. C. and C. E. Baird. 2002b. Indian Castle Shale: late synorogenic siliciclastic succession in an evolving Middle to Late Ordovician foreland basin, eastern New York State. Physics and Chemistry of the Earth **27**(1-3):231-263.

Cadwell, D. H., R. J. Dineen, G. G. Connally, P. J. Fleisher, and J. L. Rich. 1987. Surficial geologic map of New York: Hudson-Mohawk sheet. New York State Museum and Science Service, Albany, NY. Map and Chart Series 40. Scale 1:250,000.

Christie, C. E. and J. P. Smol. 1986. Recent and long-term acidification of Upper Wallface Pond (N.Y.) as indicated by mallomonadacean microfossils. Hydrobiologia **143**:355-360.

Connally, G. G. 1983. Wisconsinan time-, rock-, and morpho-stratigraphy of the mid-Hudson Valley, New York. Abstracts with Programs - Geological Society of America **15**(3):133.

Connally, G. C. and L. A. Sirkin. 1971. Luzerne Readvance near Glens Falls, New York. Geological Society of America Bulletin **82**(4):989-1008.

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 and Science Service, Albany, NY. Bulletin 455.

Cushing, H. P. and R. Ruedemann. 1914. Geology of Saratoga Springs and vicinity. New York State Museum and Science Service, Albany, NY. Bulletin 169.

Daigle, T. and D. T. Rodbell. 2005. A high resolution sediment record of the last approximately 11,240 ^{14}C yr from a laminated lake core from Ballston Lake, eastern New York State. Abstracts with Programs - Geological Society of America **37**(1):28.

Dean, W. E. and J. R. Eggleston. 1978. Freshwater oncolites, Onondaga Lake, New York. AAPG Bulletin **62**(3):509.

Dineen, R. J. 1986. Deglaciation of the Hudson Valley between Hyde Park and Albany, New York. Pages 89-108 *in* Cadwell, D. H., editor. The Wisconsinan Stage of the First Geological District, eastern New York. New York State Museum and Science Service, Albany, NY. Bulletin 455.

Dineen, R. J. and N. G. Miller. 2006. Age and paleoecology of plant fossils associated with the Quaker Springs stage of Lake Albany, and a chronology of deglacial events in the Hudson-Champlain Lowlands, New York. Abstracts with Programs - Geological Society of America **38**(2):8-9.

Dineen, R. J. and W. B. Rogers. 1979. Sedimentary environments in glacial Lake Albany in the Albany section of the Hudson-Champlain Lowlands. Pages 87-119 (Trip A-3) *in* Friedman, G. M., editor.

Joint annual meeting of New York State Geological Association, 51st annual meeting and New England intercollegiate geological conference, 71st annual meeting. New York State Geological Association, Staten Island, NY.

Dineen, R. J., W. B. Rogers, and M. R. Buyce. 1978. Paleowind, age and climate of late Pleistocene sand dunes in Albany and Schenectady counties, New York. Abstracts with Programs - Geological Society of America **10**(7):390.

Dixit, S. S., B. F. Cumming, H. J. B. Birks, J. P. Smol, J. C. Kingston, A. J. Uutala, D. F. Charles, and K. E. Camburn. 1993. Diatom assemblages from Adirondack lakes (New York, USA) and the development of inference models for retrospective environmental assessment. Journal of Paleolimnology **8**(1):27-47.

Donnelly, J. P., N. Driscoll, E. Uchupi, L. Keigwin, W. Schwab, E. Thieler, and S. Swift. 2004. Catastrophic drainage of glacial Lake Iroquois down the Hudson River valley: a potential trigger for the intra-Allerod cold period. Eos **85**(supplement to 47):F1155. Abstract PP31A-0900.

English, A. M., E. Landing, and G. C. Baird. 2005. Snake Hill Formation – syntectonic facies of the easternmost Taconic foreland basin in eastern New York. Abstracts with Programs - Geological Society of America **37**(1):18.

English, A. M., E. Landing, and G. C. Baird. 2006. Snake Hill Formation – reconstructing eastern Taconic foreland basin litho- and biofacies from a giant mélange block in eastern New York, USA. Palaeogeography, Palaeoclimatology, Palaeoecology **242**(3-4):201-213.

Fadem, C. M. 2001. Chronology of landscape evolution at Oneida Lake. Abstracts with Programs - Geological Society of America **33**(1):25.

Fisher, D. W. 1962. Correlation of the Ordovician rocks in New York State. New York State Museum and Science Service, Albany, NY. Map and Chart Series 3.

Fisher, D. W. 1977. Correlation of the Hadrynian, Cambrian and Ordovician rocks in New York State. New York State Museum and Science Service, Albany, NY. Map and Chart Series 25.

Fisher, D. W. and E. M. Reilly Jr. 1969. New discoveries of late Pleistocene mammals in the Hudson valley. Abstracts with Programs - Geological Society of America **1**(1):18.

Fisher, D. W. and A. S. Warthin Jr. 1976. Stratigraphic and structural geology in western Dutchess County, New York. Trip B-6 *in* Johnsen, J. H., editor. Guidebook to field excursions at the 48th annual meeting of the New York State Geological Association. New York State Geological Association, Staten Island, NY.

Fisher, D. W., Y. W. Isachsen, and L. V. Rickard. 1970. Geologic map of New York: Hudson-Mohawk sheet. New York State Museum and Science Service, Albany, NY. Map and Chart Series 15. Scale 1:250,000.

Fisher, D. W., Y. W. Isachsen, and L. V. Rickard. 1971. Generalized tectonic-metamorphic map of New York. New York Museum and Science Service, Albany, NY. Map and Chart Series 15.

Friedman, G. M. 2008. Explosive bolide impact designates the Cambrian explosion, terminating the Cambrian event in New York. Northeastern Geology and Environmental Sciences **30**(1):61-68.

Funk, R. E. 1977. Early cultures in the Hudson drainage basin. Annals of the New York Academy of Sciences **288**:316-332.

Garrand, J. L., D. T. Rodbell, and N. G. Miller. 2000. The sedimentologic and palynologic record of the last deglaciation from Ballston Lake, New York. New York State Museum and Science Service, Albany, NY. Circular 62:61.

Gaudreau, D. C. 1982. Holocene vegetational history of central New England and the Hudson River valley. Program and Abstracts - American Quaternary Association **7**:93.

Goldman, D. 1995. Taxonomy, evolution, and biostratigraphy of the *Orthograptus quadrimucronatus* species group (Ordovician, Graptolithina). Journal of Paleontology **69**(3):516-540.

Goldman, D., C. E. Mitchell, S. M. Bergstrom, J. W. Delano, and S. Tice. 1994. K-bentonites and graptolites biostratigraphy in the Middle Ordovician of New York State and Quebec: a new chronostratigraphic model. Palaios **9**(2):124-143.

Goldman, D., C. E. Mitchell, G. C. Baird, and C. E. Brett. 1995. Tectonic and eustatic controls on graptolite relative abundance patterns. Abstracts with Programs - Geological Society of America **27**(1):48.

Goldman, D., C. E. Mitchell, and M. P. Joy. 1999. The stratigraphic distribution of graptolites in the classic upper Middle Ordovician Utica Shale of New York State: an evolutionary succession or a response to relative sea-level change? Paleobiology **25**(3):273-294

Goldman, D., K. T. Barrett, and S. M. Bergstrom. 2000. Working toward a standard Upper Ordovician graptolite zonation: correlation of the Mt. Merino and Utica shales in New York State. Abstracts with Programs - Geological Society of America **32**(4):A-15.

Goldstein, A., J. Knight, and K. Kimball. 1998. Deformed graptolites, finite strain and volume loss during cleavage formation in rocks of the Taconic slate belt, New York and Vermont, U.S.A. Journal of Structural Geology **20**(12):1769-1782.

Goodwin, B. P., R. H. Waines, and J. H. MacDonald. 2003. Preliminary stratigraphy and structure of a medial Ordovician Mount Merino inlier within the Livingston Taconic tectonic thrust slice in west-central Dutchess County, mid-Hudson Valley, New York. Abstracts with Programs - Geological Society of America **35**(3):94-95.

Gurrieri, J. T. and L. B. Musiker. 1990. Late Wisconsinan ice margins and recessional events in the north-central Adirondack Mountains, New York. Northeastern Geology **12**(4):185-197.

Hartnagel, C. A. and S. C. Bishop. 1921. The mastodons, mammoths and other Pleistocene mammals of New York State. New York State Museum and Science Service, Albany, NY. Bulletins 241 and 242.

Hurowitz, J. A. and S. M. McLennan. 2000. Neodymium isotopic evolution of the eastern margin of Laurentia: from rifting to the Taconian Orogeny. Abstracts with Programs - Geological Society of America **32**(1):25-26.

Hurowitz, J. A. and S. M. McLennan. 2005. Geochemistry of Cambro-Ordovician sedimentary rocks of the northeastern United States: changes in sediment sources at the onset of Taconian orogenesis. The Journal of Geology **113**(5):571-587.

Ibe, R. A. and R. R. Pardi. 1985. A radiocarbon-dated pollen diagram for Heart's Content Bog, Green County, New York. Northeastern Geology **7**(3-4):201-208.

Jackson, S. T. 1989. Postglacial vegetational changes along an elevational gradient in the Adirondack Mountains (New York): a study of plant macrofossils. New York State Museum and Science Service, Albany, NY. Bulletin 465.

Jackson, S. T. and D. R. Whitehead. 1991. Holocene vegetation patterns in the Adirondack Mountains. Ecology **72**(2):641-653.

Johnson, C. W. 1998. The nature of Vermont: introduction and guide to a New England environment. University Press of New England, Hanover, NH.

Karabinos, P., J. N. Aleinikoff, and C. M. Fanning. 1999. Distinguishing Grenvillian basement from pre-Taconian cover rocks in the Northern Appalachians. American Journal of Science **299**(6):502-515.

Karabinos, P., H. M. Stoll, and J. C. Hepburn. 2003. The Shelburne Falls arc – lost arc of the Taconic orogeny. Pages B3-1-B3-17 *in* Brady, J. and J. Chaney, editors. New England Intercollegiate Geologic Conference, Amherst, MA.

Kay, G. M. 1937. Stratigraphy of the Trenton group. Geological Society of America Bulletin **48**(2):233-302.

Kay, G. M. 1953. Geology of the Utica Quadrangle, New York. New York State Museum and Science Service, Albany, NY. Bulletin 347.

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* Lucas, S. G., 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, NM. Bulletin 34. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed September 2009.

Kidd, W. S. F., A. Plesch, and F. W. Vollmer. 1995. Lithofacies and structure of the Taconic flysch, melange, and allochthon, in the New York Capital District. Pages 57-80 (Trip A-4) *in* Garver, J. I. and J. A. Smith, editors. Field trip guidebook for the 67th annual meeting of the New York State Geological Association. New York State Geological Association, Staten Island, NY.

Kluessendorf, J. 1998. National Historic Landmark nomination: Petrified Sea Gardens. Online. http://pdfhost.focus.nps.gov/docs/NHLS/Text/99000631.pdf. Accessed January 2010.

Krall, D. B. 1977. Late Wisconsinan ice recession in east-central New York. Geological Society of America Bulletin **88**(12):1697-1710.

Landing, E. 1988. Depositional tectonics and biostratigraphy of the western portion of the Taconic Allochthon, eastern New York State. Pages 96-110 *in* Landing, E., editor. Sesquicentennial celebration of the New York State Geological Survey: proceedings of meeting. New York State Museum and Science Service, Albany, NY. Bulletin 462.

Landing, E. 2000. Lower Paleozoic of the East Laurentian continental slope: eustatic/climate controls on macro- and microscale mudstone alternations. Abstracts with Programs - Geological Society of America **33**(1):16.

Landing, E. and K. E. Bartowski. 1996. Oldest shelly fossils from the Taconic Allochthon and late Early Cambrian sea-levels in eastern Laurentia. Journal of Paleontology **70**(5):741-761.

Landing, E., G. Pe-Piper, W. S. F. Kidd, and K. Azmy. 2003. Tectonic setting of outer trench slope volcanism; pillow basalt and limestone in the Taconian Orogen of eastern New York. Canadian Journal of Earth Sciences **40**(12):1773-1787.

Lehmann, D., C. E. Brett, S. Britt, M. Parsons, and D. Ryan. 1990. Fossil concentrations in black shale environments: the role of gradient currents. Abstracts with Programs - Geological Society of America **22**(7):A82.

Lehmann, D., C. E. Brett, and R. Cole. 1994. Tectonic and eustatic influences upon the sedimentary environments of the Upper Ordovician strata of New York and Ontario. Concepts in Sedimentology and Paleontology **4**:181-201.

Lehmann, D., C. E. Brett, R. Cole, and G. Baird. 1995. Distal sedimentation in a peripheral foreland basin: Ordovician black shales and associated flysch of the western Taconic Foreland, New York State and Ontario. Geological Society of America Bulletin **107**(6):708-724.

Levin, H. L. 1999. The Earth through time (6th edition). Saunders College Publishing, Fort Worth, TX.

Martin, J. P. 2005. Utica Shale deposition in the Taconic foreland basin: evolution and the potential for natural gas production. Abstracts with Programs - Geological Society of America **37**(1):5.

McLelland, J. M. and D. W. Fisher. 1976. Stratigraphy and structural geology in the Harlem Valley, S.E. Dutchess County, New York. Trip C-7 *in* Johnsen, J. H., editor. Guidebook to field excursions at the 48th annual meeting of the New York State Geological Association. New York State Geological Association, Staten Island, NY.

Mitchell, C. E., D. Goldman, S. M. Bergström, J. W. Delano, and S. D. Samson. 1992. Chronostratigraphy of the Trenton Group and Utica Shale: Pt. I, Preliminary revision of lithofacies and age relationships. Abstracts with Programs - Geological Society of America **24**(7):A196.

Muller, E. H. and P. E. Calkin. 1993. Timing of Pleistocene glacial events in New York State. Canadian Journal of Earth Science **30**(9):1829-1845.

Muller, E. H., D. A. Franzi, and J. C. Ridge. 1983. Pleistocene stratigraphy of the western Mohawk Valley, New York. Abstracts with Programs - Geological Society of America **15**(3):134.

Mullins, H. T. and R. P. Lyons. 2005. Drill core results from Onondaga Valley, New York: implications for deglaciation and environmental stratigraphy. Northeastern Geology and Environmental Sciences **27**(4):326-336.

National Park Service, Geologic Resources Division. 2008. Geologic resource evaluation scoping summary: Saratoga National Historical Park & Roosevelt-Vanderbilt National Historic Sites. National Park Service, Geologic Resources Division, Denver, CO. Online. http://www.nature.nps.gov/geology/inventory/publications/s_summaries/ROVA-SARA_gre_scoping_summary_2008-0924.pdf. Accessed September 2009.

Overpeck, J. T. 1985. A pollen study of a late Quaternary peat bog, south-central Adirondack Mountains, New York. Geological Society of America Bulletin **96**(1):145-154.

Rayburn, J. A., D. A. Franzi, and P. L. K. Knuepfer. 2002. A large late glacial breakout flood through the Champlain and Hudson Lowlands, New York. Abstracts with Programs - Geological Society of America **34**(6):475.

Ridge, J. C., D. A. Franzi, and E. H. Muller. 1991. Late Wisconsinan, pre-Valley Heads glaciation in the western Mohawk Valley, central New York, and its regional implications. Geological Society of America Bulletin **103**(8):1032-1048.

Ries, H. 1891. Quaternary deposits of the Hudson River valley between Croton and Albany, with notes on the brick clays and the manufacture of brick. New York State Geologist Annual Report **10**:110-155.

Rigby, S. 1993. Population analysis and orientation studies of graptoloids from the Middle Ordovician Utica Shale, Quebec. Palaeontology **36**(2):267-282.

Robinson, G., D. A. Burney, and L. P. Burney, L. P. 2000. Megafaunal fossil sites of the lower Hudson Valley region. New York State Museum and Science Service, Albany, NY. Circular 62:41.

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.

Rodgers, J. 1971. The Taconic Orogeny. Geological Society of America Bulletin **82**(5):1141-1178.

Rogers, W. B., Y. W. Isachsen, T. D. Mock, and R. E. Nyahay. 1990. New York State geological highway map. New York State Museum and Science Service, Albany, NY. Educational Leaflet 33.

Roloson, M., C. E. Mitchell, B. Sell, S. D. Samson, and G. Baird. 2008. Further constraints on the age of the Taconic foreland basin fill in eastern NY: graptolite biostratigraphy and tephrochronology from core 75NY2, Ballston Spa, NY. Abstracts with Programs - Geological Society of America **40**(2):63.

Rowell, H. C. 1996. Paleolimnology of Onondaga Lake: the history of anthropogenic impacts on water quality. Lake and Reservoir Management **12**(1):35-45.

Rowley, D. B. and W. S. F. Kidd. 1981. Stratigraphic relationships and detrital composition of the medial Ordovician flysch of western New England: implications for the tectonic evolution of the Taconic Orogeny. Journal of Geology **89**(2):199-218.

Rowley, D. B., W. S. F. Kidd, and L. L. Delano. 1979. Detailed stratigraphic and structural features of the Giddings Brook slice of the Taconic Allochthon in the Granville area. Pages 186-242 (Trip A-8) *in* Friedman, G. M., editor. Joint annual meeting of New York State Geological Association, 51st annual meeting and New England intercollegiate geological conference, 71st annual meeting. New York State Geological Association, Staten Island, NY.

Ruedemann, R. 1912. The lower siluric shales of the Mohawk Valley. New York State Museum and Science Service, Albany, NY. Bulletin 162.

Ruedemann, R. 1916a. Account of some new or little-known species of fossils. Pages 7-97 *in* Ruedemann, R. Paleontologic contributions from the New York State Museum. New York State Museum and Science Service, Albany, NY. Bulletin 189.

Ruedemann, R. 1916b. *Spathiocaris* and the Discinocarina. Pages 98-112 *in* Ruedemann, R. Paleontologic contributions from the New York State Museum. New York State Museum and Science Service, Albany, NY. Bulletin 189.

Ruedemann, R. 1925a. The Utica and Lorraine formations of New York: Part 1. Stratigraphy. New York State Museum and Science Service, Albany, NY. Bulletin 258.

Ruedemann, R. 1925b. The Utica and Lorraine formations of New York: Part 2. Systematic paleontology: No. 1. Plants, sponges, corals, graptolites, crinoids, worms, bryozoans, brachiopods. New York State Museum and Science Service, Albany, NY. Bulletin 262.

Ruedemann, R. 1926. The Utica and Lorraine formations of New York: Part 2. Systematic paleontology: No. 2. Mollusks, crustaceans, and eurypterids. New York State Museum and Science Service, Albany, NY. Bulletin 272.

Ruedemann, R. 1930. Geology of the Capital District (Albany, Cohoes, Troy, and Schenectady Quadrangles). New York State Museum and Science Service, Albany, NY. Bulletin 285.

Sanders, J. E. 1995. Lower Paleozoic carbonate-clast diamictites: relationship to thrust sheets that advanced across the floor of the northern Appalachian Ordovician foreland basin. Northeastern Geology and Environmental Sciences **17**(1):23-45.

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

Scully, R. W. and R. W. Arnold. 1981. Holocene alluvial stratigraphy in the upper Susquehanna River basin, New York. Quaternary Research **15**(3):327-344.

Silverman, M. H. 2004. Soil survey of Saratoga County, New York. U.S. Department of Agriculture, Soils Conservation Service, Washington, DC.

Smith, A. J., D. L. Dettman, J. W. King, and C. F. M. Lewis. 2007. Mid-Holocene ostracode and isotope record from Fayetteville Green Lake, New York: a detailed record of hydroclimatic change linked to the Laurentian Great Lakes. Program and Abstracts of the 50th Conference of the International Association for Great Lakes Research **50**:182.

Smol, J. P. and S. S. Dixit. 1990. Patterns of pH change inferred from chrysophyte microfossils in Adirondack and northern New England lakes. Journal of Paleolimnology **4**(1):31-41.

Smol, J. P., D. F. Charles, and D. R. Whitehead. 1984. Mallomonadacean microfossils provide evidence of Recent lake acidification. Nature **307**(5952):628-630.

Stanley, R. S. and N. M. Ratcliffe. 1985. Tectonic synthesis of the Taconian orogeny in western New England. Geological Society of America Bulletin **96**(10):1227-1250.

Stein, E. R., K. A. Koltar, and J. W. Kick. 2008. Soil survey of Oneida County, New York. U.S. Department of Agriculture, Soils Conservation Service, Washington, DC. Online. http://soildatamart.nrcs.usda.gov/Manuscripts/NY065/0/oneida.pdf. Accessed October 2009.

Stevens, C., L. White, W. Griswold, and M. C. Brown. 2007. Cultural landscape report and archeological sensitivity assessment for Victory Woods. National Park Service, Boston, MA.

Stürmer, W. and J. Bergström. 1973. New discoveries on trilobites by X-rays. Paläontologische Zeitschrift **47**(1-2):104-141

Thieler, E. R., B. Butman, W. C. Schwab, M. A. Allison, N. W. Driscoll, J. P. Donnelly, and E. Uchupi. 2007. A catastrophic meltwater flood event and the formation of the Hudson Shelf valley. Palaeogeography, Palaeoclimatology, Palaeoecology **246**(1):120-136.

Toots, H. 1976. Structural geology of the Taconic unconformity. Trip B-2 *in* Johnsen, J. H., editor. Guidebook to field excursions at the 48th annual meeting of the New York State Geological Association. New York State Geological Association, Staten Island, NY.

Uutala, A. J. 1990. *Chaoborus* (Diptera: Chaoboridae) mandibles: paleolimnological indicators of the historical status of fish populations in acid-sensitive lakes. Journal of Paleolimnology **4**(2):139-151.

Yuretich, R. F. and P. T. Leclair. 1980. Holocene sediments in Otsego Lake, East-central New York State. Abstracts with Programs - Geological Society of America **12**(2):90.

Zen, E-an. 1964. Taconic stratigraphic names: definitions and synonymies. U.S. Geological Survey, Reston, VA. Bulletin 1174. Online. http://pubs.er.usgs.gov/usgspubs/b/b1174. Accessed October 2009.

Zen, E-an. 1967. Time and space relationships of the Taconic allochthon and autochthon. Geological Society of America, Boulder, CO. Special Paper 97.

Additional References

Baldwin, B. and A. V. Raiford. 1988. Taconic geology near Fair Haven, Vermont. Vermont Geology **5**:G1-G13.

Berry, W. B. N. 1977. Ecology and age of graptolites from graywackes in eastern New York. Journal of Paleontology **51**(6):1102-1107.

Brewer, R. S., G. A. von Metzsch, and T. W. Rayne. 2009. Interaction of ground water and surface water affected by road salting in a peat bog and adjacent sand aquifer, Rome sand plans, Rome, New York. Abstracts with Programs - Geological Society of America **41**(3):21.

Clarke, J. M. 1903. Mastodons of New York. Pages 921-933 *in* Merrill, F. J. H. and J. M. Clarke, editors. Report of the State Paleontologist 1902. New York State Museum and Science Service, Albany, NY. Bulletin 69.

Connally, G. G. and L. A. Sirkin. 1973. Wisconsinan history of the Hudson-Champlain Lobe. Pages 47-69 *in* Black, R. F., R. P. Goldthwait, and H. B. Willman, editors. The Wisconsinan Stage. Geological Society of America, Boulder, CO. Memoir 136.

Dineen, R. J. 1979. Stratigraphy of glacial Lake Albany and its successors in the Albany area, New York. Abstracts with Programs - Geological Society of America **11**(1):10.

Dudley, J. 1814. Letter from Governour Dudley to the Reverend Cotton Mather: Roxbury, 10 July, 1706. Collections of the Massachusetts Historical Society **2**:263-264.

Fisher, D. W. and G. F. Hanson. 1951. Revisions in the geology of Saratoga Springs, New York and vicinity. American Journal of Science **249**(11):795-814.

Guilday, J. E. 1968. Archaeological evidence of caribou from New York and Massachusetts. Journal of Mammalogy **49**(2):344-345.

Heath, R. C. and J. A. Tannenbaum. 1963. Ground-water studies in Saratoga County, New York: Part 3. Ground-water resources of Saratoga National Historical Park and vicinity. Pages 77-128 *in* Heath, R. C., F. K. Mack, and J. A. Tannenbaum. Ground-water studies in Saratoga County, New York. New York State Water Resources Commission, Albany, NY. Bulletin GW-49.

Kidd, W. S. F., L. L. Delano, and D. B. Rowley. 1981. Depositional history of the Taconic continental rise compared with equivalent sequences along the Northern Appalachians. Abstracts with Programs - Geological Society of America **13**(3):141.

Kozlowski, A. L. and D. Pair. 2007. The New York cross-state channels: evidence for complex and large scale late Wisconsin meltwater drainage events. Abstracts with Programs - Geological Society of America **39**(1):88-89.

La Fleur, R. G. 1979. Wisconsinan stratigraphy in east-central New York. Abstracts with Programs - Geological Society of America **11**(1):21.

LaPorta, P. C. Jr. and M. C. Brewer. 2004. A prehistoric quarry landscape in the Taconic Appalachians: conservation and mitigation in the shadows of active mining. Abstracts with Programs - Geological Society of America **36**(5):214.

Mack, F. K., F. H. Pauszek, and J. R. Crippen. 1964. Geology and hydrology of the West Milton area, Saratoga County, New York. U.S. Geological Survey, Reston, VA. Water-Supply Paper 1747. Online. http://pubs.er.usgs.gov/usgspubs/wsp/wsp1747. Accessed October 2009.

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

McGuier, H. 1869. On the antiquity of man as shown by excavations in Saratoga Springs, New York. Proceedings of the Boston Society of Natural History **12**:398-400.

Miller, N. G. and P. L. Nester. 2006. Paleoecology of a late Pleistocene wetland and associated mastodon remains in the Hudson Valley, southeastern New York State. Pages 291-304 *in* Greb, S. F. and W. A. DiMichele. Wetlands through time. Geological Society of America, Boulder, CO. Special Paper 399.

Muller, E. H., D. A. Franzi, and J. C. Ridge. 1986. Pleistocene geology of the western Mohawk Valley, New York. Pages 143-157 *in* Cadwell, D. H., editor. The Wisconsinan Stage of the First Geological District, eastern New York. New York State Museum and Science Service, Albany, NY. Bulletin 455.

Rayburn, J. A., P. L. K. Knuepfer, and D. A. Franzi. 2005. A series of large, late Wisconsinan meltwater floods through the Champlain and Hudson Valleys, New York State, USA. Quaternary Science Reviews **24**(22):2410-2419.

Rayburn, J. A., D. A. Franzi, and P. L. K. Knuepfer. 2007. Evidence from the Lake Champlain Valley for a later onset of the Champlain Sea and implications for late glacial meltwater routing to the North Atlantic. Palaeogeography, Palaeoclimatology, Palaeoecology **246**(1):62-74.

Rodgers, J. 1989. Geology and the Saratoga Campaign of 1777. Pages 38-39 *in* Rodgers, J., T. X. Grasso, W. M. Jordan, C. Hepburn, E. S. Belt, M. E. Johnson, and G. M. Friedman, leaders. Metamorphism and tectonics of eastern and central North America: Volume 1. Boston to Buffalo, in the footsteps of Amos Eaton and Edward Hitchcock. Hanshaw, P. M., editor. Field trips for the 28th international geological congress. American Geophysical Union, Washington, DC.

Theokritoff, G. 1964. Taconic stratigraphy in northern Washington County, New York. Geological Society of America Bulletin **75**(3):171-190.

Thompson, J. B. Jr. 1990. An introduction to the geology and Paleozoic history of the Glens Falls 1 degrees X 2 degrees Quadrangle, New York, Vermont, and New Hampshire. Pages A1-A13 *in* Slack, J. F., editor. Summary results of the Glens Falls CUSMAP project, New York, Vermont, and New Hampshire. U.S. Geological Survey, Reston, VA. Bulletin 1887. Online. http://pubs.er.usgs.gov/usgspubs/b/b1887. Accessed October 2009.

Thompson, L. 1994. Discovery of the American mastodon (*Mammut americanum*) in New York State: 1921-1994. Thesis. University of Rochester, Rochester, NY.

Thomson, K. S. 2008. The legacy of the mastodon: the golden age of fossils in America. Yale University, New Haven, CT.

Data Sets

Saratoga National Historical Park Paleontological Archives
1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Saratoga National Historical Park Collections
1938–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by SARA staff; status: Active.

Fort Stanwix National Historic Site Paleontological Archives
1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

New York Digital Geologic Map
1999-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by New York State Museum staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=NY.

New York State Museum
1938-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by NYSM staff; status: Active.

Saugus Iron Works National Historic Site

Saugus Iron Works National Historic Site (SAIR) is the site of the first integrated ironworks in North America, operated between 1646 and 1668. The site includes a reconstructed blast furnace, forge, and mill, as well as a restored mansion from the 1680s. SAIR was authorized April 5, 1968. It encompasses 3.44 ha (8.51 acres), all of which are under federal administration.

Geological Background

SAIR is located in Saugus, Massachusetts, in southern Essex County, about 14 km (9 miles) north of central Boston. It is on the banks of the Saugus River, about 5 km (3 miles) upstream of the river's confluence with the Atlantic Ocean to the southeast. Just south of the town of Saugus is the Boston Basin, the eroded remains of a Late Proterozoic structural basin (see the appendix for a geological time scale). Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held for SAIR during July 2007, which resulted in a geologic scoping summary (Thornberry-Ehrlich 2008); this is an internal NPS document.

Most of New England is made up of exotic accreted terranes, which are blocks of crust that originated somewhere other than their present location and are demonstrably different from surrounding rocks. The timing of assembly and the origins of the various terranes are heavily debated (Skehan 2001; Wintsch et al. 1993, 2007). SAIR, Boston, and the surrounding area of coastal Massachusetts are part of a terrane known under several names, including the Milford-Dedham Zone (Kaye 1982; Zen et al. 1983; Hatch et al. 1984; Goldsmith and Weed 1991), the Boston-Avalon Terrane (Hepburn et al. 1987, 1993), and the Avalon Terrane (Skehan 2001). To be consistent with the SAIR geologic scoping summary (Thornberry-Ehrlich 2008), Avalon will be used here. The Avalon Terrane is bordered on the west by the Nashoba Terrane. The Bloody Bluff Fault, named for a feature in Minute Man National Historical Park (MIMA; see the MIMA summary in this report for more information), separates the two terranes. This fault zone traces a much older zone of disturbance (the Burlington Mylonite Zone) that developed approximately 610 Ma (million years ago) where the Avalon Terrane was overriding another plate (Skehan 2001).

The Avalon Terrane separated from the landmass to which it was originally attached approximately 550 Ma. One interpretation of the events that followed is that the Avalon Terrane was part of a larger continental fragment that split into multiple slivers. These slivers periodically collided with each other on their way to the proto-North American continent called Laurentia, where they were accreted onto what is now the east coast by approximately 370 Ma (Rast and Skehan 1990; Skehan 2001). Other authors reject this interpretation (Acaster and Bickford 1999). Regardless of how it arrived, by some point in the Late Paleozoic, the Avalon Terrane had collided with Laurentia during the larger collisional events that resulted in the assembly of the supercontinent Pangaea (Levin 1999; Skehan 2001).

The majority of the rocks underlying the Boston area formed during the Avalonian Orogeny, a mountain-building event that occurred during the late Proterozoic (Hepburn et al. 1993; Skehan 2001). Near SAIR, deep-seated intrusive igneous rocks (the Dedham Granite) formed at approximately 610 Ma over a subduction zone, where one plate was overriding another. Following the intrusions, magma worked its way to the surface and erupted at approximately 596 Ma, forming volcanic rocks. To the south, the Boston Basin formed as a rift basin within this volcanic arc as magmatic activity waned (Hepburn et al. 1993; Skehan 2001). At that time, the Boston area was at mid-latitudes (38° at roughly 596 Ma), probably in the Southern Hemisphere, where the Avalon Terrane would have been either attached to, or located near, what is now West Africa (Thompson et al. 2007). Igneous activity slowed as the orogeny waned and the setting shifted from compression and uplift associated with the orogeny to extension with rifting, which eventually formed a marine basin (Goldsmith and Weed 1991; Skehan and Rast 1992).

Some younger (Cambrian-age) sedimentary rocks were deposited in the Boston area, when the depositional environment had changed from a subsiding basin to a stable shelf (Goldsmith and Weed 1991), but these are not present at SAIR. There was probably later Paleozoic deposition, as elsewhere in

the Avalon Terrane, but any trace is now eroded (Masterson et al. 1996). Multiple episodes of deformation, including folding and faulting, occurred during the plate collisions and accompanying orogenies of the Paleozoic (Kaye 1982). Igneous intrusions commonly accompanied these collisional events (Goldsmith and Weed 1991). Some faulting, igneous rocks, and sedimentary rocks were formed during the continental rifting of North America and Africa during the Late Triassic-Early Jurassic as Pangaea broke up (Kaye 1982; Goldsmith and Weed 1991). The geologic history of the Boston area has been relatively quiet since Pangaea broke up, although there have been some large earthquakes, such as those of 1727 and 1755 (Brankman and Braise 2008). As with the late Paleozoic, there was probably deposition of Cretaceous and early Cenozoic coastal plain sedimentary rocks in the Boston area, comparable to those of extreme southeast Massachusetts, but they are now eroded away. In this case, they would have been eroded during a global sea level low at approximately 25 Ma (Masterson et al. 1996).

The Boston area was greatly affected by Pleistocene glaciation (between 2.59 Ma and approximately 12,000 years ago). Although the glacial history of Boston is not completely understood, there are two prominent tills (unsorted glacial deposits), dating to different parts of the last glacial period (Wisconsinan, postdating 125,000 years ago) (Colgan and Rosen 2001). Reconstructing the most recent glacial activity has proven particularly complex because Boston was along a zone where two glacial lobes met (the Narragansett Bay-Buzzards Bay lobe on the west and the Cape Cod Bay lobe on the east; Skehan 2001). This configuration led to weak flow (glaciers flow fastest at their centers) and relatively little till deposition (Kaye 1976). Additionally, Boston was near the marine margin at that time, causing the ice to behave differently depending on whether it flowed atop land or water (Kaye 1976).

The deglaciation of the Boston area began approximately 15,000 radiocarbon years before present (note that radiocarbon dates are not the same as calendar dates, and that radiocarbon years require calibration to yield calendar years. Uncalibrated radiocarbon dates in publications are often denoted with "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. Therefore, dates that are not labeled with "calendar years" or something similar should be assumed to be uncalibrated radiocarbon dates). At this time the area was still depressed from the weight of the ice sheets, and thus the local sea level was higher, at least 22 m (72 ft) above its present elevation. A glaciomarine clay known informally as the Boston Blue Clay was deposited across the Boston area at this time (Colgan and Rosen 2001; Rosen and FitzGerald 2004). Glacial lakes also formed intermittently from temporarily dammed meltwater, such as Glacial Lake Bouvé south of Boston Harbor, lakes in the Nashua Valley, and lakes in the upper basins of the Charles and Neponset rivers, southwest of SAIR (Crosby and Grabou 1896; Skehan 2001). With the retreat of the heavy mass of glacial ice, the crust began to rise within a thousand years (this phenomenon is known as isostatic rebound), and by 12,000 radiocarbon years before present local sea level was 40 m (130 ft) lower than its present elevation. The eventual rise of global sea level, from the return of water from ice, then caused marine waters to encroach upon the area again. For example, Back Bay was inundated approximately 5,600 radiocarbon years before present (Colgan and Rosen 2001; Rosen and FitzGerald 2004), and the present sea level of Boston Harbor was attained about 2,000 years ago (Jones and Fisher 1990). Humans entered the area by the time that sea level was rising, as shown by the presence of Paleoindian sites in and around Boston (Luedtke and Rosen 1993).

From oldest to youngest, the bedrock geology of SAIR consists of the Dedham Granite and Lynn Volcanics (also Volcanic Complex or Mattapan-Lynn Volcanics) (Ediacaran age) (Kaye 1980; Zen et al. 1983). When the Kaye (1980) and Zen et al. (1983) maps were made, the age of the Lynn Volcanics was uncertain, but these rocks are now known to be slightly younger than the Dedham Granite, dating between 597.4 ± 1.5 Ma and 595.7 ± 1.6 Ma (Thompson et al. 2007). The surficial geology of SAIR is mostly composed of Pleistocene-age stratified drift, deposited under marine influence (Kaye 1978). It is not known if fossils are present within SAIR, although there are Pleistocene marine fossils in clay just north of the park (Thornberry-Ehrlich 2008). Fossils are much more likely to be found in the Quaternary sediments at SAIR than the bedrock units, which are primarily igneous rocks formed at a time before the appearance of organisms with hard body parts.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic unit within SAIR. However, it has produced fossils elsewhere, and future investigations within the park may uncover fossils in it.

Quaternary rocks and sediments (Pleistocene-Holocene)

The surficial geology of SAIR is mostly composed of Pleistocene-age stratified drift. These deposits include sand, gravel, clay, and some glacial till. SAIR is part of an area along the Saugus River that was submerged by marine waters during the late Pleistocene and early Holocene, therefore marine clays and sands dominate the drift. Most of the surrounding higher ground is rocky, with bedrock outcrops and thin drift deposits (Kaye 1978). At SAIR, most Quaternary sediment is clay, possibly the Boston Blue Clay (Thornberry-Ehrlich 2008). If the clay is part of the Boston Blue Clay, it would date to the early postglacial interval, beginning approximately 15,000 years before present (Colgan and Rosen 2001). The SAIR area may represent a flat sandy glacial delta (Thornberry-Ehrlich 2008). Clay just north of SAIR has Pleistocene marine fossils, so there is the possibility that such fossils are present in the park (Thornberry-Ehrlich 2008). Quaternary marine fossils have been reported from the Boston area for over two hundred years, when shells were found in glacial deposits at Telegraph Hill, Hull (12 km [19 miles] southeast of SAIR), during the American Revolution (Crosby and Ballard 1894). Other Quaternary deposits in and around Boston are also fossiliferous. Boston Harbor Islands National Recreation Area (BOHA) has numerous Quaternary fossil localities; see the BOHA summary in this report for more information.

The Quaternary stratigraphy of the Boston area is complex (Kaye 1976), involving at least two glacial tills and possibly a third, with multiple glaciomarine clays (Colgan and Rosen 2001) and younger deposits (Masterson et al. 1996). As noted, the clay at SAIR may be part of the glaciomarine Boston Blue Clay (Thornberry-Ehrlich 2008). The Boston Blue Clay has yielded foraminifera (protists that form "shells," usually out of carbonate), diatoms (algae with silica "shells"), pollen (Judson 1949), mollusks, barnacles, and ostracodes (seed shrimp) (Kaye 1976). Similar fossil assemblages are found in the lower of two main glacial till units found in the Boston area, although these date to the last interglacial period (Sangamonian) (Colgan and Newman 1999; Colgan and Rosen 2001), now thought to have spanned the time period between 125,000 and 75,000 years ago, approximately, on the basis of amino acid racemization dates (Belknap 1979; Stea et al. 1992) and correlation to similar analyses on Nantucket Island that are tied to a uranium-series dated coral (Oldale et al. 1982). The marine fossils from the lower till include foraminifera (Colgan and Rosen 2001), sponges, stony corals, bryozoans, bivalves, gastropods, worm tubes, barnacles, crabs (Crosby and Ballard 1894; Shimer 1918), and ostracodes (Colgan and Rosen 2001). The till fossils may be partially replaced by silica (Rosen and FitzGerald 2004), and represent shallow marine and estuarine organisms (Colgan and Rosen 2001). The most detailed discussion of these fossils is in Crosby and Ballard (1894). Fossils are not known to be present in the upper till (Skehan 2001).

Younger, Holocene-age deposits in the Boston area contain both marine and terrestrial fossils, as sea level fell and then rose (Colgan and Rosen 2001; Skehan 2001), which provided a variety of environments for habitation. Holocene-age marine and estuarine deposits include shells and organic deposits (Masterson et al. 1996). Peat deposits of former marshes, from the brief period between glacial rebound and sea level rise, can be richly fossiliferous (Kaye 1982). These deposits are of great interest because their fossils record changes in paleoclimate and other environmental factors over the present postglacial period, spanning approximately the last 15,000 years. Plant remains dating to the time after the last glacial period, including swamp plants, deciduous leaves, and tree stumps, are known from several localities (Shimer 1918). Beetle fragments are known from peat deposits at Cambridge (Argus and Davis 1962). Shell middens left by humans engaged in clamming on the Boston Harbor islands have fossils of hickory nuts, mollusks, fish, reptiles, birds, dogs, deer, and unidentified mammals (Luedtke and Rosen 1993). Ancient human remains may also be found (Humphrey et al. 1993). The best known and most diverse Holocene finds in the Boston area come from the Boylston Street Fishweir, where prehistoric people built a series of fishweirs (fish traps made of stick fences) (Johnson 1949) between 4,700 and 3,700 radiocarbon years before present (Newby and Webb 1994). Post-Boston Blue Clay sediments began to accumulate at this site approximately 5,630 radiocarbon years before present, when marine transgression and submergence

began (Rosen et al. 1993). Sediments examined during the excavations have yielded foraminifera (Stetson and Parker 1942), dinoflagellates (a type of plankton that move using whip-like flagella) (as *Hystrichospera*; Wilson 1949), the euglenid *Trachelomonas* (another type of flagellate plankton) (Wilson 1949), diatoms (Linder 1942), spores, pollen (Knox 1942), seeds, fruits (Barghoorn 1949), grass fragments, sedges, roots, other plant tissues, fungi, sponge spicules, insect chitin (Johnson 1942a), bivalves, gastropods (Clench 1942), marine worms (Wilson 1949), barnacles (Lindquist 1942), cladocerans (water fleas) (Wilson 1949), worm and sponge trace fossils on mollusks (Nelson 1942), mollusk borings on wood (Johnson 1942b), small fish bones (Johnson 1942a), bones of a shorebird (perhaps a Greater Yellowlegs; Johnson 1942b), and organic debris (Johnson 1942a). Most of these fossils are from peat immediately above the Boston Blue Clay (Johnson 1942a; Wilson 1949), and similar fossils could be present at SAIR or its immediate vicinity.

Large mammal fossils are quite rare in Massachusetts, although a horn core and attached skull material from a bison were recovered from Late Pleistocene deposits at Harvard, 48 km (30 miles) west of SAIR (Romer 1951). Mastodon and mammoth teeth are known from the floor of Massachusetts Bay as well, dating to the early portion of the current postglacial interval, when local sea level was relatively low (Oldale et al. 1988).

Park Collections

SAIR has no paleontological material in its collections to date.

Cultural Resource Contexts

Fossils have not yet been reported from cultural resource contexts at SAIR. People were present in the vicinity of SAIR as far back as between 12,000 and 9,000 years ago, when Paleoindian people quarried Saugus "jasper" less than 1 km (0.6 miles) downstream (Thornberry-Ehrlich 2008) (not actually jasper but instead volcanic rock; Hollander and Hermes 1999). The Boylston Street Fishweir and shell middens are the best known examples of fossils in cultural resource contexts in the Boston area, showing the importance of prehistoric marine resources. SAIR is near the outermost extent of late Pleistocene-early Holocene marine inundation (Kaye 1978), so there is some possibility of similar finds. Unlike some other areas, the stones selected by prehistoric people for tools in the Boston area are not potentially fossiliferous, instead being varieties of volcanic rock (Luedtke 1998; Hollander and Hermes 1999; Hermes 2000). 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

- The NPS Geologic Resources Division coordinated a geologic resource inventory scoping session for SAIR during July 2007, which includes a discussion on paleontological resources (Thornberry-Ehrlich 2008). Fossils are not presently known from SAIR. The most likely potential source for fossils at the park is in the Quaternary deposits.
- Park staff should be encouraged to observe sedimentary material for fossil material while conducting their usual duties. Staff should photodocument and potentially 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. 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).
- Future archeological excavations or infrastructure developments should consider scheduling site monitoring by a trained paleontologist in order to document and protect fossil resources.

- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

Literature Cited

Acaster, M. and M. E. Bickford. 1999. Geochronology and geochemistry of Putnam-Nashoba Terrane metavolcanic and plutonic rocks, eastern Massachusetts: constraints on the early Paleozoic evolution of eastern North America. Geological Society of America Bulletin **111**(2):240-253.

Argus, G. W. and M. B. Davis. 1962. Microfossils from a late-glacial deposit at Cambridge, Massachusetts. American Midland Naturalist **67**(1):106-117.

Barghoorn, E. S. Jr. 1949. Paleobotanical studies of the Fishweir and associated deposits. Pages 49-83 *in* Johnson, F., editor. The Boylston Street Fishweir II. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology **4**(1).

Belknap, D. F. 1979. Application of amino acid geochronology to stratigraphy of Late Cenozoic emerged marine units of the Atlantic Coastal Plain. Dissertation. University of Delaware, Newark, DE.

Brankman, C. M., and L. G. Baise. 2008. Liquefaction susceptibility mapping in Boston, Massachusetts. Environmental & Engineering Geoscience **14**(1):1-16.

Clench, W. J. 1942. The mollusks. Pages 45-48 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Colgan, P. M. and W. A. Newman. 1999. Amino acid evidence for the age of the lower till in Boston Harbor, Massachusetts. Abstracts with Programs - Geological Society of America **31**(2):A-10.

Colgan, P. M. and P. S. Rosen. 2001. Quaternary environments and history of Boston Harbor, Massachusetts. Pages I1-I20 *in* West, D. P. Jr. and R. H. Bailey, editors. Guidebook for geological field trips in New England. Geological Society of America, Boulder, CO.

Crosby, W. O. and H. O. Ballard. 1894. Distribution and probable age of the fossil shells in the drumlins of the Boston Basin. American Journal of Science **48**(288):486-496. [full text available on Google Books, but must be searched for using regular Google search]

Crosby, W. O. and A. W. Grabau. 1896. Glacial lakes of the Boston Basin. American Geologist **17**:128-130. [full text available on Google Books]

Goldsmith, R. and E. G. A. Weed. 1991. Stratigraphy of the Milford-Dedham Zone, eastern Massachusetts: an Avalonian terrane. Pages E1-E62 *in* Hatch, N. L. Jr., editor. The bedrock geology of Massachusetts. U.S. Geological Survey, Reston, VA. Professional Paper 1366-E-J. Online. http://pubs.er.usgs.gov/usgspubs/pp/pp1366EJ. Accessed December 2009.

Hatch, N. L. Jr., E-an Zen, R. Goldsmith, N. M. Ratcliffe, P. Robinson, R. S. Stanley, and D. R. Wones. 1984. Lithotectonic assemblages as portrayed on the new bedrock geologic map of Massachusetts. American Journal of Science **284**(9):1026-1034.

Hepburn, J. C., M. Hill, and R. Hon. 1987. The Avalonian and Nashoba terranes, eastern Massachusetts, U.S.A.: an overview. Maritime Sediments and Atlantic Geology **23**(1):1-12.

Hepburn, J. C., R. Hon, G. R. Dunning, R. H. Bailey, and K. Galli. 1993. The Avalon and Nashoba terranes (eastern margin of the Appalachian Orogen in southeastern New England). Pages X.1-X.31 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Hermes, O. D. 2000. What is this stuff anyway? Characterizing lithics in southeastern New England. Abstracts with Programs - Geological Society of America **32**(7):416.

Hollander, S. A. and O. D. Hermes. 1999. Petrological characterization of "Saugus Jasper". Abstracts with Programs - Geological Society of America **31**(2):A-24.

Humphrey, J., J. Hager, and D. Woodhouse. 1993. A geohistorical boat tour of Boston Harbor. Pages W.1-W.16 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Johnson, F. 1942a. The cross section of the building excavation. Pages 13-23 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Johnson, F. 1942b. Miscellaneous identifications and discussion. Pages 130 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Johnson, F. 1949. Introduction. Pages 3-5 *in* Johnson, F., editor. The Boylston Street Fishweir II. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology **4**(1).

Jones, J. R. and J. J. Fisher. 1990. Environmental factors affecting prehistoric shellfish utilization: Grape Island, Boston Harbor, Massachusetts. Pages 137-146 *in* Lasca, N. P. and J. Donahue, editors. Archaeological geology of North America. Geological Society of America, Boulder, CO. Centennial Special Volume 4.

Judson, S. S. Jr. 1949. The Pleistocene stratigraphy of Boston, Massachusetts and its relation to the Boylston Street Fishweir. Pages 7-48 *in* Johnson, F., editor. The Boylston Street Fishweir II. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology **4**(1).

Kaye, C. A. 1976. Outline of the Pleistocene geology of the Boston Basin. Pages 46-63 *in* Cameron, B., editor. Geology of southeastern New England: a guidebook for field trips to the Boston area and vicinity. Science Press, Princeton, NJ. Annual Meeting - New England Intercollegiate Geological Conference 68.

Kaye, C. A. 1978. Surficial geologic map of the Boston area, Massachusetts. U.S. Geological Survey, Reston, VA. Open-File Report 78-111. Online. http://pubs.er.usgs.gov/usgspubs/ofr/ofr78111. Accessed December 2009.

Kaye, C. A. 1980. Bedrock geologic maps of the Boston North, Boston South, and Newton quadrangles, Massachusetts. U.S. Geological Survey, Reston, VA. Miscellaneous Field Studies Map 1241. Scale 1:24,000.

Kaye, C. A. 1982. Bedrock and Quaternary geology of the Boston area, Massachusetts. Reviews in Engineering Geology **5**:25-40.

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* Lucas, S. G., 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, NM. Bulletin 34. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed December 2009.

Knox, A. S. 1942. The pollen analysis of the silt and the tentative dating of the deposits. Pages 105-129 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Levin, H. L. 1999. The Earth through time (6th edition). Saunders College Publishing, Fort Worth, TX.

Linder, D. H. 1942. The diatoms. Pages 67-81 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Lindquist, R. L. 1942. Notes on *Balanus eburneus* Gould. Pages 65-66 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Luedtke, B. E. 1998. Rediscovery of the Wyoming Quarry Site, Melrose, MA. Abstracts with Programs - Geological Society of America **30**(1):58-59.

Luedtke, B. E. and P. S. Rosen. 1993. Archaeological geology on Long Island, Boston Harbor. Pages T.1-T.15 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Masterson, J. P., B. D. Stone, and R. R. Rendigs. 1996. Geohydrology and potential water-supply development on Bumkin, Gallops, Georges, Grape, Lovell, and Peddocks islands, eastern Massachusetts. U.S. Geological Survey, Reston, VA. Open-File Report 96-117. Online. http://pubs.er.usgs.gov/usgspubs/ofr/ofr96117. Accessed December 2009.

Nelson, T. C. 1942. The oysters. Pages 49-64 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Newby, P. E. and T. Webb III. 1994. Radiocarbon-dated pollen and sediment records from near the Boylston Street fishweir site in Boston, Massachusetts. Quaternary Research **41**(2):214-224.

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., J. R. Grimes, and F. C. Whitmore Jr. 1988. Late-Wisconsinan elephant teeth from the western Gulf of Maine. Abstracts with Programs - Geological Society of America **20**(1):59.

Rast, N. and J. W. Skehan. 1990. The late Proterozoic geologic setting of the Boston Basin. Pages 235-247 *in* Socci, A. D., J. W. Skehan, and G. W. Smith, editors. Geology of the composite Avalon Terrane of southern New England. Geological Society of America, Boulder, CO. Special Paper 245.

Romer, A. S. 1951. *Bison crassicornis* in the late Pleistocene of New England. Journal of Mammalogy **32**(2):230-231.

Rosen, P. S. and D. M. FitzGerald. 2004. Processes and evolution of Boston Harbor islands: Peddocks and Lovells Islands. B6-1-B6-18 *in* Hansen, L., editor. Guidebook for field trips in the eastern Massachusetts region. New England Intercollegiate Geologic Conference, Amherst, MA. Annual Meeting - New England Intercollegiate Geological Conference 96.

Rosen, P. S., B. M. Brenninkmeyer, and L. M. Maybury. 1993. Holocene evolution of Boston inner harbor, Massachusetts. Journal of Coastal Research **9**(2):363-377.

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

Shimer, H. W. 1918. Postglacial history of Boston. Proceedings of the American Academy of Arts and Sciences **53**(6):441-463.

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

Skehan, J. W. and N. Rast. 1992. The Avalon Superterrane and the enigma of the Nashoba. Abstracts with Programs - Geological Society of America **24**(7):A289.

Stea, R. R., R. J. Mott, D. F. Belknap, and U. Radtke. 1992. The Pre-Late Wisconsinan chronology of Nova Scotia, Canada. Pages 185-206 *in* Clarke, P. U. and P. D. Lea, editors. The last interglacial transition in North America. Geological Society of America, Boulder, CO. Special Paper 270.

Stetson, H. C. and F. L. Parker. 1942. Mechanical analysis of the sediments and the identification of the Foraminifera from the building excavation. Pages 41-44 *in* Johnson, F., editor. The Boylston Street Fishweir: a study of the archaeology, biology, and geology of a site on Boylston Street in the Back Bay District of Boston, Massachusetts. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology 2.

Thompson, M. D., A. M. Grunow, and J. Ramezani. 2007. Late Neoproterozoic paleogeography of the southeastern New England Avalon Zone: insights from U-Pb geochronology and paleomagnetism. Geological Society of America Bulletin **119**(5-6):681-696.

Thornberry-Ehrlich, T. 2008. Geologic resource evaluation scoping summary: Minute Man NP & Saugus Iron Works NHS. National Park Service, Geologic Resources Division, Denver, CO. Online. http://www.nature.nps.gov/geology/inventory/publications/s_summaries/MIMA-SAIR_gre_scoping_summary_2008-0930.pdf. Accessed December 2009.

Wilson, L. R. 1949. A microfossil analysis of the Lower Peat and associated sediments at the John Hancock Fishweir site. Pages 84-98 *in* Johnson, F., editor. The Boylston Street Fishweir II. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology **4**(1).

Wintsch, R. P., J. F. Sutter, M. J. Kunk, J. N. Aleinikoff, and J. L. Boyd. 1993. Alleghanian assembly of Proterozoic and Paleozoic lithotectonic terranes in south central New England: new constraints from geochronology and petrology. Pages H.1-H.30 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip

guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Wintsch, R. P., J. N. Aleinikoff, G. J. Walsh, W. A. Bothner, A. M. Hussey II, and C. M. Fanning. 2007. SHRIMP U-Pb evidence for a Late Silurian age of metasedimentary rocks in the Merrimack and Putnam-Nashoba Terranes, eastern New England. American Journal of Science **307**(1):119-167.

Zen, E-an, R. Goldsmith, N. M. Ratcliffe, P. Robinson, R. S. Stanley, N. L. Hatch, A. F. Shride, E. G. A. Weed, and D. R. Wones. 1983. Bedrock geologic map of Massachusetts. U.S. Geological Survey, Reston, VA. Scale 1:250,000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_16357.htm. Accessed December 2009. Accessed December 2009.

Additional References

Allen, G. M. 1920. Bison remains from New England. Journal of Mammalogy **1**(4):161-164.

Belknap, D. F. 1980. Amino acid geochronology and the Quaternary of New England and Long Island. Program and Abstracts - American Quaternary Association **6**:16-17.

Cardoza, K. D., J. C. Hepburn, and R. Hon. 1990. Geochemical constraints on the paleotectonic settings of two late Proterozoic mafic volcanic suites, Boston-Avalon Zone, eastern Massachusetts. Pages 113-131 *in* Socci, A. D., J. W. Skehan, and G. W. Smith, editors. Geology of the composite Avalon Terrane of southern New England. Geological Society of America, Boulder, CO. Special Paper 245.

Conger, P. S. 1949. The diatoms. Pages 109-123 *in* Johnson, F., editor. The Boylston Street Fishweir II. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology **4**(1).

Hepburn, J. C. 2008. Mid-Paleozoic arc accretion on the eastern side of the Appalachian Orogen, eastern Massachusetts and adjacent areas. Abstracts with Programs - Geological Society of America **40**(2):75.

Kaye, C. A. 1961. Pleistocene stratigraphy of Boston, Massachusetts. Pages B73-B76 *in* Geological Survey research 1961: short papers in the geologic and hydrologic sciences. U.S. Geological Survey, Reston, VA. Professional Paper 424-B.

Koteff, C., G. R. Robinson, R. Goldsmith, R. and W. B. Thompson. 1993. Delayed postglacial uplift and synglacial sea levels in coastal central New England. Quaternary Research **40**(1):46-54.

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

Morse, E. S. 1920. On certain fossil shells in the boulder clay of Boston Basin. American Journal of Science **49**(291):157-165.

Murphy, J. B., J. D. Keppie, and R. D. Nance. 2007. What is the Acadian Orogeny? Abstracts with Programs - Geological Society of America **39**(1):69.

Newman, W. A., D. M. Mickelson, R. C. Berg, R. R. Rendigs, R. N. Oldale, and R. H. Bailey. 1993. Pleistocene geology of the Boston Basin and its adjacent surroundings. Pages U.1-U.24 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

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

Patterson, W. A., J. A. Richburg, K. H. Clark, and S. Shaw. 2005. Paleoecology of Calf Island in Boston's Outer Harbor. Northeastern Naturalist **12**(special issue 3):31-48.

Phleger, F. B. Jr. 1949. The Foraminifera. Pages 99-108 *in* Johnson, F., editor. The Boylston Street Fishweir II. Phillips Academy, Andover, MA. Papers of the Robert S. Peabody Foundation for Archaeology **4**(1).

Rhodin, A. G. J. 1992. Chelonian zooarchaeology of eastern New England: turtle bone remains from Cedar Swamp and other prehistoric sites. Bulletin of the Massachusetts Archaeological Society **53**(1):21-30. Online. http://www.chelonian.org/wp-content/uploads/file/Rhodin_1992_CedarSwamp.pdf. Accessed January 2010.

Richardson, J. B. III. 1985. Prehistoric man on Martha's Vineyard. Oceanus **28**(1):35-42. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/oceanusv2801wood]

Rosen, P. S., L. Maybury, B. Brenninkmeyer, and P. Newby. 1989. Estuarine stratigraphy of Boston inner harbor: Boylston Street Fishweir site. Abstracts with Programs - Geological Society of America **21**(2):63.

Sears, J. H. 1905. The physical geography, geology, mineralogy, and paleontology of Essex County. The Essex Institute, Salem, MA. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/physicalgeograph00searuoft]

Thompson, M. D., O. D. Hermes, S. A. Bowring, C. E. Isachsen, J. R. Besancon, and K. L. Kelly. 1996. Tectonostratigraphic implications of late Proterozoic U-Pb zircon ages in the Avalon Zone of southeastern New England. Pages 179-191 *in* Nance, R. D. and M. D. Thompson, editors. Avalonian and related peri-Gondwanan terranes of the Circum-North Atlantic. Geological Society of America, Boulder, CO. Special Paper 304.

Thomson, K. S. 2008. The legacy of the mastodon: the golden age of fossils in America. Yale University, New Haven, CT.

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

Data Sets

Saugus Iron Works National Historic Site Paleontological Archives
1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Massachusetts Digital Geologic Map
1998-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by Boston College staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=MA.

Springfield Armory National Historic Site

Springfield Armory National Historic Site (SPAR) is the site of Springfield Armory, which is the first federal armory, a manufacturing site for U.S. military small arms between 1794 and 1968, and a place of technological innovation. SPAR also includes the Armory Museum, one of the world's most extensive collections of firearms. SPAR was authorized October 26, 1974, and established March 21, 1978. It encompasses 22.23 ha (54.93 acres), 8.34 ha (20.60 acres) of which are under federal administration. SPAR is not officially included in the Northeast Temperate Network. However, it is geographically within the network, and is associated with the location of a historically important fossil discovery, discovered in a rock unit that is also historically important in paleontology.

It is important to differentiate the historical Springfield Armory and SPAR, as SPAR does not include all of Springfield Armory, including the fossil locality discussed here. Springfield Armory included two main sites, the Hillshops (or Hill Shops) and the Watershops (or Water Shops) sites. The Hillshops was a storage depot that dated to the American Revolution era. Approximately 22 ha (55 acres) of this site was declared a National Historic Landmark in 1960, and 8 ha (20 acres) within the National Historic Landmark was declared a National Historic Site in 1974. It was the Hillshops site that became SPAR, and the smaller National Historic Site became the federally-administered section; the rest of it is owned by the Commonwealth of Massachusetts. The other site, the Watershops, began as three locations on the Mill River approximately 1.6 km (1 mile) south of the Hillshops, constructed as heavy manufacturing sites for the Hillshops around the turn of the 19th century. It was during the 1855 consolidation of the three locations into one that a partial skeleton of the early dinosaur *Anchisaurus* was discovered. The Watershops are not part of SPAR at the time and are presently under private ownership, but the park interprets the site and maintains a relationship with the owners (A. MacKenzie, SPAR archivist, pers. comm., March 2010). In this document, SPAR will be used to refer to the modern NPS unit, and Springfield Armory to the original complex, including the Watershops.

Geological Background

SPAR is located in central Hampden County, south-central Massachusetts, within the city of Springfield in the Connecticut River Valley. The site is just east of the Connecticut River and is in the central part of the Hartford Basin, an early Mesozoic-age structural feature (see the appendix for a geological time scale). SPAR is unusual among New England NPS units because it is associated with a historically important vertebrate fossil: the holotype or name-bearing specimen of the early dinosaur *Anchisaurus polyzelus*. The paleontology of Springfield Armory has been discussed in a number of publications. Every publication that mentions *Anchisaurus* could potentially be listed, but in the interest of space and relevance only English-language publications that specifically discuss the Watershops specimen are included here: Hitchcock (1858, 1865), Cope (1870), Ostrom (1971), Galton (1976), Galton and Cluver (1976), Weishampel and Young (1996), Santucci (1998), Yates (2004), Fedak and Galton (2007), and Sereno (2007).

New England has a complicated geological history, dominated by series of tectonic events during the Paleozoic, with each event overprinting the previous event, over a backdrop of the formation of the supercontinent Pangaea (Levin 1999). The deep basement rock of Springfield is hidden by the Hartford Basin's sedimentary rocks, but based on geography may be part of the Ordovician-age Bronson Hill or Ganderia terranes, examples of the volcanic arcs and continental slivers that were displaced from elsewhere on the North American continent or were brought to North America through plate tectonics (Aleinikoff et al. 2007).

Three major tectonic events trace the formation of the supercontinent Pangaea in northeastern North America (Levin 1999), and their effects are visible at several NETN parks. SPAR and its surroundings provide a glimpse of what happened as Pangaea broke apart. The breakup of Pangaea began during the Triassic, creating a system of rift basins paralleling the Appalachian Mountains. The sediments deposited

in these basins are grouped together as the Newark Supergroup. They are found from northern South Carolina to Nova Scotia and record 35 million years of continental rifting (pulling apart). The Hartford Basin and Deerfield Basin to the north are among the rift basins now filled with Newark Supergroup rocks (Olsen 1980a). The Hartford Basin is a half-graben, meaning it is bounded on one side by a major fault (Hubert et al. 1978). This fault is on the east side of the Hartford Basin, so the formations thicken to the east as they approach the source of movement. This configuration also means that the youngest formations, including the Portland Formation (the bedrock of SPAR), are found in the eastern part of the basin (Horne et al. 1993). Springfield is near the heart of the basin, with the thickness of rift basin rocks just to the south as roughly 5 km (3 miles) (Hubert et al. 1992). The basin is approximately 140 km (85 miles) long, tilted to the east, and has a basement of heavily metamorphosed Paleozoic rocks (Hubert et al. 1978). Rocks from the mountain ranges that formed during the late Paleozoic upheavals eroded into the basin, particularly from the east (Wintsch et al. 1997). While it was once proposed that the Hartford Basin is actually part of a much larger basin that includes the Newark Basin to the south as well as a hidden western fault to complete the graben (the "Broad Terrane" hypothesis; see Hubert et al. 1978 for a description), this has been rejected (Schlische and Olsen 1989; Horne et al. 1993). The Hartford and Newark basins were influenced by the same tectonic and climatic events, though (Schlische and Olsen 1989), and the various rift basins were neither completely isolated nor fully connected (Olsen 1997).

Flood basalts, faulting, and folding accompanied the rifting (Olsen 1980b). The eruption of the Newark Supergroup's flood basalts probably occurred over a time span of less than 600,000 years at approximately 201 Ma (million years ago) (Olsen et al. 1996, 2003a), which is approximately the Triassic-Jurassic boundary. Note that recent dates for the Triassic-Jurassic boundary vary from 199.6 Ma to 201.6 Ma depending on the source, with the most recent work indicating an age of 201.4 Ma for the oldest basalts of the Newark Supergroup, including the Hartford Basin, and 201.3 Ma for the Triassic-Jurassic boundary (Schoene et al. 2010). This igneous event was part of the largest known eruptions on Earth, extending over much of central Pangaea from present-day France to eastern North America, West Africa, and southwestern Brazil, and eventually covering about 11,000,000 km^2 (4,200,000 $miles^2$). The volcanic rocks are now recognized as the Central Atlantic Magmatic Province (CAMP) (Marzoli et al. 1999). In the neighborhood of SPAR, the Mount Tom vent, 16 km (10 miles) to the north, had at least five volcanic events (Foose et al. 1968).

The rocks of the Newark Supergroup are known for their cyclic deposits, shifting from rivers and floodplains to great rift lakes and back to terrestrial deposition (Olsen 1980c). Such cycles are present in the Hartford Basin, and are evidence of ancient Milankovitch cycles in the Newark Supergroup (Olsen 1997). Milankovitch cycles are climate cycles that are keyed to various features of Earth's movement in space (Olsen and Whiteside 2008). Their modern durations can be used to establish internal chronologies in the rocks. Particularly notable among the rock cycles are Van Houten cycles, interpreted as representing the approximately 20,000-year cycle of the precession of the equinoxes (Olsen 1997); thus, dry-wet-dry cycles have a periodicity of about 20,000 years (Malinconico 2000). Several other cycles are evident in the Hartford Basin rocks, including cycles with durations of approximately 100,000 years, 405,000 years, and 1.75 million years (Olsen 1997; Olsen and Kent 1999; Olsen et al. 2002). These three cycles are derived from orbital eccentricity (Olsen 1997), with each longer cycle built on the variations in the smaller cycles within them (Olsen 1997; Olsen et al. 1998). Climate cycles interacted with the tectonics of the basin to control the basin's depositional processes (Olsen 1997).

As Pangaea moved north, the Hartford Basin moved with it, from 11° N to 23° N latitude during its depositional history. The Portland Formation, present at the top of the Hartford Basin rocks, was deposited at paleolatitudes of approximately 21° N to 23° N, based on data from the Newark Basin (Kent and Tauxe 2005). Interestingly, humidity increased at the Triassic-Jurassic boundary, when the basin was deep within arid latitudes (Olsen 1997), possibly because of the climatic effects of CO_2 from the eruption of the CAMP (Bonis et al. 2010).

After deposition ceased, the Hartford Basin sediments were modified by additional structural changes and other events. A hydrothermal event occurred in the basin approximately 180 Ma (Hubert and

Dutcher 1999). Post-deposition tilting brought the rocks to their present southeastern dip (Hubert et al. 1978). The rifting stresses shifted direction during the Middle Jurassic, from northwest-southeast extension to east-west extension, with associated tilting and uplift. As time passed and the young Atlantic Ocean widened, stress shifted from extension to compression, first to northeast-southwest and then north-south compression during the Late Jurassic, and then to east-west compression during the Early Cretaceous, which has continued to the present (Hubert et al. 1992). Some tilting and normal faulting occurred after 135 Ma (Wintsch et al. 1997). There are few traces of geological activity in Springfield between this time and the Pleistocene glaciations to come.

Glacial activity during the Pleistocene (between 2.59 Ma and approximately 12,000 years ago) scoured and reworked the preexisting topography of New England. The glacial lobe that most recently affected the Springfield area was the Connecticut Valley Lobe (Larsen 1988). Springfield was covered by ice as recently as just over 17,000 years ago (Benner et al. 2009), and the Chicopee River just north of SPAR was a site where the retreating glacial front experienced a brief readvance (Larsen 1988; Benner et al. 2009). The last glacial period overprinted previous glacial activity and left a great quantity of loose sediments. As the ice sheet retreated, vast lakes of glacial meltwater formed in valleys that were blocked by ice and sediment dams. The largest of these in New England was Glacial Lake Hitchcock, which was present in what is now the Connecticut River Valley and adjoining tributary valleys. First appearing about 17,900 years ago in the lower valley, it extended north as the ice sheets continued retreating and persisted after the ice was gone, lasting until about 12,600 years ago. Following the deglaciation of Springfield approximately 17,000 years ago, the area was inundated by Glacial Lake Hitchcock (Benner et al. 2009). The history of Glacial Lake Hitchcock has been studied through the use of varves (annual sediment layers) that allow for a very detailed chronology of events (Ridge and Larsen 1990; Ridge et al. 1999). The lake drained from the part of the valley south of the Holyoke Range (including SPAR) approximately 16,100 years ago (Stone and Ridge 2009), and the remaining drainage system began to take on its present form (Wise et al. 1992; K. Curran and Dincauze 1999). After the ice sheets and glacial lakes had disappeared, the climate was still harsh (Thorson and McBride 1988; Ashley and Stone 1995; Ashley et al. 1999). A brief period of climatic recovery was interrupted by the cold dry Younger Dryas period between 13,000 and 11,600 years ago (Truebe et al. 2007). Humans first appeared in the area at about this time. They were present in southern New York over 12,500 years ago, and had reached the Connecticut River Valley by at least 10,000 years ago (M. Curran and Dincauze 1977).

The bedrock geology of SPAR consists of dominantly red sandstone and siltstone of the Portland Formation (Early Jurassic) (Zen et al. 1983), and the surficial geology includes glacial till and glacial lake delta outwash deposits (Quaternary) (Hartshorn and Koteff 1967). Fossils have been found in the Portland Formation at Springfield Armory's Watershops site, and the Quaternary deposits are potential fossil sources.

Sources of Paleontological Resources

The fossils of the armory present opportunities for education, interpretation, and continued or future scientific research.

Hartford Group: Portland Formation (Lower Jurassic)

The Portland Formation is a thick sedimentary unit (over 3,500 m [11,500 ft] per Olsen et al. 2005; note that thickness figures vary for this unit) composed of sandstone, siltstone, conglomerate, and shale. Much of the sandstone is a variety known as arkose, which is rich in feldspar, and usually reddish and fairly coarse (Krynine 1950). The formation varies widely in composition vertically and horizontally (LeTourneau and McDonald 1985), and its rocks are usually coarser in the east than the west (Krynine 1950). It is the uppermost of the formations that make up the Hartford Group, composed of rocks deposited in the Hartford Basin during the Mesozoic rifting (Hubert et al. 1992; more recent references may drop the Hartford Group for the Agawam Group, which includes all Newark Supergroup rift rocks deposited above the volcanics [Weems and Olsen 1997]). The Portland Formation was deposited on top of the uppermost volcanic units of the rift. In most areas, the youngest volcanics are part of the Hampden

Basalt (Hubert et al. 1978), which is locally replaced in the north part of the basin by the Granby Tuff (also Granby Basaltic Tuff), an equivalent unit that formed from welded volcanic ash (Olsen 1997). The name "Portland Formation" was first used for rocks in Connecticut (Krynine 1950, as Portland Arkose) and was extended into Massachusetts during the 1960s. Massachusetts references predating this typically use the Longmeadow Sandstone for these rocks and some of the underlying section (Emerson 1898a, 1898b; Balk 1957), and some authors have since used the Longmeadow Sandstone as a local member of the Portland Formation (Cornet and Traverse 1975). The lower Portland Formation can be divided into several members based on the ~400,000-year cycles mentioned above (Olsen et al. 2002; Kent and Olsen 2008), although they have not yet achieved wide use. The formation is now thought to have been deposited during the first half of the Early Jurassic (between 201.3 and approximately 195 Ma) (Weems and Olsen 1997; Olsen et al. 2002; Kent and Olsen 2008), although references from before the late 1970s describe it as Late Triassic (for example Lull 1915 and Krynine 1950), and some references from the late 1970s to the 1990s extend it to at least the late Early Jurassic (Olsen 1980d; Olsen 1988).

The Portland Formation has distinct lower and upper portions. The lower half is mostly composed of fine- to medium-grained red arkose and siltstone, with some dark shale, while the upper half is mostly medium- to coarse-grained red arkose with conglomerate and dark shale (Krynine 1950). These differences stem from changes in the basin that led to different depositional environments. The lower Portland Formation was a closed basin where subsidence (sinking of the rocks) exceeded deposition, allowing for the formation of large lakes. The opposite was true of the upper Portland Formation (Olsen 1997). Deposition in the lower half is dominated by cyclical shallow water red rocks, with some darker rocks that were deposited in deep lakes, and some red fluvial and alluvial fan rocks. The upper half is primarily made up of coarse red rocks from fluvial and alluvial fan settings (McDonald 1992). Tectonics and climate controlled the depositional environments and thus the type of rock deposited. Tectonics controlled the depth of the basin and rate of subsidence, and climate controlled the amount of water in the system (LeTourneau 1985a; LeTourneau and McDonald 1985). As subsidence decreased, fluvial processes came to dominate over lake processes (Hubert et al. 1992); lakes are limited to the lower half of the formation (Hubert et al. 1978; Olsen et al. 2002).

Rocks of the Portland Formation can be divided into groups based on rock type and bedding features. While there are different schools of thought on the exact divisions (compare LeTourneau and McDonald 1985 or LeTourneau 1985a to Wizevich and Drzewiecki 2004 and Drzewiecki et al. 2006), the overall concepts are similar. Conglomerates represent various parts of alluvial fans; sandstones typically represent braided river systems or the far ends of alluvial fans; siltstones were deposited in floodplains; gray sandstones and siltstones represent lake margins; and dark gray to black siltstones and shales are deposits of the rift lakes (LeTourneau 1985a). Some minor eolian (wind-blown) sandstones may also be present (Smoot 1991). Fossils are often restricted to subsets of these environments. For example, bivalves are typically found in shoreline settings (Olsen 1988), reptile skeletons are found in the coarse red beds of the formation in floodplain or alluvial plain settings (McDonald 1992), and most footprints are found in shoreline or mudflat rocks above or below lake sequences, with a few associated with rivers (Olsen and Rainforth 2003). SPAR's bedrock is of the part of the formation dominated by sandstone (LeTourneau and McDonald 1985), from fluvial deposits (Olsen et al. 1998).

The paleogeography of the Portland Formation has been described in some detail (see for example LeTourneau and McDonald 1985). Large alluvial fan conglomerates accumulated in the eastern part of the Portland Formation's basin, shed off of the fault that forms its eastern border. Most of the rock debris that makes up the Portland Formation came from a narrow band of rocks to the east, immediately adjacent to the fault (Krynine 1950). The alluvial fans on the east extended to the shoreline when lakes were active, leading to interbedding of the two types of deposits. During wet periods, the rift lake would grow over the edges of the fans, whereas during dry periods alluvial fan and ephemeral braided streams would be the major depositional environments (LeTourneau 1985b; Horne et al. 1993). Lakes were deepest and longest-lived in the deeper eastern part of the basin, whereas much of the western and central parts of the basin were occupied by broad, low-gradient plains with shallow alkaline lakes (McDonald and LeTourneau 1988). Deltas spread from the west into the basin (Hubert et al. 1992).

Paleoclimatological interpretations of the formation typically emphasize seasonality and semi-aridity (Lull 1912; LeTourneau and McDonald 1985). Krynine (1950) provided a very detailed interpretation, describing the climate as savanna-like and tropical, with a high constant temperature (possibly 27 °C [80 °F]), heavy seasonal precipitation (more than 127 cm [50 in]), and a dry season lasting three months or more. The lower Portland Formation was relatively arid, but the upper part of the formation was more humid (Drzewiecki and Gierlowski-Kordesch 2008) and possibly cooler, perhaps due to regional uplift (Cornet 1989; Cornet and Olsen 1989). The perennial lakes are thought to have been slightly saline, and the ephemeral lakes were more saline (Drzewiecki 2009). As noted, over long periods of time the climate oscillated between humid and semi-arid (McDonald and LeTourneau 1988). SPAR's bedrock is from the upper, entirely fluvial part of the formation, above the transition from the largely lacustrine strata of the lower Portland Formation (P. Olsen, Lamont-Doherty Earth Observatory, Columbia University, pers. comm., February 2010).

The Portland Formation can boast both the earliest report of what would come to be known as dinosaur tracks from North America (the 1802 discovery by Pliny Moody of the tracks of "Noah's Raven"; Olsen et al. 1992) and the first collection (1818) and publication (1820) of dinosaur bones from North America (the East Windsor well specimen; Santucci 1998); see below for more information on both finds. Currently, a diverse fossil assemblage is known from the formation. The four citations at the end of the following list provide overlapping information; in those cases where a fossil organism was not included in one of them, a separate citation is provided. Fossils known from the formation include algal structures (including oncolites [spherical] and stromatolites [columnar and mat structures]), palynomorphs (organic microfossils such as pollen and spores), plant debris (some coalified), ferns (as spores; Cornet and Olsen 1989), the horsetail *Equisetites*, cycads (as pollen; Cornet and Olsen 1989), bennettitales (cycad-like plants) (McMenamin and Ulm 2004), conifers (particularly *Brachyphyllum*, *Hirmeriella*, and *Pagiophyllum*), bivalves, conchostracans (clam shrimp), ostracodes (seed shrimp), beetles, cockroaches (Huber et al. 2003), possible orthopterans (insects such as grasshoppers, crickets, locusts) (Huber et al. 2003), insect fragments and larvae (Huber et al. 2003), arthropod burrows and trails (including those of possible crayfish and insects), the fish "*Acentrophorus*", *Diplurus*, *Redfieldius*, and *Semionotus*, the early crocodile relative *Stegomosuchus*, the theropod dinosaur (bipedal carnivore) *Podokesaurus*, the prosauropod dinosaurs (general term for early bipedal and quadrupedal herbivorous dinosaurs lacking beaks) *Ammosaurus* and *Anchisaurus* (possibly the same animal), footprints of the reptile trace genera *Anomoepus* (from ornithischian dinosaurs, the group of beaked herbivores), *Batrachopus* (from crocodile-like animals), *Anchisauripus*, *Eubrontes*, *Grallator* (from theropod dinosaurs), and *Otozoum* (from prosauropods; see below), and coprolites (fossil feces) (Olsen 1980d, 1988; LeTourneau and McDonald 1985; McDonald 1992). While the tracks and tetrapod body fossils have attracted the most attention, several of the other segments of the Portland Formation assemblage have been described in detail, including palynomorphs (Cornet and Traverse 1975; Cornet and Olsen 1989), insects (Huber et al. 2003), and plants (Cornet 1989; Cornet and Olsen 1989; Olsen 1989; Cornet and McDonald 1995; McMenamin and Ulm 2004; Axsmith et al. 2008). One published palynomorph locality is approximately 3 km (2 miles) southwest of SPAR, in Agawam (Cornet and Traverse 1975). Plant fragments (LeTourneau and Smoot 1985) and fish body fossils (Olsen et al. 1989) are locally abundant.

Some of the fossil plants were substantial. Casts of large tree trunks have been known for years (Lull 1912), and among the floral assemblage are log casts up to 30 cm (12 in) in diameter, and horsetail stem pieces 45 cm (18 in) long (Hubert et al. 1982). Significant turnover in the floral assemblage occurred midway through deposition, when plants from the Deerfield Basin to the north spread south. This change is signified by different plant taxa and notably larger plants. The size increase suggests a more humid and possibly cooler climate than before (Cornet 1989; Cornet and Olsen 1989).

The history of fossil finds in the Portland Formation goes back to 1802, when Pliny Moody found tracks at his family's farm in South Hadley, Massachusetts, about 16 km (10 miles) north of SPAR. At the time, the tracks were called those of "Noah's Raven," of Biblical fame; these tracks are now known to be examples of *Anomoepus*, tracks thought to have been made by early ornithischians. As mentioned, these tracks represent the earliest report of what are now known to be dinosaur tracks in North America (Olsen

et al. 1992). However, scientific study of footprints in the Connecticut River Valley did not take off until the middle 1830s. In 1835, tracks were reported in what is now known to be the Turners Falls Formation at Greenfield, Massachusetts, 53 km (33 miles) north of SPAR. The finds attracted Edward B. Hitchcock of Amherst College, who soon made the study of the valley's tracks his life's work (Weishampel and Young 1996), producing his first publication in 1836 (Hitchcock 1836). Most of Hitchcock's work was done in the Turners Falls Formation, the equivalent rock unit to the Portland Formation in the Deerfield Basin (Olsen et al. 1992). As the title of one of his early works made clear (Hitchcock 1836), he at first conceived of the trackmakers as birds, which in hindsight is not a poor interpretation as he was dealing with the tracks of bipedal and bird-like three-toed dinosaurs. By the end of his life he had acquired enough tracks and traces to envision a diverse bestiary of invertebrates and bipedal and quadrupedal vertebrates (Hitchcock 1858, 1865). Edward Drinker Cope in 1867 regarded the birdlike tracks as having been made by *Bathygnathus* (then usually thought to be a dinosaur but now known to be a pelycosaur ["mammal-like reptile"] similar to *Dimetrodon*) (Cope 1867), but as late as 1896, Cope's great rival Othniel Charles Marsh was still holding out the possibility that some of the tracks were made by birds (Marsh 1896). The birdlike tracks were firmly ascribed to dinosaurs a few years later (Lull 1904a).

The taxonomy of the Portland Formation tracks is extremely convoluted (Olsen et al. 1998; Rainforth 2002a; Olsen and Rainforth 2003). By 1912, there were 98 ichnospecies in 43 ichnogenera (Lull 1912), for what are now recognized to be about a half-dozen common ichnogenera. One trackmaker-body fossil connection seems well-supported: the small crocodile relative *Stegomosuchus* and the tracks named *Batrachopus* (Lull 1904b; Olsen and Padian 1986). In some older references, *Otozoum* is listed as a nondinosaurian track genus (Hubert et al. 1982), but this is no longer considered the case (Olsen et al. 1998; Rainforth 2002b). Of the three well-known theropod track genera (*Anchisauripus*, *Eubrontes*, and *Grallator*), *Eubrontes* is the oldest (Olsen et al. 1998), although further research indicates that the long-forgotten name *Ornithichnites* is based upon the same material as *Eubrontes* (Rainforth 2002a). *Anchisauripus*, *Eubrontes*, and *Grallator* are proportionally distinct but could be footprints of the same animals, only at different stages of growth (Olsen et al. 1998). Thus, one solution to the taxonomic problems of the Connecticut River Valley theropod tracks is to include *Anchisauripus*, *Eubrontes*, and *Grallator* in *Ornithichnites* (Rainforth 2002a). *Grallator* and *Anomoepus* are usually distinguished in the field by the spread of the toes; a narrower toe spread is thought to be representative of *Grallator*, while prints with toes spread wider are assigned to *Anomoepus*. This characteristic is actually not as diagnostic as believed (Olsen and Rainforth 2003; Rainforth 2006).

Tetrapod body fossils are very rare in the Portland Formation, being limited to eight specimens of more than one bone, and a few isolated bones (Galton 1976). These specimens are important because they come from a time when tetrapods were undergoing diversification after an extinction event, and they come from an area with comparatively few tetrapod body fossils. However, studying these specimens has been frustrating, because of the small sample size and some unfortunate circumstances: one of the specimens was lost in a fire, two consist of nothing but natural casts and molds, two were damaged by blasting, and one was partially built into a bridge, with most of what was thought to have been present still missing.

The first collection of dinosaur bones from North America was made from the Portland Formation in 1818, from rocks at Ketch's Mills, East Windsor, Connecticut, 24 km (15 miles) south of SPAR (Santucci 1998). The specimen was discovered during blasting for a well, in red sandstone some 7 m (23 ft) below the surface and 5.5 m (18 ft) below the top of the rock. Because its value was not immediately comprehended, it was accidentally partially blown up before recovery; some bones were also taken by workmen. Solomon Ellsworth was responsible for retaining most of what was left and bringing it to the attention of Nathan Smith, who published the first description. What was left was initially described as possibly human bones (Smith 1820). This was rejected by 1855, when Wyman (1855) regarded them as reptilian, and crocodile-like, but notably hollow. Marsh reported them as dinosaurian in 1896 (Marsh 1896). A more modern assessment reports that the specimen, now YPM 2125 (Peabody Museum of Natural History, Yale University, New Haven, Connecticut), consists of at least three partial tail vertebrae, part of the left femur, traces of the lower leg bones, and an articulated partial arm of a sauropodomorph

dinosaur (the group including prosauropods and their larger, fully quadrupedal relatives the sauropods, such as *Diplodocus* and *Brachiosaurus*) (Galton 1976). While at one time assigned to *Anchisaurus colurus* (see below), it is now regarded as an indeterminate sauropodomorph (Galton 1976), although it may represent a distinct taxon from *Anchisaurus*, perhaps a true prosauropod (Yates 2004).

Anchisaurus *from Springfield Armory*

The second tetrapod body fossil from the formation is the most important in regards to SPAR, as it was recovered from the grounds of the Armory. This specimen is currently reposited at Amherst College's Pratt Museum of Natural History, catalogued as ACM 41109 (K. Wellspring, Pratt Museum of Natural History collections manager, pers. comm., December 2009); the designation has also been given as AM 41/109. It was found by William Smith during blasting operations for improvements to the Watershops site of Springfield Armory at Mill Pond (Santucci 1998) in 1855 (A. MacKenzie, pers. comm., March 2010). Most of the remains were taken by workmen before Smith intervened. Smith gathered as much as he could and turned over the remains to Hitchcock (Santucci 1998). The fossils were described by Wyman for Edward Hitchcock's seminal 1858 work (Hitchcock 1858), but were not named until 1865, when Hitchcock's son Edward Jr. coined *Megadactylus polyzelus* in an appendix to the supplement to Hitchcock's 1858 work, after consulting the famous British anatomist Sir Richard Owen (who coined the term "dinosaur" in 1842) (Hitchcock 1865). While the skeleton was later briefly described by Edward Drinker Cope (Cope 1870), it was O. C. Marsh who is responsible for its current name, and who also described additional similar skeletons found in Connecticut during the 1880s. When *Megadactylus* proved to have already been in use for another animal, Marsh renamed the genus *Amphisaurus* and created the family Amphisauridae (Marsh 1882). *Amphisaurus* was also already in use, so Marsh substituted *Anchisaurus* and Anchisauridae (Marsh 1885). Being the specimen upon which the name was based, ACM 41109 is the holotype specimen for the genus and species *Anchisaurus polyzelus*.

ACM 41109 consists of eleven vertebrae from the back and tail, a partial scapula (shoulder blade), an almost complete right hand, portions of the right forearm, a partial left hindlimb (femur [thigh bone], partial tibia [shin bone], fibula, and foot), and two partial ischia (part of the pelvis) (Galton 1976; Santucci 1998). It was damaged by the blasting that brought it to light, and some parts have been lost since the discovery. In older references the rock unit is known as the Longmeadow Sandstone (Galton 1976). As with YPM 2125, the hollow bones attracted scientific comment. The press at the time took little notice, however; dinosaurs had yet to enter the American consciousness (Santucci 1998), and the specimen was not identified as dinosaurian until Cope (1870).

Other significant tetrapod skeletal specimens from the Portland Formation, outside of Springfield Armory

The next tetrapod skeletal fossil found in the Portland Formation was first mentioned in 1864, but languished in obscurity for many years. This specimen, BSNH (Boston Society of Natural History) 13656, consists of a natural cast of the right pubis, shin, and some ribs of a small theropod perhaps 2.5 to 3 m (8 to 10 ft) long. Its provenance is uncertain, but it probably came from the Middletown area of Connecticut, 61 km (38 miles) south of SPAR (Colbert and Baird 1958). It was assigned to *Coelophysis* sp. by Colbert and Baird (1958), and to *C. holyokensis* by Colbert (1964) (see below), but given the scanty remains, it is probably better to regard it as an indeterminate theropod.

Three skeletons were found in quick succession at a single quarry in the 1880s. All three are skeletons of sauropodomorphs, probably *Anchisaurus*, and each was first described by O. C. Marsh as its own species. The locality was the Buckland Quarry (or Wolcott Quarry), 35 km (22 miles) south of SPAR (Hubert et al. 1982). To date, this is the most productive locality for dinosaur skeletons on the East Coast (Weishampel and Young 1996), but unfortunately the site is presently occupied by a shopping mall. It was a 19th century brownstone quarry, its particular stone being known as "redstone." This locality is interpreted as a setting of ephemeral braided streams with occasional high-energy shallow floods, just west of the large alluvial fans that formed on the east border of the Hartford Basin. The climate at the site was seasonal and semi-arid, and streams flowed from the south to the north (Hubert et al. 1982).

YPM 208, the first skeleton from the quarry, was first named *Anchisaurus major* by Marsh (Marsh 1889). He decided two years later that it warranted its own genus, *Ammosaurus* (Marsh 1891). YPM 208 consists of parts of six back vertebrae, pelvic vertebrae (sacrals), ribs, most of the right scapula, most of the pelvis, the left leg, right femur, and right foot (Galton 1976). The specimen was found October 1884; Charles Wolcott, the owner at the time, set it aside for Marsh, but unfortunately the block thought to contain the anterior half and skull had been incorporated into a bridge abutment. When the bridge (the Hop Brook bridge in south Manchester) was demolished in the summer of 1969, a diligent search by a crew working for the noted paleontologist John Ostrom turned up the missing half of the right femur and some miscellaneous dinosaur bones, but the rest of the absent bones remain missing (Hubert et al. 1982).

In the same paper that he named *Ammosaurus*, Marsh coined another species for *Anchisaurus* from the Buckland Quarry: *A. colurus* (Marsh 1891). *A. colurus* is based on YPM 1883, a partial skeleton missing much of the neck, the tail, and much of the left side (most of the left arm, part of the hip, and the left leg) (Galton 1976). Marsh mentioned that some of the neck and tail were lost before the importance of the specimen was realized (Marsh 1893). He extensively illustrated the specimen, providing a skeletal reconstruction in 1893 with missing parts based on *Anchisaurus solus* (see below) (Marsh 1893). Because Friedrich von Huene (an eminent German paleontologist), was of the opinion that *Anchisaurus polyzelus* was an example of the European genus *Thecodontosaurus*, he coined the name *Yaleosaurus* for *A. colurus* (Huene 1932). This name is commonly seen in dinosaur books from the middle of the 20th century, but was synonymized with *Anchisaurus* (and *A. colurus* with *A. polyzelus*) by Galton (1971, 1976).

The last skeleton from the quarry was named *Anchisaurus solus* by Marsh (Marsh 1892). This specimen, YPM 209, consists of a nearly complete but poorly preserved skeleton of a young individual, approximately 1 m (3 ft) long, with only the end of the tail and the part of the right arm missing (Galton 1976; Fedak and Galton 2007). Galton synonymized *Anchisaurus solus* with *Ammosaurus major* as a juvenile (Galton 1971, 1976; Galton and Cluver 1976).

The next skeleton from the Portland Formation was actually a natural cast. It was recovered from the Hines Quarry (now Hoover Quarry) east of East Longmeadow, Massachusetts, 7 km (4 miles) southeast of SPAR, during the 1890s (Emerson and Loomis 1904). This site has since yielded several types of invertebrate traces and burrows, and *Eubrontes* tracks, from a setting interpreted as a dry or shallow lake, or river (Collette et al. 2006). In 1904 Emerson and Loomis described this specimen (AM 900), a small reptile, as a new species of the aetosaur (armored herbivorous reptile related to crocodilians) *Stegomus*: *S. longipes*. The specimen had been found at least seven years prior, but had been kept in the discoverer's yard. When obtained for description, the specimen was in three pieces, mostly consisting of part and counterpart impressions of the skull roof and bony armor (Emerson and Loomis 1904). Friedrich von Huene gave it the new genus name *Stegomosuchus* in 1922, and moved it to its own family (Stegomosuchidae) in the Pseudosuchia, a nebulous group of crocodile-like reptiles (Huene 1922). It was redescribed as a juvenile of an early crocodile relative related to *Protosuchus* in 1968 (Walker 1968), and is now regarded as an early crocodile relative of uncertain relationships (Whetstone and Whybrow 1983).

To date the most recently recovered tetrapod skeleton from the Portland Formation is the holotype of *Podokesaurus holyokensis*, a small (8.6 cm [3.4 in] femur length) theropod dinosaur. It was found in a glacially-transported boulder of Portland Formation sandstone near Mount Holyoke College, 16 km (10 miles) north of SPAR. Similar to *Stegomosuchus*, the boulder containing the remains of *Podokesaurus* split along the fossil plane. The main portion consisted of an articulated partial skeleton from the base of the neck to the pelvis, lacking most of the feet and arms. Some tail vertebrae, possible skull parts, and a possible gastrolith (potentially the first recognized in a carnivorous dinosaur) were also present. It was described by Mignon Talbot in 1911. Before description, she had interpreted it as an ornithischian because of a misinterpretation of the pelvis, but corrected this before publication (Talbot 1911). Unfortunately, this specimen was not well preserved, and destroyed in a fire at Mount Holyoke College. Only casts remain (Colbert 1964). Ned Colbert, who spent many years working on the bones of the related genus *Coelophysis* from Ghost Ranch, New Mexico, suspected that *Podokesaurus* was a small *Coelophysis* (Colbert and Baird 1958), and formalized this by assigning it to the genus as *C. holyokensis*

(along with BSNH 13656) (Colbert 1964). He later revoked this, returning it to its former genus (Colbert 1989).

***Discussion of the taxonomy of* Anchisaurus *and* Ammosaurus**

Anchisaurus and *Ammosaurus* had been considered different animals since Marsh first named *Ammosaurus*. Galton's separation of the two by foot characteristics proved influential for several decades: in brief, *Ammosaurus* had broad feet, while *Anchisaurus* had slender feet (Galton 1971, 1976; Galton and Cluver 1976). This separation has since been questioned, starting with Sereno (1999). Of the most recent studies to comment on the matter in detail, one (Galton and Upchurch 2004) was in favor of retaining separate genera, and three concluded that the two are the same animal. Yates (2004) and Fedak and Galton (2007) united all four of the most-complete specimens (ACM 41109, YPM 208, YPM 209, and YPM 1883) under *Anchisaurus polyzelus*. However, Sereno (2007) considered ACM 41109 to be undiagnostic, and recommended classifying YPM 208, 209, and 1883 as *Ammosaurus major*. This assessment of ACM 41109 is not unprecedented, as both Cope and Marsh recognized some deficiencies with it; Cope considered it to be fragmentary (Cope 1870), which is noteworthy given both the quality of material he had to work with at the time and some of the material he named in his career, and Marsh's restoration of the genus was based on YPM 1883, his *Anchisaurus colurus* (Marsh 1893). Because YPM 1883 is represented by more complete material, it is usually the specimen of reference when *Anchisaurus* is considered. However, although distinguishing characteristics may not be evident in the Watershops specimen ACM 41109 at the present, that does not mean that none exist. It is not as if ACM 41109 is a single tooth or vertebra; there are a number of bones in the specimen from different areas of the skeleton, and basal sauropodomorphs are a topic of ongoing research. Additionally, all known specimens of the Portland Formation sauropodomorph probably represent immature individuals (Fedak and Galton 2007 [but see Yates 2004]), which has some bearing on how they are classified. Therefore, it seems premature to discard such an historically important name at this point. Given the similarities between *Ammosaurus* and *Anchisaurus*, it is likely that they are the same genus, which by the rules of nomenclature would be identified as *Anchisaurus* (if ACM 41109 is accepted as diagnostic). *Anchisaurus* recently attracted attention as possibly the most primitive and smallest sauropod (Yates 2004). However, this assessment is controversial and subject to change.

For reference, the two fragmentary skeletons from the Navajo Sandstone of Arizona that were assigned to *Ammosaurus* cf. *major* by Galton (1971) do not pertain to *Ammosaurus* or *Anchisaurus* (Irmis 2005; 149 Sereno 2007). Additionally, specimens from the McCoy Brook Formation of Nova Scotia first described as *Ammosaurus* belong to their own, currently-undescribed genus (Fedak 2005).

***Paleobiology of* Anchisaurus**

Anchisaurs, like other prosauropods, had iguana-like teeth, and probably were also mostly herbivorous, supplementing their diet with carrion and small prey (Galton and Upchurch 2004). Known specimens of *Anchisaurus* were modestly sized for a dinosaur; the thigh bones of ACM 41109, YPM 1883, and YPM 208 are 18.0 cm (7.1 in) (estimated), 21.1 cm (8.3 in), and 22.1 cm (8.7 in) long, respectively (Carrano 2006; Fedak and Galton 2007), with the length of YPM 208 estimated at 3 m (10 ft) (Galton 1976). If indeed all known specimens are immature (Fedak and Galton 2007), the adult size is not yet known. Although commonly interpreted as quadrupeds, prosauropods like *Anchisaurus* were probably unable to walk on all fours, based on their arm anatomy (Bonnan and Senter 2007). Anchisaurs may have been members of a rare upland fauna (Galton and Cluver 1976). They are known from the upper, fluvial part of the Portland Formation, along with *Stegomosuchus*, while *Podokesaurus* and the indeterminate theropod are from lake margin or fluvial intervals of the cyclic lower Portland Formation (Olsen et al. 2003b).

Views on the paleobiology of *Anchisaurus* have changed substantially since the 1870s, when Cope described "*Megadactylus polyzelus*" as a leaping carnivore that dispatched prey with its claws (Cope 1870). Although skulls had been described as early as 1896 (Marsh 1896), *Anchisaurus* and *Ammosaurus* were thought to be carnivores well into the 20th century (Lull 1912; Krynine 1950). *Anchisaurus* and *Ammosaurus* were also considered theropods for many years (Marsh 1896). It took until 1971 for *Ammosaurus* to be firmly removed from Theropoda (Galton 1971). Part of this confusion is reflected in

the ichnogenus *Anchisauripus*. *Anchisaurus* and *Ammosaurus* were regarded as among the trackmakers of the formation (Marsh 1893), and the name *Anchisauripus* was chosen for this. This ichnogenus is now regarded as a theropod dinosaur track (Galton 1971).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic unit within SPAR. However, it is known to preserve fossils elsewhere, and future investigations within the park may uncover fossils in it.

Quaternary rocks and sediments (Pleistocene-Holocene)

The Quaternary deposits of SPAR include glacial till and glacial lake delta outwash deposits (Quaternary) (Hartshorn and Koteff 1967), which opens the possibility of Quaternary fossils at the park. Quaternary fossils of Massachusetts and adjacent areas of Connecticut, New Hampshire, Rhode Island, and Vermont generally fall into two categories: mammal bones, especially those of large extinct mammals like mastodons; and material useful for paleoecological studies, such as pollen, spores, and algal and invertebrate microfossils. Sites of both types are found within approximately 100 km (60 miles) of SPAR (Schuchert 1914; Hay 1923; Deevey 1939, 1943; M. Curran and Dincauze 1977; Lucas 1993). Older fossils may also occasionally be found in glacial deposits, such as the holotype skeleton of *Podokesaurus*, which was found in a glacially-transported boulder (Talbot 1911).

The record of Quaternary mammals in Massachusetts and Connecticut is sparse. Connecticut has only eight reports: six mastodons (two from the same location), a caribou, and a deer (Lucas 1993; the report of a Pleistocene horse in this article was later determined to be inaccurate, as the bones were not Pleistocene but modern [Faux and Joyce 2006]). Massachusetts has even fewer. Within the 60 km/100 mile radius there are only two reports, both of mastodons: a tooth from Colrain (or Coleraine), 64 km (40 miles) north-northwest of SPAR, and teeth and bones from peat in Shrewsbury, 72 km (45 miles) northeast of the park (Hay 1923). The nearest finds to SPAR come from central Connecticut, including a nearly complete mastodon skeleton from Farmington, 48 km (30 miles) south-southwest of SPAR, a mastodon vertebra and other bones from New Britain, 52 km (32 miles) south of SPAR, and undescribed mastodon fossils from Bristol, 56 km (35 miles) southwest of SPAR. The only find of any completeness is the Farmington mastodon. This specimen was discovered in 1914 and is now at the Peabody Museum of Natural History (Lucas 1993).

SPAR, and the rest of Springfield adjacent to the Connecticut River, was inundated by Glacial Lake Hitchcock approximately 17,000 years ago (Benner et al. 2009). A variety of fossils are known from deposits of Glacial Lake Hitchcock along the Connecticut River Valley. These include remains of spores, plants (Knecht et al. 2009), snails (Ridge et al. 2009), crustaceans (Knecht et al. 2009), midges, and ostracodes, a single bone from a dace-like fish, and trace fossils from worm-like invertebrates, tadpole shrimp, and at least two types of fish, one a large fish (possibly brook trout), the other a sculpin (Benner et al. 2009). The nearest trace fossil sites are in Chicopee, adjacent to Springfield to the north; East Windsor, Connecticut, 24 km (15 miles) south of SPAR; near North Sugarloaf Mountain, 45 km (28 miles) north of SPAR; and the Canoe Brook area, 100 km (60 miles) north of SPAR (Benner et al. 2008, 2009). Tufts University (Medford, MA) hosts a glacial varve database (Ridge 2009; http://ase.tufts.edu/geology/varves/).

Canoe Brook also has macroscopic plant fossils (Ridge and Larsen 1990; Ridge et al. 1999). Other Pleistocene plant macrofossil sites along the Connecticut River Valley include south of Hadley, 28 km (16 miles) north of SPAR, near Amherst, 33 km (21 miles) north of SPAR (Emerson 1898a, 1898b; Hollick 1931), and Bloomfield, Connecticut, 36 km (22 miles) southwest of SPAR (the Matianuck Avenue site; Ashley et al. 1999; Stone and Ridge 2009). Pleistocene plant sites may include gyttja (organic muck), peat, pollen, seeds, leaves, twigs, and wood (Ashley et al. 1999; Ridge et al. 1999). Pleistocene beetles have also been found from the Hadley area, in the old bed of the Fort River (Emerson 1989b).

A number of Quaternary lake and bog microfossil sites from Massachusetts and Connecticut have been described as well. Partial lists of these sites can be found in Deevey (1939, 1943), M. Curran and Dincauze (1977), Gaudreau (1982), and the National Oceanic and Atmospheric Administration's paleoclimatology databases (accessible from http://www.ncdc.noaa.gov/paleo/; see especially the lake and pollen databases). These microfossil sites are most useful for studying the paleoecology of the Holocene. Some sites that have been described in multiple publications include Kampoosa Bog, 63 km (39 miles) northwest of SPAR (Kehoe 2003; Newton et al. 2005; Neurath and Newton 2008); Berry Pond, 77 km (48 miles) northwest of SPAR (Whitehead et al. 1973; Whitehead 1979; Gaudreau 1982); Lower Linsley Pond, 90 km (55 miles) south of SPAR (see below for some publications); and Rogers Lake, 92 km (57 miles) south-southeast of SPAR (Davis 1969; M. Curran and Dincauze 1977; Gaudreau 1982). By far the best known of these sites is Lower Linsley Pond. Often simply called Linsley Pond, this site has a diverse fossil assemblage spanning approximately the last 12,500 years (Vallentyne and Swabey 1955). Aside from pollen (Deevey 1939), microfossils described from the pond include organic debris, diatoms (algae that encase themselves in silica), other algae, the aquatic moss *Fontinalis*, plant fragments (including leaves and stems), sponges, bryozoans (*Plumatella*), possible eggs of rotifers and gastrotrichs (zooplanktonic animals), *Bosmina* and other cladocerans (crustaceans known as "water fleas"), fragments of insects (particularly midge and alderfly head and jaw parts) (Deevey 1942; Vallentyne and Swabey 1955), and various unidentified objects (the "black spheres," "supposed suctorian cysts," and "wheels" of Vallentyne and Swabey [1955]). Other fossils that have been found at these sites include dinoflagellates (a type of plankton that move using whip-like flagella), spores (Whitehead et al. 1973), bivalves, and gastropods (Neurath and Newton 2008). There is also a report of freshwater bivalves and gastropods found with a mastodon vertebra (the New Britain find; Silliman 1834).

Park Collections

As discussed above, ACM 41109, the holotype of *Anchisaurus polyzelus*, was removed from Springfield Armory grounds (but not modern SPAR) and is presently in the collections of Amherst College's Pratt Museum of Natural History, Amherst, Massachusetts (Galton 1976).

Cultural Resource Contexts

Humans reached the Connecticut River Valley by at least 10,000 years ago (M. Curran and Dincauze 1977, which includes a map of Paleoindian localities; Thorson and McBride 1988). Many ancient human sites also have paleontological material. The mastodon bones from Shrewsbury reportedly came from the same level as a human skull (Hay 1923). Several dozen rock shelter sites with evidence of human habitation are known from Connecticut. These sites can have shells, bones of fish, turtles, birds, and mammals, and tools (MacGurdy 1914). Similar fossils are known at other sites in the state (Thorson and McBride 1988). Stone tools and artifacts are often made of potentially fossiliferous materials, such as chert, dolomite, sandstone, and shale (Calogero and Philpotts 1998), at least some of which were imported from west of Connecticut and Massachusetts (Calogero et al. 1999). Given the record, a human-fossil resource association would not be unprecedented. To date, there are no reported examples of a fossil from a cultural resource context at SPAR. 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

- ACM 41109, the holotype specimen of *Anchisaurus polyzelus*, was recovered from the Portland Formation of Springfield Armory's Watershops site.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

Literature Cited

Aleinikoff, J. N., R. P. Wintsch, R. P. Tollo, D. M. Unruh, C. M. Fanning, and M. D. Schmitz. 2007. Ages and origins of rocks of the Killingworth Dome, south-central Connecticut: implications for the tectonic evolution of southern New England. American Journal of Science **307**(1):63-118.

Ashley, G. M. and J. R. Stone. 1995. The paleoclimate record for southern New England, 15 ka to 12 ka. Abstracts with Programs - Geological Society of America **27**(1):27-28.

Ashley, G. M., J. R. Stone, and D. M. Peteet. 1999. Chronology and paleoclimate implications from radiocarbon-dated paleobotanical records, Connecticut River valley, CT. Abstracts with Programs - Geological Society of America **31**(2):A-2.

Axsmith, B. J., I. H. Escapa, and P. Huber. 2008. An araucarian conifer bract-scale complex from the Lower Jurassic of Massachusetts: implications for estimating phylogenetic and stratigraphic congruence in the Araucariaceae. Palaeontologia Electronica **11**(3):article 13A:unpaginated. Online. http://palaeo-electronica.org/2008_3/153/index.html. Accessed December 2009.

Balk, R. 1957. Geology of Mount Holyoke Quadrangle, Massachusetts. Geological Society of America Bulletin **68**(4):481-504.

Benner, J. S., J. C. Ridge, and N. K. Taft. 2008. Late Pleistocene freshwater fish (Cottidae) trackways from New England (USA) glacial lakes and a reinterpretation of the ichnogenus *Broomichnium* Kuhn. Palaeogeography, Palaeoclimatology, Palaeoecology **260**(3-4):375-388.

Benner, J. S., J. C. Ridge, and R. J. Knecht. 2009. Timing of post-glacial reinhabitation and ecological development of two New England, USA, drainages based on trace fossil evidence. Palaeogeography, Palaeoclimatology, Palaeoecology **272**(3-4):212-231.

Bonis, N. R., M. Ruhl, and W. M. Kürschner. 2010. Climate change driven black shale deposition during the end-Triassic in the western Tethys. Palaeogeography, Palaeoclimatology, Palaeoecology (in press).

Bonnan, M. F. and P. Senter. 2007. Were the basal sauropodomorph dinosaurs *Plateosaurus* and *Massospondylus* habitual quadrupeds? Pages 139-155 *in* Barrett, P. M. and D. J. Batten. Evolution and palaeobiology of early sauropodomorph dinosaurs. The Palaeontological Association, London, United Kingdom. Special Papers in Palaeontology 77.

Calogero, B. L. and A. R. Philpotts. 1998. They came with gifts: material analysis of two cremation cemeteries. Abstracts with Programs - Geological Society of America **30**(1):9-10.

Calogero, B. L., A. R. Philpotts, K. L. Feder, N. F. Bellantoni, S. Paustian, and C. Wickman. 1999. Stone blades caches in Connecticut. Abstracts with Programs - Geological Society of America **31**(2):A-8.

Carrano, M. T. 2006. Body-size evolution in the Dinosauria. Pages 225-268 *in* Carrano M. T., R. W. Blob, T. J. Gaudin, and J. R. Wible, editors. Amniote paleobiology: perspectives on the evolution of mammals, birds, and reptiles. University of Chicago Press, Chicago IL. Online. http://si-pddr.si.edu/dspace/bitstream/10088/7637/1/paleo_Carrano_06.pdf. Accessed December 2009.

Colbert, E. H. 1964. The Triassic dinosaur genera *Podokesaurus* and *Coelophysis*. American Museum Novitates 2168. Online. http://digitallibrary.amnh.org/dspace/bitstream/2246/3350/1/N2168.pdf. Accessed December 2009.

Colbert, E. H. 1989. The Triassic dinosaur *Coelophysis*. Museum of Northern Arizona, Flagstaff, AZ. Bulletin 57.

Colbert, E. H. and D. Baird. 1958. Coelurosaur bone casts from the Connecticut Valley Triassic. American Museum Novitates 1901. Online. http://digitallibrary.amnh.org/dspace/bitstream/2246/2486/1/N1901.pdf. Accessed December 2009.

Collette, J. H., P. R. Getty, and J. W. Hagadorn. 2006. An Early Jurassic non-marine fossil assemblage from the Portland Formation, Hartford Basin, Massachusetts. Abstracts with Programs - Geological Society of America **38**(7):68.

Cope, E. D. 1867. [An account of the extinct reptiles which approached the birds]. Proceedings of the Academy of Natural Sciences of Philadelphia **19**:234-235. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/proceedingsofaca19acad]

Cope, E. D. 1870. On the *Megadactylus polyzelus* of Hitchcock. American Journal of Science **49**:390-392. [full text available on Google Books]

Cornet, B. 1989. Hartford Basin, Connecticut and Massachusetts: Jurassic conifer assemblages and their paleoclimatic implications. Pages 117-118 *in* Olsen, P. E., R. W. Schlische, and P. J. W. Gore, editors. Sedimentation and basin analysis in siliciclastic rock sequences: Volume 2. Tectonic, depositional, and paleoecological history of early Mesozoic rift basins, eastern North America. Hanshaw, P. M., editor. Field trips for the 28th international geological congress. American Geophysical Union, Washington, DC.

Cornet, B. and N. G. McDonald. 1995. A new cheirolepid conifer bearing flowers from the early Jurassic of Connecticut, USA. Abstracts with Programs - Geological Society of America **27**(1):37.

Cornet, B. and P. E. Olsen. 1989. Jurassic rift basin floras and their climatic implications. International Geological Congress, Abstracts **28**(1):1.328.

Cornet, B. and A. Traverse. 1975. Palynological contributions to the chronology and stratigraphy of the Hartford Basin in Connecticut and Massachusetts. Geoscience and Man **11**:1-33. Online. http://bcornet.tripod.com/hartford/Hartford.htm. Accessed December 2009.

Curran, M. L. and D. F. Dincauze. 1977. Paleoindians and paleo-lakes: new data from the Connecticut drainage. Annals of the New York Academy of Sciences **288**:333-348.

Curran, K. and D. F. Dincauze. 1999. Archaeological chronometry for Connecticut River valley surfaces. Abstracts with Programs - Geological Society of America **31**(2):A-11.

Davis, M. B. 1969. Climatic changes in southern Connecticut recorded by pollen deposition at Rogers Lake. Ecology **50**(3):409-422.

Deevey, E. S. Jr. 1939. Studies on Connecticut lake sediments. I. A postglacial climate chronology for southern New England. American Journal of Science **237**:691-724.

Deevey, E. S. Jr. 1942. Studies on Connecticut lake sediments. III. The biostratonomy of Linsley Pond. American Journal of Science **240**:233-264, 313-338.

Deevey, E. S. Jr. 1943. Additional pollen analyses from southern New England. American Journal of Science **241**:717-752.

Drzewiecki, P. 2009. Interpretation of a playa system from a Jurassic hothouse climate, East Berlin and lower Portland Formations, Hartford Basin, Connecticut. Abstracts with Programs - Geological Society of America **41**(3):34.

Drzewiecki, P. and E. Gierlowski-Kordesch. 2008. Response of early Jurassic paleosols to environmental changes in the Hartford Basin, Connecticut. Abstracts with Programs - Geological Society of America **40**(6):281.

Drzewiecki, P. A., K. Duggan, A. R. Dwyer III, E. Gierlowski-Kordesch, and K. M. Bohacs. 2006. Facies and facies stacking patterns in lacustrine strata of the Lower Jurassic Portland Formation, Hartford Basin, Connecticut. Abstracts with Programs - Geological Society of America **38**(7):85.

Emerson, B. K. 1898a. Outlines of the geology of western Massachusetts: description of the Holyoke Quadrangle. U.S. Geological Survey, Reston, VA. Geological Atlas Folio 50.

Emerson, B. K. 1898b. Geology of old Hampshire County, Massachusetts, comprising Franklin, Hampshire, and Hampden counties. U.S. Geological Survey, Reston, VA. Monograph 29.

Emerson, B. K. and F. B. Loomis. 1904. On *Stegomus longipes*, a new reptile from the Triassic sandstones of the Connecticut Valley. American Journal of Science **17**(4):377-380. [full text available on Google Books]

Faux, C. and W G. Joyce. 2008. Connecticut's Pleistocene horse reassigned to the 19th Century. Peabody Museum of Natural History Bulletin **49**(1):131-132.

Fedak, T. 2005. New dinosaur diversity in the earliest Jurassic of North America. Program with Abstracts - Joint Annual Meeting of the Geological Association of Canada, the Mineralogical Association of Canada, and the Canadian Geophysical Union **30**:56-57. Online. http://www.gac.ca/activities/abstracts/Halifax2005Abstracts.pdf. Accessed December 2009.

Fedak, T. J. and P. M. Galton. 2007. New information on the braincase and skull of Anchisaurus polyzelus (Lower Jurassic, Connecticut, USA: Saurischia, Sauropodomorpha): implications for sauropodomorph systematics. Pages 245-260 *in* Barrett, P. M. and D. J. Batten, editors. Evolution and palaeobiology of early sauropodomorph dinosaurs. The Palaeontological Association, London, United Kingdom. Special Papers in Palaeontology 77.

Foose, R. M., J. J. Rytuba, and M. F. Sheridan. 1968. Volcanic plugs in the Connecticut Valley Triassic near Mount Tom, Massachusetts. Geological Society of America Bulletin **79**(11):1655-1661.

Galton, P. M. 1971. The prosauropod dinosaur *Ammosaurus*, the crocodile *Protosuchus*, and their bearing on the age of the Navajo Sandstone of northeastern Arizona. Journal of Paleontology **45**(5):781-795.

Galton, P. M. 1976. Prosauropod dinosaurs (Reptilia: Saurischia) of North America. Postilla 169.

Galton, P. M. and M. A. Cluver. 1976. *Anchisaurus capensis* (Broom) and a revision of the Anchisauridae: Reptilia, Saurischia. Annals of the South African Museum **69**(6):121-159.

Galton, P. M. and P. Upchurch. 2004. Prosauropoda. Pages 232-258 *in* Weishampel, D. W., P. Dodson, P. and H. Osmólska, editors. The Dinosauria, 2nd edition. University of California Press, Berkeley, CA.

Gaudreau, D. C. 1982. Holocene vegetational history of central New England and the Hudson River valley. Program and Abstracts - American Quaternary Association **7**:93.

Hartshorn, J. H. and C. Koteff. 1967. Geologic map of the Springfield South quadrangle, Hampden County, Massachusetts and Hartford and Tolland Counties, Connecticut. U.S. Geological Survey, Reston, VA. Online. http://pubs.er.usgs.gov/usgspubs/gq/gq678. Accessed December 2009.

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°. Carnegie Institution of Washington Publication 322. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/pleistoceneofnor00hayouoft]

Hitchcock, E. B. 1836. Description of the footmarks of birds (Ornthichnites) on new red sandstone in Massachusetts. American Journal of Science **29**(2):307-340.

Hitchcock, E. 1858. Ichnology of New England. White, Boston, MA. [full text available on Google Books]

Hitchcock, E. 1865. Supplement to the ichnology of New England. Wright and Potter, Boston, MA. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/EH1865download.html. Accessed December 2009.

Hollick, C. A. 1931. Plant remains from a Pleistocene lake deposit in the upper Connecticut River Valley. Brittonia **1**(1):35-55.

Horne, G. S., N. G. McDonald, P. M. LeTourneau, and J. Z. de Boer. 1993. Paleoenvironmental traverse across the early Mesozoic Hartford rift basin, Connecticut. Pages P.1-P.26 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States: 1993 Boston GSA. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **67**(2).

Huber, P., N. G. McDonald, and P. E. Olsen. 2003. Early Jurassic insects from the Newark Supergroup, northeastern United States. Pages 206-233 *in* LeTourneau, P. M. and P. E. Olsen, editors. The great rift valleys of Pangea in eastern North America. Volume 2: Sedimentology, stratigraphy, and paleontology. Columbia University Press, New York, NY. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/huber_et_al_03.pdf. Accessed December 2009.

Hubert, J. F. and J. A. Dutcher. 1999. Sedimentation, volcanism, stratigraphy, and tectonism at the Triassic-Jurassic boundary in the Deerfield Basin, Massachusetts. Northeastern Geology and Environmental Sciences **21**(3):188-201.

Hubert, J. F., A. A. Reed, W. L. Dowdall, and J. M. Gilchrist. 1978. Guide to the redbeds of Central Connecticut: 1978 field trip, Eastern Section of SEPM. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts 32.

Hubert, J. F., J. M. Gilchrist, and A. A. Reed. 1982. Jurassic redbeds of the Connecticut Valley: 1, Brownstones of the Portland Formation; 2, Playa-playa lake-oligomictic lake model for parts of the East Berlin, Shuttle Meadow and Portland formations. Pages 103-141 *in* Joesten, R. and S. S. Quarrier, editors. Guidebook for fieldtrips in Connecticut and south-central Massachusetts. New England Intercollegiate Geologic Conference, Amherst, MA. Annual Meeting - New England Intercollegiate Geological Conference 74.

Hubert, J. F., P. E. Feshbach-Meriney, and M. A. Smith. 1992. The Triassic-Jurassic Hartford rift basin, Connecticut and Massachusetts: evolution, sandstone diagenesis, and hydrocarbon history. AAPG Bulletin **76**(11):1710-1734.

Huene, F. v. 1922. The Triassic reptilian order Thecodontia. American Journal of Science **4**(19):22-26. [full text available on Google Books]

Huene, F. v. 1932. Die fossile Reptil-Ordnung Saurischia, ihre Entwicklung und Geschichte [The fossil reptile order Saurischia, their development and history]. Monographien zur Geologie und Palaeontologie, serie 1 **4**(1-2):1-361.

Irmis, R. 2005. A review of the vertebrate fauna of the Lower Jurassic Navajo Sandstone. Pages 55-71 *in* McCord, R. D., editor. Vertebrate paleontology of Arizona. Mesa Southwest Museum, Mesa, AZ. Bulletin 11. Online. http://socrates.berkeley.edu/~irmisr/navajo.pdf. Accessed December 2009.

Kehoe, S. W. 2003. High resolution climate proxies for a late Pleistocene-Holocene lake, Kampoosa Bog, western Massachusetts. Abstracts with Programs - Geological Society of America **35**(6):414.

Kent, D. V. and P. E. Olsen. 2008. Early Jurassic magnetostratigraphy and paleolatitudes from the Hartford continental rift basin (eastern North America): testing for polarity bias and abrupt polar wander in association with the central Atlantic magmatic province. Journal of Geophysical Research **113**:B06105.

Kent, D. V. and L. Tauxe. 2005. Corrected Late Triassic latitudes for continents adjacent to the North Atlantic. Science **307**(5707):240-244. Online. http://magician.ucsd.edu/~ltauxe/CV/reprints/kent05.pdf. Accessed February 2010.

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* Lucas, S. G., 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, NM. Bulletin 34. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed December 2009.

Knecht, R. J., J. S. Benner, D. C. Rogers, and J. C. Ridge. 2009. *Surculichnus bifurcauda* n. igen., n. isp., a trace fossil from late Pleistocene glaciolacustrine varves of the Connecticut River valley, USA, attributed to notostracan crustaceans based on neoichnological experimentation. Palaeogeography, Palaeoclimatology, Palaeoecology **272**(3-4):232-239.

Krynine, P. D. 1950. Petrology, stratigraphy, and origin of the Triassic sedimentary rocks of Connecticut. State Geological and Natural History Survey of Connecticut, Hartford, CT. Bulletin 73.

Larsen, F. D. 1988. Glaciotectonic features associated with the Chicopee readvance of the Connecticut Valley lobe, Massachusetts. Abstracts with Programs - Geological Society of America **20**(1):31-32.

LeTourneau, P. M. 1985a. Alluvial fan development in the Lower Jurassic Portland Formation, central Connecticut: implications for tectonics and climate. Pages 17-26 *in* Robinson, G. R. Jr. and A. J. Froelich, editors. Proceedings of the second U.S. Geological Survey workshop on the early Mesozoic basins of the Eastern United States. U.S. Geological Survey, Reston, VA. Circular 946. Online. http://pubs.er.usgs.gov/usgspubs/cir/cir946. Accessed December 2009.

LeTourneau, P. M. 1985b. Lithofacies analysis of the Portland Formation in central Connecticut. Abstracts with Programs - Geological Society of America **17**(1):31.

LeTourneau, P. M. and N. G. McDonald. 1985. The sedimentology, stratigraphy and paleontology of the Lower Jurassic Portland Formation, Hartford Basin, central Connecticut. Pages 353-391 *in* Tracy, R. J., editor. Guidebook for fieldtrips in Connecticut and adjacent areas of New York and Rhode Island. State Geological and Natural History Survey of Connecticut, Hartford, CT. Guidebook 6.

LeTourneau, P. M. and J. P. Smoot. 1985. Comparison of ancient and modern lake margin deposits from the Lower Jurassic Portland Formation, Connecticut, and Walker Lake, Nevada. Abstracts with Programs - Geological Society of America **17**(1):31.

Levin, H. L. 1999. The Earth through time (6th edition). Saunders College Publishing, Fort Worth, TX.

Lucas, S. G. 1993. A Pleistocene horse from Connecticut. The Mosasaur **5**:43-46.

Lull, R. S. 1904a. Fossil footprints of the Jura-Trias of North America. Boston Society of Natural History Memoir 5:461-557. Online. http://www.archive.org/details/memoirsofbostons05bost. Accessed December 2009.

Lull, R. S. 1904b. Notes on the probable footprints of *Stegomus longipes*. American Journal of Science **17**(4):381-382. [full text available on Google Books]

Lull, R. S. 1912. The life of the Connecticut Trias. American Journal of Science **33**(197):397-422. [full text available on Google Books]

Lull, R. S. 1915. Triassic life of the Connecticut Valley. Connecticut Geological and Natural History Survey, Hartford, CT. Bulletin 24. [full text available on Google Books]

MacCurdy, G. G. 1914. The passing of a Connecticut rock shelter. American Journal of Science **38**(228):511-522.

Malinconico, M. L. 2000. Patterns of organic sedimentation in lake cycles and sequences of the Mesozoic Newark and Richmond basins. Abstracts with Programs - Geological Society of America **32**(1):32, 57.

Marsh, O. C. 1882. Classification of the Dinosauria. American Journal of Science **23**(133):81-86. Online. http://sauroposeidon.net/marsh/Marsh%201882%20-%20Classification%20of%20the%20Dinosauria.pdf. Accessed December 2009.

Marsh, O. C. 1885. Names of extinct reptiles. American Journal of Science **29**:169. Online. http://sauroposeidon.net/marsh/Marsh%201885%20-%20Names%20of%20extinct%20reptiles.pdf. Accessed December 2009.

Marsh, O. C. 1889. Notice of new American Dinosauria. American Journal of Science **37**(220):331-336. Online. http://sauroposeidon.net/marsh/Marsh%201889%20-%20Notice%20of%20new%20American%20Dinosauria.pdf. Accessed December 2009.

Marsh, O. C. 1891. Notice of new vertebrate fossils. American Journal of Science **42**(249):265-269. Online. http://sauroposeidon.net/marsh/Marsh%201891%20-%20Notice%20of%20new%20vertebrate%20fossils.pdf. Accessed December 2009.

Marsh, O. C. 1892. Notes on Triassic Dinosauria. American Journal of Science **43**(258):543-546. Online. http://sauroposeidon.net/marsh/Marsh%201892%20-%20Notes%20on%20Triassic%20Dinosauria.pdf. Accessed December 2009.

Marsh, O. C. 1893. Restoration of *Anchisaurus*. American Journal of Science **45**(266):169-170. Online. http://sauroposeidon.net/marsh/Marsh%201893%20-%20Restoration%20of%20Anchisaurus.pdf. Accessed December 2009.

Marsh, O. C. 1896. The dinosaurs of North America. Pages 133-414 *in* Sixteenth Annual Report of the United States Geological Survey to the Secretary of the Interior, 1894-1895: Part 1. U.S. Geological

Survey, Reston, VA. Annual Report 16 (Part 1). Online. http://pubs.er.usgs.gov/usgspubs/ar/ar16_1 [large file]. Accessed December 2009.

Marzoli, A., P. R. Renne, E. M. Piccirillo, M. Ernesto, G. Bellieni, and A. De Min. 1999. Extensive 200-million-year-old continental flood basalts of the Central Atlantic magmatic province. Science **284**(5414):616-618. Online. http://www.csam.montclair.edu/earth/eesweb/gorring/geos444/marzoli.99.pdf. Accessed February 2010.

McDonald, N. G. 1992. Paleontology of the early Mesozoic (Newark Supergroup) rocks of the Connecticut Valley. Northeastern Geology **14**:185-200.

McDonald, N. G. and P. M. LeTourneau. 1988. Paleoenvironmental reconstruction of a fluvial-deltaic-lacustrine sequence, Lower Jurassic Portland Formation, Suffield, Connecticut. Pages 24-30 *in* Froelich, A. J. and G. R. Robinson Jr., editors. Studies of the early Mesozoic basins of the Eastern United States. U.S. Geological Survey, Reston, VA. Bulletin 1776. Online. http://pubs.er.usgs.gov/usgspubs/b/b1776 [large file]. Accessed December 2009.

McMenamin, M. A. S. and L. B. Ulm. 2004. First report of the Mesozoic cycadeoid *Ptilophyllum* from Massachusetts. Northeastern Geology and Environmental Sciences **26**(4):279-284.

National Oceanic and Atmospheric Administration. 2009 (most recent year). NOAA Paleoclimatology. Online. http://www.ncdc.noaa.gov/paleo/. Accessed December 2009.

Neurath, R. A. and R. M. Newton. 2008. From lake to fen: a record of Holocene climate change at Kampoosa Bog, Stockbridge, Massachusetts. Abstracts with Programs - Geological Society of America **40**(6):256.

Newton, R. M., R. T. Indrick, A. Pufall, S. W. Kehoe, A. L. Rhodes, and N. E. Tibert. 2005. Variations in clay mineralogy as a proxy for late Pleistocene to Holocene climate change at Kampoosa Bog, Stockbridge Massachusetts. Abstracts with Programs - Geological Society of America **37**(1):6.

Olsen, P. E. 1980a. Triassic and Jurassic formations of the Newark Basin. Pages 2-39 *in* Manspeizer, W., 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, NY. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_formations_80_sm.pdf. Accessed November 2009.

Olsen, P. E. 1980b. The latest Triassic and Early Jurassic formations of the Newark Basin (eastern North America, Newark Supergroup): stratigraphy, structure and correlation. New Jersey Academy of Science Bulletin **25**(2):25-51. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_njas_80_sm.pdf. Accessed November 2009.

Olsen, P. E. 1980c. Fossil great lakes of the Newark Supergroup in New Jersey. Pages 352-398 *in* Manspeizer, W., 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, NY. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_gr_80_vsm.pdf. Accessed November 2009.

Olsen, P. E. 1980d. Comparison of the vertebrate assemblages from the Newark and Hartford basins (Early Mesozoic, Newark Supergroup) of eastern North America. Pages 35-53 *in* Jacobs, L. L., editor. Aspects of vertebrate history. Museum of Northern Arizona Press, Flagstaff, AZ. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_80_comp_2.pdf. Accessed December 2009.

Olsen, P. E. 1988. Paleontology and paleoecology of the Newark Supergroup (early Mesozoic, eastern North America). Pages 185-230 in Manspeizer, W., editor. Triassic-Jurassic rifting: continental breakup and the origin of the Atlantic Ocean and passive margins. Developments in Geotectonics **22**(Part A). Elsevier, Amsterdam, The Netherlands. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_88_sm3.pdf. Accessed December 2009.

Olsen, P. E. 1989. Hartford Basin, Connecticut and Massachusetts: Stop 7.6: Holyoke Dam, Holyoke, MA. Pages 115-117 *in* Olsen, P. E., R. W. Schlische, and P. J. W. Gore, editors. Sedimentation and basin analysis in siliciclastic rock sequences: Volume 2. Tectonic, depositional, and paleoecological history of early Mesozoic rift basins, eastern North America. Hanshaw, P. M., editor. Field trips for the 28th international geological congress. American Geophysical Union, Washington, DC.

Olsen, P. E. 1997. Stratigraphic record of the early mesozoic breakup of Pangea in the Laurasia-Gondwana rift system. Annual Review of Earth and Planetary Sciences **25**:337-401. Online. http://www.ldeo.columbia.edu/~polsen/newark_gechron/Olsen.1997.pdf. Accessed December 2009.

Olsen, P. E. and D. V. Kent. 1999. Long-period Milankovitch cycles from the Late Triassic and Early Jurassic of eastern North America and their implications for the calibration of the early Mesozoic time scale and the long-term behavior of the planets. Philosophical Transactions of the Royal Society of London (series A) **357**:1761-1787.

Olsen, P. E. and K. Padian. 1986. Earliest records of *Batrachopus* from the Southwest U.S., and a revision of some Early Mesozoic crocodilomorph ichnogenera. Pages 259-273 in Padian, K., editor. The Beginning of the Age of Dinosaurs: faunal change across the Triassic-Jurassic boundary. Cambridge University Press, New York, NY. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_padian_86_sm.pdf. Accessed December 2009.

Olsen, P. E. and E. C. Rainforth. 2003. The Early Jurassic ornithischian dinosaurian ichnogenus *Anomoepus*. Pages 314-368 *in* LeTourneau, P. M. and P. E. Olsen, editors. The great rift valleys of Pangea in eastern North America: Volume 2, Sedimentology, stratigraphy, and paleontology. Columbia University Press, New York, NY. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_rainforth_cu_proofs_03.pdf. Accessed December 2009.

Olsen, P. E., and J. H. Whiteside. 2008. Pre-Quaternary Milankovitch cycles and climate variability. Pages 826-835 *in* Gornitz, V., editor. Encyclopedia of paleoclimatology and ancient environments. Encyclopedia of earth science. Kluwer Academic Publishers, Dordretch, the Netherlands. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_whiteside_2008_sm.pdf. Accessed November 2009.

Olsen, P. E., B. Cornet, and N. G. McDonald. 1989. Cyclostratigraphy of the Chicopee Fish Bed and adjacent strata: implications for the palynostratigraphy of the Portland Formation (Early Jurassic, Newark Supergroup). Abstracts with Programs - Geological Society of America **21**(2):56.

Olsen, P. E., B. Cormet, N. G. McDonald, and P. Huber. 1992. Stratigraphy and paleoecology of the Deerfield rift basin (Triassic-Jurassic, Newark Supergroup), Massachusetts. Pages 488-535 *in* Robinson, P. and J. B. Brady. Guidebook for field trips in the Connecticut Valley region of Massachusetts and adjacent states. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **66**(2).

Olsen, P. E., R. W. Schlische, and M. S. Fedosh. 1996. 580 ky duration of the Early Jurassic flood basalt event in eastern North America estimated using Milankovitch cyclostratigraphy. Pages 11-22 *in* Morales, M., editor. The continental Jurassic. Museum of Northern Arizona, Flagstaff, AZ. Bulletin

60. Online. http://geology.rutgers.edu/~schlisch/A16_1996_CAMP_duration.pdf. Accessed November 2009.

Olsen, P. E., J. B. Smith, and N. G. McDonald. 1998. Type material of the type species of the classic theropod footprint genera *Eubrontes*, *Anchisauripus*, and *Grallator* (Early Jurassic, Hartford and Deerfield basins, Connecticut and Massachusetts, U.S.A.). Journal of Vertebrate Paleontology **18**(3):586-601. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_et_al_98_eubrontes.pdf [large file]. Accessed December 2009.

Olsen, P. E. D. V. Kent, and P. M. LeTourneau. 2002. Stratigraphy and age of the Early Jurassic Portland Formation of Connecticut and Massachusetts: a contribution to the time scale of the Early Jurassic. Abstracts with Programs - Geological Society of America **34**(1):61

Olsen, P. E., D. V. Kent, M. Et-Touhami, and J. H. Puffer. 2003a. Cyclo-, magneto-, and bio-stratigraphic constraints on the duration of the CAMP event and its relationship to the Triassic-Jurassic boundary. Pages 7-32 *in* Hames, W.E., J. G. McHone, P. R. Renne, and C. Ruppel, editors. The Central Atlantic Magmatic Province: insights from fragments of Pangea. American Geophysical Union, Washington, D.C. Geophysical Monograph Series 136. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen.et.al.camp.03.pdf. Accessed December 2009.

Olsen, P. E., J. H. Whiteside, and P. Huber. 2003b. Causes and consequences of the Triassic-Jurassic mass extinction as seen from the Hartford basin. Pages B5-1-B5-41 *in* Brady, J. B. and J. T. Cheney, editors. Guidebook for field trips in the Five College region, 95th New England Intercollegiate Geological Conference. Department of Geology, Smith College, Northampton, MA. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_whiteside_huber_03.pdf. Accessed December 2009.

Olsen, P. E., J. H. Whiteside, P. M. LeTourneau, and P. Huber. 2005. Jurassic cyclostratigraphy and paleontology of the Hartford basin. Pages A4-1-4-51 *in* Skinner, B. J. and A. R. Philpotts, editors. 97th New England Intercollegiate Geological Conference. Department of Geology and Geophysics, Yale University, New Haven, CT. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/olsen_et_al_neigc_2005_sm.pdf. Accessed December 2009.

Ostrom, J. H. 1971. Report to the National Park Service on Mesozoic vertebrate paleontological sites for possible inclusion in the Registry of Natural Landmarks. Peabody Museum of Natural History, Yale University, New Haven, CT.

Rainforth, E. C. 2002a. Ornithichnology: the ichnotaxonomic legacy of Edward Hitchcock and the status of the grallatorid ichnogenera *Grallator*, *Anchisauripus* and *Eubrontes*. Abstracts with Programs - Geological Society of America **34**(1):31-32.

Rainforth, E. C. 2002b. The Pangean ichnites *Otozoum* and *Pseudotetrasauropus*: an example of relationships among and between tetrapod ichnotaxa and skeletal taxa. Journal of Vertebrate Paleontology **22**(supplement to 3):98A.

Rainforth, E. C. 2006. The “stony books”: three-dimensional footprints from Early Jurassic strata of the Connecticut Valley. Abstracts with Programs - Geological Society of America **38**(3):71

Ridge, J. C. 2009 (most recent year). North American Glacial Varve Project. Tufts University, Medford, MA. Online. http://ase.tufts.edu/geology/varves/. Accessed October 2009.

Ridge, J. C. and F. D. Larsen. 1990. Re-evaluation of Antevs' New England varve chronology and new radiocarbon dates of sediments from glacial Lake Hitchcock. Geological Society of America Bulletin **102**(7):889-899.

Ridge, J. C., M. R. Besonen, M. Brochu, S. L. Brown, J. W. Callahan, G. J. Cook, R. S. Nicholson, and N. J. Toll. 1999. Varve, paleomagnetic, and ^{14}C chronologies for late Pleistocene events in New Hampshire and Vermont (U.S.A.). Geographie Physique et Quaternaire **53**(1):79-107.

Ridge, J. C., C. C. Beck, E. B. Voytek, R. L. Bayless, and J. L. Dean. 2009. Calibration of a unified New England varve chronology: deglaciation rates and moraine building in the Connecticut Valley of New Hampshire and Vermont. Abstracts with Programs - Geological Society of America **41**(3):36.

Santucci, V. L. 1998. Early discoveries of dinosaurs from North America and the significance of the Springfield Armory dinosaur site. Pages 152-154 *in* Santucci, V. L. and L. McClelland, editors. National Park Service Paleontological Research 3. NPS Technical Report NPS/NRGRD/GRDTR-98/01. Online. http://www.nature.nps.gov/geology/paleontology/pub/grd3_3/spar1.htm. Accessed December 2009.

Schlische, R. W. and P. E. Olsen. 1989. Hartford Basin, Connecticut and Massachusetts: Geology of the Hartford and Deerfield basin. Pages 107-109 *in* Olsen, P. E., R. W. Schlische, and P. J. W. Gore, editors. Sedimentation and basin analysis in siliciclastic rock sequences: Volume 2. Tectonic, depositional, and paleoecological history of early Mesozoic rift basins, eastern North America. Hanshaw, P. M., editor. Field trips for the 28th international geological congress. American Geophysical Union, Washington, DC.

Schoene, B., J. Guex, A. Bartolini, U. Schaltegger, and T. J. Blackburn. 2010. A correlation between the Triassic-Jurassic boundary mass extinction and flood basalt eruption at the 100 ka-level using ID-TIMS U/Pb zircon geochronology. Geology (in press).

Schuchert, C. 1914. *Mammut americanum* in Connecticut; with a note on the Farmington specimen, by Richard S. Lull. American Journal of Science **37**(220):321-330. [full text available on Google Books]

Sereno, P. C. 1999. The evolution of dinosaurs. Science **284**(5423):2137-2147.

Sereno, P. C. 2007. Basal Sauropodomorpha: historical and recent phylogenetic hypotheses, with comments on *Ammosaurus major* (Marsh, 1889). Pages 261-289 *in* Barrett, P. M. and D. J. Batten, editors. Evolution and palaeobiology of early sauropodomorph dinosaurs. The Palaeontological Association, London, United Kingdom. Special Papers in Palaeontology 77.

Silliman, B. 1834. Vertebral bone of a mastodon. American Journal of Science **27**:165-166.

Smith, N. 1820. Fossil bones found in red sandstone. American Journal of Science and Arts **2**(1):146-147.

Smoot, J. P. 1991. Eolian sandsheet and dune strata in the Upper Triassic New Haven Arkose, Hartford Basin, Connecticut. Abstracts with Programs - Geological Society of America **23**(1):130.

Stone, J. R. and J. C. Ridge. 2009. A new varve record and C-14 dates from the southern basin of glacial Lake Hitchcock. Abstracts with Programs - Geological Society of America **41**(3):36

Talbot, M. 1911. *Podokesaurus holyokensis*, a new dinosaur from the Triassic of the Connecticut Valley. American Journal of Science **31**(186):469-479. [full text available on Google Books]

Thorson, R. M. and K. McBride. 1988. The Bolton Spring Site, Connecticut: early Holocene human occupation and environmental changes in southern New England. Geoarchaeology **3**(3):221-234.

Truebe, S. A., W. W. Oswald, D. R. Foster, and E. Doughty. 2007. Lake-sediment evidence for variation in mid-Holocene climate and vegetation in western Massachusetts. Eos **88**(supplement to 25):JA298. Abstract PP43C-01.

Vallentyne, J. R. and Y. S. Swabey. 1955. A reinvestigation of the history of Lower Linsley Pond, Connecticut. American Journal of Science **253**:313-340.

Walker, A. D. 1968. *Protosuchus*, *Proterochampsa*, and the origin of phytosaurs and crocodiles. Geological Magazine **105**(1):1-14.

Weems, R. E. and P. E. Olsen. 1997. Synthesis and revision of groups within the Newark Supergroup, eastern North America. Geological Society of America Bulletin **109**(2):195-209. Online. http://www.ldeo.columbia.edu/~polsen/nbcp/weems.olsen.97.pdf. Accessed December 2009.

Weishampel, D. B. and L. Young. 1996. Dinosaurs of the East Coast. Johns Hopkins University Press, Baltimore, MA.

Whetstone, K. N. and P. J. Whybrow. 1983. A "cursorial" crocodilian from the Triassic of Lesotho (Basutoland), southern Africa. Occasional Papers of the Museum of Natural History, the University of Kansas **106**:1-37.

Whitehead, D. R. 1979. Late-glacial and postglacial vegetational history of the Berkshires, western Massachusetts. Quaternary Research **12**(3):333-357.

Whitehead, D. R., H. Rochester Jr., S. W. Rissing, C. B. Douglass, and M. C. Sheehan. 1973. Late glacial and postglacial productivity changes in a New England pond. Science **181**(4101):744-747.

Wintsch, R. P., M. K. Roden-Tice, and D. R. Lux. 1997. The Hartford Basin, Connecticut: rifted continental basin. Abstracts with Programs - Geological Society of America **29**(1):90.

Wise, D. U., J. F. Hubert, and E. C. Belt. 1992. Mohawk trail cross section of the Mesozoic Deerfield Basin: structure, stratigraphy, and sedimentology. Pages 170-198 *in* Robinson, P. and J. B. Brady. Guidebook for field trips in the Connecticut Valley region of Massachusetts and adjacent states. University of Massachusetts, Amherst, MA. Contribution - Geology Department, University of Massachusetts **66**(1).

Wizevich, M. C. and P. A. Drzewiecki. 2004. Depositional processes and stratigraphy of alluvial deposits in the Jurassic Portland Formation, Connecticut. Abstracts with Programs - Geological Society of America **36**(2):89.

Wyman, J. 1855. Notice of fossil bones from the Red Sandstone of the Connecticut River Valley. American Journal of Science and Arts **20**(60):394-397. [full text available on Google Books]

Yates, A. M. 2004. *Anchisaurus polyzelus* (Hitchcock): the smallest known sauropod dinosaur and the evolution of gigantism among sauropodomorph dinosaurs. Postilla 230.

Zen, E-an, R. Goldsmith, N. M. Ratcliffe, P. Robinson, R. S. Stanley, N. L. Hatch, A. F. Shride, E. G. A. Weed, and D. R. Wones. 1983. Bedrock geologic map of Massachusetts. U.S. Geological Survey, Reston, VA. Scale 1:250,000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_16357.htm. Accessed December 2009.

Additional References

Cotter, J. F. P., E. B. Evenson, L. Sirkin, and R. Stuckenrath. 1984. The interpretation of "bog-bottom" radiocarbon dates in glacial chronologies. Pages 299-316 *in* Mahaney, W. C., editor. Correlation of Quaternary chronologies. GeoBooks, Norwich, United Kingdom.

Cox, J. W. and J. W. Niemitz. 1997. Geochemical comparison of Early Jurassic stratigraphy, Hartford and Newark basins: implications for paleoclimatic interpretations of Van Houten cycles. Abstracts with Programs - Geological Society of America **29**(1):38.

Davis, M. B. 1958. Three pollen diagrams from central Massachusetts. American Journal of Science **256**:540-570.

Davis, P. T., D. P. Dethier, and R. Nickmann. 1995. Deglaciation chronology and late Quaternary pollen record from Woodford Bog, Bennington County, Vermont. Abstracts with Programs - Geological Society of America **27**(1):38.

Drzewiecki, P. A. and S. Zuidema. 2007. Sequence stratigraphy of playa and perennial lake deposits, Jurassic East Berlin Formation, central Connecticut. Northeastern Geology and Environmental Sciences **29**(1):49-68.

Emerson, B. K. 1891. On the Triassic of Massachusettts. Geological Society of America Bulletin **2**:451-456.

Getty, P. R. 2006. A description of the dinosaur footprints on display at the Springfield Science Museum, Springfield, Massachusetts. Northeastern Geology and Environmental Sciences **28**(4):334-341.

Gilfillan, A. M. and P. E. Olsen. 2000. The coelacanth, *Diplurus longicaudatus* as the origin of the large coprolites occurring in the Triassic-Jurassic lacustrine strata of eastern North America. Abstracts with Programs - Geological Society of America **32**(1):A-20.

Hitchcock, E. Jr. 1872. Discovery of a tooth of a mastodon in Massachusetts. American Journal of Science **3**:146. [full text available on Google Books]

Hubert, J. F. and J. Dutcher. 2005. Synsedimentary sand pillows on a lacustrine delta slope (Turners Falls Formation) and sheetflood deposition of alluvial-fan gravels (Mount Toby Formation), Early Jurassic Deerfield Basin, Massachusetts. Northeastern Geology and Environmental Sciences **27**(1):18-36.

Hugo, C. and C. E. Geiss. 2007. An investigation of potential pingo remnants in the southern Connecticut Valley. Abstracts with Programs - Geological Society of America **39**(6):79.

Huvane, J. K. and D. R. Whitehead. 1996. The paleolimnology of North Pond: watershed-lake interactions. Journal of Paleolimnology **16**(3):323-354.

Koteff, C. 1972. Unconsolidated materials, Springfield South Quadrangle, Massachusetts-Connecticut. U.S. Geological Survey, Reston, VA. Open-File Report 72-212. Online. http://pubs.er.usgs.gov/usgspubs/ofr/ofr72212. Accessed December 2009.

Kunk, M. J., J. Blevins-Walker, and R. P. Wintsch. 2001. An eastern provenance for the New Haven Arkose and the Portland Formation of the Hartford and Pomperaug basins: broad terrane revisited. Abstracts with Programs - Geological Society of America **33**(1):81.

Larsen, F. D. 1978. Retreat of an active ice lobe in the Connecticut Valley, Massachusetts. Abstracts with Programs - Geological Society of America **10**(2):72.

Lull, R. S. 1914. New mastodon find in Connecticut. Geological Society of America Bulletin **25**:143.

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

McDonald, N. G. 1982. Paleontology of the Mesozoic rocks of the Connecticut Valley. Pages 143-172 *in* Joesten, R. and S. S. Quarrier, editors. Guidebook for fieldtrips in Connecticut and south-central Massachusetts. New England Intercollegiate Geologic Conference, Amherst, MA. Annual Meeting - New England Intercollegiate Geological Conference 74.

Moecher, D. P., M. A. Cosca, and G. N. Hanson. 1997. Petrologic and $^{40}Ar/^{39}Ar$ geochronological constraints on the middle to late Paleozoic thermotectonic history of the southern Connecticut Valley zone, New England Appalachians. Geological Society of America Bulletin **109**(2):164-175.

Murphy, J. B., J. D. Keppie, and R. D. Nance. 2007. What is the Acadian Orogeny? Abstracts with Programs - Geological Society of America **39**(1):69.

Rittenour, T. M., J. Brigham-Grette, and M. E. Mann. 2000. El Nino-like climate teleconnections in New England during the late Pleistocene. Science **288**(5468):1039-1042.

Rittenour, T., M. E. Mann, and J. Brigham-Grette. 2000. Drainage history of glacial Lake Hitchcock and paleoclimatic implications of late Quaternary sediments and terraces in the central Connecticut Valley, New England. Abstracts with Programs - Geological Society of America **33**(1):14.

Robinson, P. and G. W. Luttrell. 1985. Revision of some stratigraphic names in central Massachusetts. Pages A71-A78 *in* Stratigraphic notes, 1984. U.S. Geological Survey, Reston, VA. Bulletin 1605-A. Online. http://pubs.er.usgs.gov/usgspubs/b/b1605A. Accessed December 2009.

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

Schoch, R. M. and S. G. Lucas. 1982. Pleistocene mammals from Connecticut. Abstracts with Programs - Geological Society of America **14**(1-2):80.

Shufeldt, R. W. 1916. The restoration of the dinosaur *Podokesaurus holyokensis*. Journal of the Washington Academy of Sciences:258-259. [full text available on Google Books]

Thomson, K. S. 2008. The legacy of the mastodon: the golden age of fossils in America. Yale University, New Haven, CT.

Thorson, R. M. and C. A. Schile. 1995. Deglacial eolian regimes in New England. Geological Society of America Bulletin **107**(7):751-761.

Vallentyne, J. R. 1956. Epiphasic carotenoids in post-glacial lake sediments. Limnology and Oceanography **1**(4):252-262.

Wintsch, R. P., J. F. Sutter, M. J. Kunk, J. N. Aleinikoff, and J. L. Boyd. 1993. Alleghanian assembly of Proterozoic and Paleozoic lithotectonic terranes in south central New England: new constraints from geochronology and petrology. Pages H.1-H.30 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States. Geology Department, University of Massachusetts, Amherst, MA. Contribution 67.

Data Sets

Springfield Armory National Historical Site Paleontological Archives
1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Amherst College Museum of Natural History
1974-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by ACM staff; status: Active.

Massachusetts Digital Geologic Map
1998-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by Boston College staff; status: Active. Online. http://tin.er.usgs.gov/geology/state/state.php?state=MA.

Weir Farm National Historic Site

Weir Farm National Historical Site (WEFA) was authorized October 31, 1990. It preserves the home and studio of American Impressionist painter Julian Alden Weir (1852-1919), and some of the surrounding landscapes that inspired his work. Artistic pursuits at Weir Farm have continued since Weir acquired the property in 1882; the studio of the sculptor Mahonri Young (1877-1957) is also at the site, and painter Sperry Andrews (1917-2005) also lived there. WEFA's boundaries were changed November 10, 1998. The site currently encompasses 24 ha (60 acres). Abutting natural areas include 45 ha (110 acres) of open space owned by the Weir Farm Art Center, and another 32 ha (80 acres) of natural space owned by the town of Ridgefield.

Geologic Background

WEFA is located in western Fairfield County, southwestern Connecticut, 5 km (3 miles) east of the Connecticut-New York state line, between Ridgefield and Wilton. Danbury and Bethel are about 15 km (9 miles) to the north, Norwalk is about the same distance to the south, and Bridgeport is about 23 km (14 miles) southeast of the park. The area is part of the Southwest Hills Ecoregion, and is situated in a rolling landscape of rivers, ponds, valleys, and hills. The part of the park east of Nod Hill Road is in the Norwalk River's watershed. Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held for WEFA during July 2007. The geology of WEFA was summarized in a geologic scoping summary by the National Park Service (2008), an internal NPS document.

The geologic history of southwestern Connecticut is dominated by a series of orogenies (mountain-building events) that took place during the Paleozoic (see the appendix for a geological time scale). During these orogenies, microcontinents and other small exotic landmasses were added to eastern North America, and slivers of North America were displaced by faults (Levin 1999). The most important of these orogenies for WEFA is the Taconic Orogeny, which began approximately 475 to 470 Ma (million years ago), during the Ordovician (Karabinos et al. 1998). WEFA is just east of Cameron's Line, a structural feature that separates continental shelf and slope rocks on the west from deep ocean basin rocks on the east; these deep ocean rocks were moved west by Taconic thrust faulting (Amenta and Mose 1985). Some interpretations describe the faulted rocks as a distinct land mass (Hartland Terrane per Amenta and Mose 1985; Iapetus [Oceanic] Terrane per Rodgers 1985; Iapetos Terrane per Spinek 1988). However, others simply describe the rocks as part of a larger New England structure, the Connecticut Valley Synclinorium (Sevigny and Hanson 1993; Wintsch et al. 1993), a trough that formed between volcanic arcs following the Taconic Orogeny, during a period of temporary extension between collisions (Karabinos et al. 2003). The Paleozoic history of New England and eastern New York is a complex topic, and interpretations will likely change.

The period of time from the Taconic Orogeny to the Acadian Orogeny (ending approximately 360 Ma) included nearly continuous generation of magma deep beneath the surface. Metamorphosed igneous units dated to 446 ± 2 Ma and 428 ± 2 Ma are part of the suite of rocks that underlie WEFA and its surroundings (Sevigny and Hanson 1993). Within WEFA, these granitic gneisses intrude older gneisses (NPS 2008). The metamorphosed igneous rocks postdate the thrust faulting (Amenta and Mose 1985), and were metamorphosed to gneisses before 376 Ma, during the Acadian Orogeny (Sevigny and Hanson 1993). Some folding and other deformation may have accompanied the later Alleghenian Orogeny (Spinek 1988; Wintsch et al. 1993), when North America collided with Africa in the last stage of the formation of the supercontinent Pangaea during the Pennsylvanian. The first stages of the breakup of Pangaea occurred in the vicinity with rift basins that formed during the Late Triassic, including the Hartford Basin to the east (see the summaries for Morristown National Historic Park and Springfield Armory National Historic Site in this document for more information on these events). Otherwise, southwestern Connecticut has been relatively geologically quiet, recent seismic activity at Danbury (NPS 2008) notwithstanding.

Glacial activity during the Pleistocene (between 2.59 Ma and approximately 12,000 years ago) scoured and reworked the preexisting topography of New England. The glacial lobe active in the WEFA area was the Hudson-Champlain Lobe (Bierman and Dethier 1986). Connecticut was fully covered by ice as recently as 17,500 radiocarbon years before present, and was only ice-free after 15,500 radiocarbon years before present (Faux and Joyce 2006) (note that radiocarbon dates are not the same as calendar dates, and that radiocarbon years require calibration to yield calendar years. Uncalibrated radiocarbon dates in publications are often denoted with "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. Therefore, dates that are not labeled with "calendar years" or something similar should be assumed to be uncalibrated radiocarbon dates). The last glacial advance overprinted previous glacial activity and left a great quantity of loose sediments. As the ice sheet retreated, vast lakes of glacial meltwater formed in valleys that were blocked by ice and sediment dams. Among these lakes were Glacial Lake Danbury to the north of WEFA in the Housatonic River Valley (Kelley and Thompson 1986), Glacial Lake Albany to the west in what is now the Hudson River Valley, and Glacial Lake Hitchcock to the east in the Connecticut River Valley (Benner et al. 2009). Because WEFA is located in the highlands relatively distant from the large drainage systems, it was not inundated. The glacial lakes were generally active between 17,500 and 13,500 calendar years before present (Rittenour et al. 2000). After the ice sheets and glacial lakes had disappeared, the climate was still harsh (Thorson and McBride 1988; Ashley and Stone 1995; Ashley et al. 1999). A brief period of climatic recovery was interrupted by the cold dry Younger Dryas period between 13,000 and 11,600 years ago (Truebe et al. 2007). Humans first appeared in the area at about this time. They were present in southern New York over 12,500 years ago, and had reached the Connecticut River Valley by at least 10,000 years ago (Curran and Dincauze 1977).

The bedrock geology of WEFA is composed of Ordovician and Silurian gneisses, amphibolites, schists, and granite gneisses (Rodgers 1985; NPS 2008). As these are high-grade metamorphic rocks, and most appear to have derived from intrusive igneous rocks (Sevigny and Hanson 1993), they are very unlikely candidates for fossils. The surficial geology of WEFA is composed of thin glacial till, less than 3 to 5 m (10 to 15 ft) thick (Quaternary) (London 1984; Stone et al. 2005), and outwash deposits (NPS 2008). These deposits are more likely sources for fossils. There are also architectural "outcrops" of local stone on WEFA property, in the form of its many stone walls (NPS 2008).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from within WEFA. However, Quaternary rocks and sediments are known to preserve fossils elsewhere, and future field investigations within the park may uncover fossils in it.

Quaternary rocks and sediments (Pleistocene-Holocene)

The Quaternary deposits of WEFA consist of sand-rich glacial till, and sand and gravel outwash deposits (NPS 2008). These deposits are the most likely sources for fossils at WEFA. Quaternary fossils of western Connecticut and adjacent areas of New York and New Jersey generally fall into two categories: mammal bones, especially those of large extinct mammals like mastodons; and material useful for paleoecological studies, such as pollen, spores, and algal and invertebrate microfossils. A number of sites representing both types are found within approximately 100 km (60 miles) of WEFA (Hartnagel and Bishop 1921; Hay 1923; Deevey 1939, 1943; Jepsen 1960; Curran and Dincauze 1977; Newman 1977; Cotter et al. 1984; Lucas 1993).

The record of Quaternary mammals in Connecticut is sparse, with only eight reports: six mastodons (two from the same location), a caribou, and a deer (Lucas 1993; the report of a Pleistocene horse in this article was later determined to be inaccurate, as the bones were not Pleistocene but modern [Faux and Joyce 2006]). The nearest find consists of a right humerus and left tibia of a caribou from North Haven, 50 km (30 miles) northeast of WEFA, and the only find of any completeness is the Farmington mastodon, found in 1914 near Farmington, 72 km (45 miles) northeast of WEFA. This is a nearly complete skeleton now at the Peabody Museum of Natural History (Lucas 1993). Southeastern New York has a much more

complete record of Quaternary mammals, dominated by mastodons. Within the 100 km/60 mile radius of WEFA, there were at least 48 records of mastodons documented within New York by 1923. The nearest of these is a mastodon tooth found in 1906 at Hartsdale, New York, 40 km (25 miles) southwest of WEFA (Hartnagel and Bishop 1921; Hay 1923).

A number of lake and bog microfossil sites from Connecticut have been described, particularly by Edward S. Deevey Jr. By far the best known of these sites is Lower Linsley Pond, 56 km (35 miles) east of WEFA. Often simply called Linsley Pond, this site has a diverse fossil assemblage spanning approximately the last 12,500 years (Vallentyne and Swabey 1955). Aside from pollen (Deevey 1939), microfossils described from the pond include organic debris, diatoms (algae that encase themselves in silica), other algae, the aquatic moss *Fontinalis*, plant fragments (including leaves and stems), sponges, bryozoans (*Plumatella*), possible eggs of rotifers and gastrotrichs (zooplanktonic animals), *Bosmina* and other cladocerans (crustaceans known as "water fleas"), fragments of insects (particularly midge and alderfly head and jaw parts) (Deevey 1942; Vallentyne and Swabey 1955), and various unidentified objects (the "black spheres," "supposed suctorian cysts," and "wheels" of Vallentyne and Swabey [1955]). Pond and bog sites continue to be an avenue of research (Gaudreau 1982; Geiss et al. 2005; Hugo and Geiss 2007). Finally, freshwater bivalves and gastropods have been found at some sites, including one instance where they were found with a mastodon vertebra (Silliman 1834).

Park Collections

WEFA has no paleontological material in its collections to date.

Cultural Resource Contexts

Humans were present in southern New York over 12,500 years ago, and had reached the Connecticut River Valley by at least 10,000 years ago (Curran and Dincauze 1977). Many ancient human sites also have paleontological material. Several dozen rock shelter sites with evidence of human habitation are known from Connecticut. These sites can have shells, bones of fish, turtles, birds, and mammals, and tools (MacGurdy 1914). Similar fossils are known at other sites in the state (Thorson and McBride 1988). Late Archaic sites of Long Island have charcoal, charred nut fragments, shellfish, bone fragments of food animals, artifacts of bone, and, in at least one case, a dog burial (Wyatt 1977). Stone tools and artifacts are often made of potentially fossiliferous materials, such as chert, dolomite, sandstone, and shale (Calogero and Philpotts 1998), at least some of which were imported from west of Connecticut (Calogero et al. 1999). Given the record, a human-fossil resource association would not be unprecedented. To date, there are no reported examples of a fossil from a cultural resource context at WEFA. 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

- The NPS Geologic Resources Division coordinated a geologic resource inventory scoping session for WEFA during July 2007 (NPS 2008). Fossils are not presently known from WEFA. The most likely potential source for fossils at the park is in the Quaternary deposits.
- Park staff should be encouraged to observe exposed sedimentary material for fossil material while conducting their usual duties. Staff should photodocument and potentially 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. 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).

- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

Literature Cited

Amenta, R. V. and D. G. Mose. 1985. Tectonic implications of Rb-Sr ages of granitic plutons near Cameron's line in western Connecticut. Northeastern Geology **7**(1):11-19.

Ashley, G. M. and J. R. Stone. 1995. The paleoclimate record for southern New England, 15 ka to 12 ka. Abstracts with Programs - Geological Society of America **27**(1):27-28.

Ashley, G. M., J. R. Stone, and D. M. Peteet. 1999. Chronology and paleoclimate implications from radiocarbon-dated paleobotanical records, Connecticut River valley, CT. Abstracts with Programs - Geological Society of America **31**(2):A-2.

Benner, J. S., J. C. Ridge, and R. J. Knecht. 2009. Timing of post-glacial reinhabitation and ecological development of two New England, USA, drainages based on trace fossil evidence. Palaeogeography, Palaeoclimatology, Palaeoecology **272**(3-4):212-231.

Bierman, P. R. and D. P. Dethier, D. P. 1986. Lake Bascom and the deglaciation of northwestern Massachusetts. Northeastern Geology **8**(1-2):32-43.

Calogero, B. L. and A. R. Philpotts. 1998. They came with gifts: material analysis of two cremation cemeteries. Abstracts with Programs - Geological Society of America **30**(1):9-10.

Calogero, B. L., A. R. Philpotts, K. L. Feder, N. F. Bellantoni, S. Paustian, and C. Wickman. 1999. Stone blades caches in Connecticut. Abstracts with Programs - Geological Society of America **31**(2):A-8.

Cotter, J. F. P., E. B. Evenson, L. Sirkin, and R. Stuckenrath. 1984. The interpretation of "bog-bottom" radiocarbon dates in glacial chronologies. Pages 299-316 *in* Mahaney, W. C., editor. Correlation of Quaternary chronologies. GeoBooks, Norwich, United Kingdom.

Curran, M. L. and D. F. Dincauze. 1977. Paleoindians and paleo-lakes: new data from the Connecticut drainage. Annals of the New York Academy of Sciences **288**:333-348.

Deevey, E. S. Jr. 1939. Studies on Connecticut lake sediments. I. A postglacial climate chronology for southern New England. American Journal of Science **237**:691-724.

Deevey, E. S. Jr. 1942. Studies on Connecticut lake sediments. III. The biostratonomy of Linsley Pond. American Journal of Science **240**:233-264, 313-338.

Deevey, E. S. Jr. 1943. Additional pollen analyses from southern New England. American Journal of Science **241**:717-752.

Faux, C. and W G. Joyce. 2008. Connecticut's Pleistocene horse reassigned to the 19th Century. Peabody Museum of Natural History Bulletin **49**(1):131-132.

Gaudreau, D. C. 1982. Holocene vegetational history of central New England and the Hudson River valley. Program and Abstracts - American Quaternary Association **7**:93.

Geiss, C., J. L. Abrams, R. S. Sultan, and E. A. Rodriguez. 2005. Multi-proxy analysis of lake sediments reveals paleo-environmental change in western Connecticut throughout the Holocene. Abstracts with Programs - Geological Society of America **37**(5):72.

Hartnagel, C. A. and S. C. Bishop. 1921. The mastodons, mammoths and other Pleistocene mammals of New York State. New York State Museum and Science Service, Albany, NY. Bulletins 241 and 242. [full text available on Google Books]

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°. Carnegie Institution of Washington Publication 322. [available for viewing or downloading through Internet Archive at http://www.archive.org/details/pleistoceneofnor00hayouoft]

Hugo, C. and C. E. Geiss. 2007. An investigation of potential pingo remnants in the southern Connecticut Valley. Abstracts with Programs - Geological Society of America **39**(6):79.

Jepsen, G. L. 1960 [1962 and 1964 editions as well]. A New Jersey mastodon. New Jersey State Museum, Trenton, NJ. Bulletin 6.

Karabinos, P., S. D. Samson, J. C. Hepburn, and H. M Stoll. 1998. Taconian Orogeny in the New England Appalachians: collision between Laurentia and the Shelburne Falls Arc. Geology **26**(3):215-218.

Karabinos, P., H. M. Stoll, and J. C. Hepburn. 2003. The Shelburne Falls arc – lost arc of the Taconic orogeny. Pages B3-1-B3-17 *in* Brady, J. and J. Chaney, editors. New England Intercollegiate Geologic Conference, Amherst, MA.

Kelley, G. C. and W. B. Thompson. 1986. Pleistocene stratigraphy of northwestern Connecticut. Pages 158-167 *in* Cadwell, D. H., editor. The Wisconsinan Stage of the First Geological District, eastern New York. New York State Museum and Science Service, Albany, NY. Bulletin 455.

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* Lucas, S. G., 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, NM. Bulletin 34. Online. http://nature.nps.gov/geology/paleontology/pub/fossil_conference_7/9%20Kenworthy.pdf. Accessed September 2009.

Levin, H. L. 1999. The Earth through time (6th edition). Saunders College Publishing, Fort Worth, TX.

London, E. H. 1984. Surficial geologic map of the Bethel quadrangle, Connecticut. U.S. Geological Survey, Reston, VA. Miscellaneous Field Studies Map 1519. Scale 1:24,000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_7313.htm. Accessed December 2009.

Lucas, S. G. 1993. A Pleistocene horse from Connecticut. The Mosasaur **5**:43-46.

MacCurdy, G. G. 1914. The passing of a Connecticut rock shelter. American Journal of Science **38**(228):511-522.

National Park Service, Geologic Resources Division. 2008. Geologic resource evaluation scoping summary: Weir Farm National Historical Site. National Park Service, Geologic Resources Division, Denver, CO. Online. http://www.nature.nps.gov/geology/inventory/publications/s_summaries/WEFA_scoping_summary_2008-0717.pdf. Accessed December 2009.

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.

Rittenour, T. M., J. Brigham-Grette, and M. E. Mann. 2000. El Nino-like climate teleconnections in New England during the late Pleistocene. Science **288**(5468):1039-1042.

Rodgers, J. 1985. Bedrock geological map of Connecticut. Connecticut State Geological and Natural History Survey, Hartford, CT. Connecticut Natural Resources Atlas Series. Scale 1:125,000. Online. http://ngmdb.usgs.gov/Prodesc/proddesc_54245.htm. Accessed December 2009.

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

Sevigny, J. H. and G. N. Hanson. 1993. Orogenic evolution of the New England Appalachians of southwestern Connecticut. Geological Society of America Bulletin **105**(12):1591-1605.

Silliman, B. 1834. Vertebral bone of a mastodon. American Journal of Science **27**:165-166.

Spinek, T. R. 1988. Polydeformed and polymetamorphosed melange within the Cameron's Line thrust sheet, southwestern Connecticut. Abstracts with Programs - Geological Society of America **20**(1):71.

Stone, J. R., J. P. Schafer, E. H. London, M. L. DiGiacomo-Cohen, R. S. Lewis, and W. B. Thompson. 2005. Quaternary geologic map of Connecticut and Long Island Sound Basin. U.S. Geological Survey, Reston, VA. Scientific Investigations Map 2784. Scale 1:125,000. Online. http://pubs.er.usgs.gov/usgspubs/sim/sim2784. Accessed December 2009.

Thorson, R. M. and K. McBride. 1988. The Bolton Spring Site, Connecticut: early Holocene human occupation and environmental changes in southern New England. Geoarchaeology **3**(3):221-234.

Truebe, S. A., W. W. Oswald, D. R. Foster, and E. Doughty. 2007. Lake-sediment evidence for variation in mid-Holocene climate and vegetation in western Massachusetts. Eos **88**(supplement to 25):JA298. Abstract PP43C-01.

Vallentyne, J. R. and Y. S. Swabey. 1955. A reinvestigation of the history of Lower Linsley Pond, Connecticut. American Journal of Science **253**:313-340.

Wintsch, R. P., J. F. Sutter, M. J. Kunk, J. N. Aleinikoff, and J. L. Boyd. 1993. Alleghanian assembly of Proterozoic and Paleozoic lithotectonic terranes in south central New England: new constraints from geochronology and petrology. Pages H.1-H.30 *in* Cheney, J. T. and J. C. Hepburn, editors. Field trip guidebook for the northeastern United States. Geology Department, University of Massachusetts, Amherst, MA. Contribution 67.

Wyatt, R. J. 1977. The Archaic on Long Island. Annals of the New York Academy of Sciences **288**:400-410.

Additional References

Aleinikoff, J. N., R. P. Wintsch, R. P. Tollo, D. M. Unruh, C. M. Fanning, and M. D. Schmitz. 2007. Ages and origins of rocks of the Killingworth Dome, south-central Connecticut: implications for the tectonic evolution of southern New England. American Journal of Science **307**(1):63-118.

Clarke, J. W. 1956. Geology of the Danbury and Bethel quadrangles, Connecticut. Geological Society of America Bulletin **67**(12, Part 2):1812.

Connally, G. G. and L. A. Sirkin. 1973. Wisconsinan history of the Hudson-Champlain Lobe. Pages 47-69 *in* Black, R. F., R. P. Goldthwait, and H. B. Willman, editors. The Wisconsinan Stage. Geological Society of America, Boulder, CO. Memoir 136.

Davis, M. B. 1969. Climatic changes in southern Connecticut recorded by pollen deposition at Rogers Lake. Ecology **50**(3):409-422.

Hall, L. M. 1976. Preliminary correlation of rocks in southwestern Connecticut. Pages 337-349 *in* Page, L. R., editor. Contributions to the stratigraphy of New England. Geological Society of America, Boulder, CO. Memoir 148.

Kelley, G. C. 1977. Late Pleistocene and Recent geology of the Housatonic River region in northwestern Connecticut. U.S. Geological Survey, Reston, VA. Open-File Report 77-545. Online. http://pubs.er.usgs.gov/usgspubs/ofr/ofr77545. Accessed December 2009.

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

Moecher, D. P., M. A. Cosca, and G. N. Hanson. 1997. Petrologic and $^{40}Ar/^{39}Ar$ geochronological constraints on the middle to late Paleozoic thermotectonic history of the southern Connecticut Valley zone, New England Appalachians. Geological Society of America Bulletin **109**(2):164-175.

Murphy, J. B., J. D. Keppie, and R. D. Nance. 2007. What is the Acadian Orogeny? Abstracts with Programs - Geological Society of America **39**(1):69.

Ridge, J. C., M. R. Besonen, M. Brochu, S. L. Brown, J. W. Callahan, G. J. Cook, R. S. Nicholson, and N. J. Toll. 1999. Varve, paleomagnetic, and ^{14}C chronologies for late Pleistocene events in New Hampshire and Vermont (U.S.A.). Geographie Physique et Quaternaire **53**(1):79-107.

Schoch, R. M. and S. G. Lucas. 1982. Pleistocene mammals from Connecticut. Abstracts with Programs - Geological Society of America **14**(1-2):80.

Schuchert, C. 1914. *Mammut americanum* in Connecticut; with a note on the Farmington specimen, by Richard S. Lull. American Journal of Science **37**(220):321-330.

Stewart, T. T. 1828. Teeth of the mastodon. American Journal of Science and Arts **14**(1):187-188.

Thompson, L. 1994. Discovery of the American mastodon (*Mammut americanum*) in New York State: 1921-1994. Thesis. University of Rochester, Rochester, NY.

Thorson, R. M. and C. A. Schile. 1995. Deglacial eolian regimes in New England. Geological Society of America Bulletin **107**(7):751-761.

Vallentyne, J. R. 1956. Epiphasic carotenoids in post-glacial lake sediments. Limnology and Oceanography **1**(4):252-262.

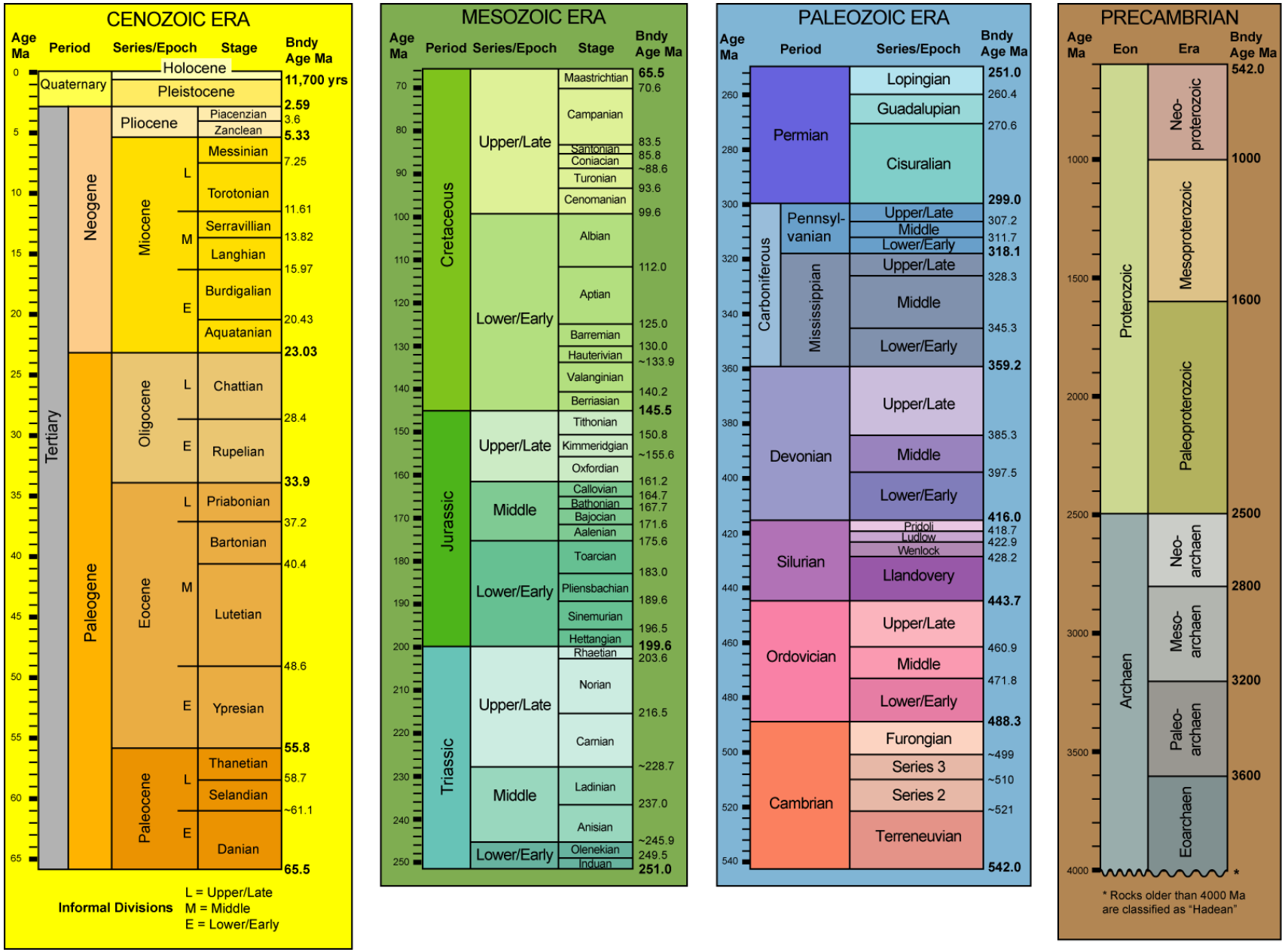
Whitehead, D. R., H. Rochester Jr., S. W. Rissing, C. B. Douglass, and M. C. Sheehan. 1973. Late glacial and postglacial productivity changes in a New England pond. Science **181**(4101):744-747.

Data Sets

Weir Farm National Historical Site Paleontological Archives
1990–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Weir Farm National Historical Site Digital Geologic Maps
2008-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online.
http://science.nature.nps.gov/nrdata/quickoutput.cfm?type=ds&cat=geology&key=GRE&parkcode=WEFA.

Connecticut Digital Geologic Map
2000-present. (geologic map data; electronic files; GIS metadata; associated report). Originated by U.S. Geological Survey and Connecticut Geological and Natural History Survey staff; status: Active. Online.
http://tin.er.usgs.gov/geology/state/state.php?state=CT.



Appendix: Geologic Time Scale. *Ma = Millions of year old. Bndy Age = Boundary Age*. Colors are standard USGS colors for geologic maps. Modified from 2009 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/).

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