National Park Service
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Natural Resource Program Center

Paleontological Resource Inventory and Monitoring
Great Lakes Inventory and Monitoring Network

Natural Resource Technical Report NPS/NRPC/NRTR—2008/120



ON THE COVER
An assortment of GLKN fossils.
Top: Eleven conodonts (tooth-like elements of enigmatic marine organisms; important for regional and global correlation) from the Munising and Au Train formations in Michigan. Many of these conodonts were found within PIRO. Scales vary, but conodonts are shown at 30-60 times actual size. Image courtesy James Miller (Missouri State University).

Bottom: A Petoskey Stone in the collections of Augustana College (Illinois). Petoskey Stones are fossils of colonial rugose coral *Hexagonaria percarinata* and also the state stone of Michigan. They commonly wash up on the shores of SLBE. Specimen is approximately 9 cm by 9 cm. Photo from senior author's collection.

See the individual park sections for additional information.

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NOTE:
This report provides baseline paleontological resource data to National Park Service administration and resource management staff. The report contains information regarding the location of non-renewable paleontological resources within NPS units.
It is *not* intended for distribution to the general public.

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U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

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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 more than 190 National Park Service units. Despite the abundance and diversity of these resources throughout the NPS, 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 appropriate management of these resources. This report is a summary of paleontological resources of the parks served by the Great Lakes Network (GLKN). The summary was compiled through extensive literature review and interviews with park staff and professional geologists and paleontologists. Preliminary paleontological resource management recommendations are also included for each park. Similar summaries have been prepared for 18 other NPS Inventory and Monitoring (I&M) Networks. The National Inventory and Monitoring Program provided funding to complete these paleontological resource summaries for each of the remaining networks.

The Great Lakes Network parks lie within two adjacent physiographic provinces within the north-central portion of the United States: the Superior Upland Province, which is the southern portion of the Canadian Shield, and the Eastern Lake section of the Central Lowland Province. The Northern Great Plains I&M Network borders the GLKN to the west, with the Heartland Network to the south. Canada and the Great Lakes form the northern and eastern boundaries of the network. All but three of the parks in this network are directly associated with either Lake Michigan or Lake Superior.

The GLKN parks share a common geologic history of continental rifting, volcanism and glaciation. Some of the oldest rocks in the GLKN extend back to the Archaen Eon, approximately 2.7 billion years ago. Rocks from the Archean and Proterozoic Eons (both "Precambrian") known from this network were primarily igneous, marine, and shallow lacustrine deposits. The remains of ancient organisms were presumably preserved in these marine and lacustrine sediments; however, most life forms from this age were simple creatures lacking easily fossilized hard parts. These units were also subjected to folding and metamorphism over their long history. The forces associated with uplift and glaciation, along with great spans of geologic time, contributed to the alteration or destruction of fossils contained within these "Precambrian" sedimentary rocks. Fossils are far better known within the Great Lakes region from younger sedimentary rocks of the Paleozoic Era (542-251 million years old) and Pleistocene Epoch (approximately 11,477 years - 1.8 million years old). These fossil remains consist typically of invertebrate and trace fossils from early to mid-Paleozoic rocks. The fossilized remains of mammals, fish and mollusks along with wood, pollen and spores preserved in the deposits of Pleistocene to Holocene epochs occur in several of the parks. Many of the parks fossil resources wash in from other locations and can vary in age. These resources are often the easy target for "beachcombing" and can be a resource management issue.

Collectively the paleontological resources of the Great Lakes Network parks are somewhat rare and isolated but represent opposite ends of the geologic time scale. Further paleontological resource inventories will serve to expand this ever-widening base of paleontological knowledge represented throughout the National Park Service. Although more than 190 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.

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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.

The establishment of baseline paleontological resource data is essential for the appropriate management of fossils found within National Park Service (NPS) areas. Although more than 190 NPS areas 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 Great Lakes I&M Network (GLKN).

The Great Lakes Network serves nine National Park Service areas in Indiana, Michigan, Minnesota and Wisconsin shown in Figure 1: Apostle Islands National Lakeshore (Wisconsin, APIS), Grand Portage National Monument (Minnesota, GRPO), Indiana Dunes National Lakeshore (Indiana, INDU), Isle Royale National Park (Michigan, ISRO), Mississippi National River and Recreation Area (Minnesota, MISS), Pictured Rocks National Lakeshore (Michigan, PIRO), Saint Croix National Scenic Riverway (Minnesota and Wisconsin, SACN), Sleeping Bear Dunes National Lakeshore (Michigan, SLBE), and Voyageurs National Park (Minnesota, VOYA). All together, the parks of the GLKN encompass more than 445,000 ha (1.1 million acres) and hosted more than 4.5 million visitors in FY2006.

The GLKN parks are unique in the NPS as they contain some of the oldest rocks on the North American continent, which date back to 2.7 billion years ago, but they also contain an important record of glacial advance and retreat over the last tens of thousands of years during the last "Ice Age". Another common geological thread through the network is the Keweenawan Rift. More than 1 billion years ago, what is now the North American continent was being ripped apart by tectonic forces within the earth. The parks of the Great Lakes region occupy the area where this rifting originated. While the rifting event failed to pull the continent apart, it created a great rift valley that allowed deposition of the thick Cambrian, Ordovician, Silurian, and Devonian marine units which preserve fossils in many of these NPS units. Likewise, the Pleistocene and Holocene deposits within many parks contain fossils documenting ecosystem changes associated with the advance and retreat of glacial ice.

While none of the parks were established specifically for paleontological resource stewardship, fossils are known from the geologic deposits and/or park collections of eight GLKN parks including Apostle Islands National Lakeshore, Indiana Dunes National Lakeshore, Isle Royale National Park, Mississippi National River and Recreation Area, Pictured Rocks National Lakeshore, Sleeping Bear Dunes National Lakeshore, Saint Croix National Scenic Riverway and Voyageurs National Park. APIS contains the remains of Proterozoic trace fossils, with coral and brachiopod remains preserved in rocks transported in glacial till. Transported crinoid remains are found at INDU, along with wood and pollen preserved in Holocene deposits. Another example of transported fossils can be seen in ISRO, where Paleozoic invertebrates were brought in with Pleistocene glacial till deposits, and pollen and spores are preserved in the Holocene aged deposits. MISS and SACN preserve similar fauna of marine invertebrate and trace fossils from the early to mid-Paleozoic. Pleistocene mammals have been found from the MISS and SACN corridors. Upper Cambrian to Ordovician-aged rocks at PIRO preserve the remains of trilobites, conodonts, brachiopods and ammonites, along with trace fossils. Petoskey stones, rugose coral from the Devonian, may be found washed up on the Lake Michigan shore of SLBE, which also preserves a wide

range of mollusk and mammalian fauna within its Pleistocene dune deposits. Finally, VOYA contains coral fossils from an unknown location in the park collections.

Shorelines are a common resource to all of the GLKN parks and many have documented, or the potential for, fossil discoveries along these shorelines. Such "loose" fossils may be a resource management issue at these GLKN parks. In this light, the SLBE section of this report contains a section written by park staff highlighting their efforts to manage "beachcombing" fossil collection.

Collectively, the paleontological resources of the parks served by the GLKN contribute much to a greater understanding of the history of life on earth. Continued paleontological resource inventories will expand this ever-widening base of paleontological knowledge represented throughout the National Park Service. Although more than 190 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 GLKN network parks. Map courtesy GLKN staff.

Paleontological Resource Inventory Strategies and Methodology

To better document fossil occurrences and to provide baseline paleontological resource data in 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 & 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 (the first park to have an inventory completed), Amistad National Recreation Area (in review May 2008), Arches National Park, Bighorn Canyon National Recreational Area, Death Valley National Park, Grand Teton National Park, Santa Monica National Recreation Area, Walnut Canyon National Monument, and Zion National Park.

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 increased the number of parks with documented 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: fossils can be preserved in the marine limestones in which caves develop; or the remains of Pleistocene/Holocene animals and plants that lived, died or were transported into caves after death. Servicewide thematic inventories have also been initiated for fossil fish (Hunt et al. 2006) and fossils that have been found in cultural resource contexts (Kenworthy and Santucci 2006).

Inventory and Monitoring Network 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 19 of the 32 I&M Networks including: the Appalachian Highlands, Chihuahuan Desert, Eastern Rivers and Mountains, Greater Yellowstone, Great Lakes (this report), Gulf Coast, Mediterranean Coast, Mid-Atlantic, Mojave Desert, National Capital Region, Northeast Coastal and Barrier, Northern Colorado Plateau, Pacific Island, Rocky Mountain, San Francisco Bay Area, Sierra Nevada, Southern Plains, Southwestern Alaska, and Upper Columbia Basin networks. Research for summaries of the Arctic, Northern Great Plains, Southeast Alaska, Southeast Coast, and South Florida/Caribbean networks are currently underway (May 2008). NPS I&M Program funding is targeted to complete paleontological resource summaries for the remaining networks by FY2009. 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 2002-2006. 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, or paleontological technicians 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 millions of 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 USGS Library in Reston, Virginia is a premier repository for geologic publications, and houses most of the publications obtained for the network-based paleontological resource inventories. Museum libraries like that of the Smithsonian Institution's National Museum of Natural History, and university libraries also provide access to a wide range of geological and paleontological publications. Individual state geological surveys are also excellent sources of information as are geologists familiar with local geology and paleontology.

The literature search also includes unpublished material (gray) literature from searches of individual 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 United States Geological Survey (USGS) and state 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). The USGS National Geologic Map Database (NGMDB; see citation below in Additional References section) lists maps for a given geographic area or place name and provides contact information for obtaining maps. Geologic maps show the types of rocks and the associated geological formations within a park area. These maps alone often indicate 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 in clearing up nomenclatural confusion. 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.

The information from these various sources for each park is then compiled and summarized in a written report and developed into individual datasets. 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.

The paleontological resource inventory reports synthesize information regarding the scope and significance of fossils documented from each 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 in Figure 2). 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. Fossil groups may occur primarily, or only, under specific environmental conditions (temperature ranges, aquatic or terrestrial habitats, etc.). Thus many fossils may be indicators of past environmental conditions. The reports 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.

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. However, the paleontological research for a particular park may vary widely from an incidental fossil discovery to over a century of intensive paleontological investigations. The inventory reports include information on the history of paleontological research, descriptions of current cooperative projects, identification of any museums or universities serving as repositories for park fossils, and a comprehensive list of publications related to paleontological research associated with the park. 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 bibliographies (Additional References). The cooperative projects section highlights paleontological resources projects, if any, that the park has funded or supported. Formal datasets are established for known associated paleontological collections, research, or activities.

Paleontological Resource Management Legislation and Guidance

I&M Network reports such as this one 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. For example, 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*. Another legislative protection for paleontological resources is found in the NPS Omnibus Management Act of 1998. Section 207: "Information concerning the nature and specific location of…paleontological objects within the units of the National Park System…may be withheld from the public source…," thus safeguarding paleontological locality information from requests under the Freedom of Information Act.

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 & 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 is assembling a geologic resource

monitoring manual that includes chapters on various geologic resources, including in situ paleontological resources, 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. Publication is expected by late 2008. Contact the Geologic Resources Division for more information or to obtain a copy of the report when it is available.

Knowledge of the fossil record is only as the most recent 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. The baseline information provided in these reports may pave the way for future fossil discoveries in NPS areas.

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General GLKN Information

GLKN I&M Network: http://www.nature.nps.gov/im/units/glkn/index.cfm

Geological Survey Websites

Many publications are available for download at geological survey websites.

Indiana Geological Survey (Bloomington): http://igs.indiana.edu/
Michigan Office of Geological Survey (Lansing): http://michigan.gov/deqogs
http://michigan.gov/deqgeologyinmichigan (out-of-print-publications)
Minnesota Geological Survey (St. Paul): http://www.geo.umn.edu/mgs/
Wisconsin Geological and Natural History Survey (Madison): http://www.uwex.edu/wgnhs/
Institute on Lake Superior Geology: http://www.lakesuperiorgeology.org/

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

U.S. Geological Survey Library Catalog: http://library.usgs.gov/
Smithsonian Institution Libraries Catalog: http://www.siris.si.edu/

Museums

University of Michigan Museum of Paleontology: http://www.paleontology.lsa.umich.edu/
University of Wisconsin-Madison Museum of Geology: http://www.geology.wisc.edu/~museum/
Field Museum of Natural History (Chicago): http://www.fieldmuseum.org/
Smithsonian National Museum of Natural History Dept. of Paleobiology: http://paleobiology.si.edu/

Resource Management/Legislation Documents

NPS 2006 Management Policies (§1.4; Park Management): www.nps.gov/policy/mp2006.pdf
NPS 2006 Management Policies (§4.8.2.1; Paleontological Resources): www.nps.gov/policy/mp2006.pdf
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 Paleontology Program: http://www.nature.nps.gov/geology/paleontology/
NPS Park Paleontology Newsletter (1998-2004):
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.
U.S. Geological Survey Geologic Terms Glossary:
http://wrgis.wr.usgs.gov/docs/parks/misc/glossarya.html
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/
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, description of physiographic provinces: http://tapestry.usgs.gov/Default.html

Apostle Islands National Lakeshore

On September 26, 1970, Apostle Islands National Lakeshore (APIS) was established to preserve the unique flora and fauna and the physiographic and geologic conditions prevailing on the Apostle Islands within the lakeshore. The park now protects 17,062 ha (42,161 acres) of land on 21 of 22 islands that compose the Apostle Islands Archepelago and 27,211 acres of park managed waters surrounding the islands. Within the park, more than 14,000 ha (35,000 acres or 80%) are designated as a Wilderness Area, all of which is on islands as opposed to the mainland. This land is managed under the Wilderness Act of 1964.

Geologic Background

Like most parks in the GLKN, geologic units exposed within APIS are from opposite ends of the geologic time scale (see Figure 2). Three Proterozoic (known informally as the "Precambrian") geological formations are known from the 22 islands that make up the Apostle Islands area: the Orienta, Devils Island, and Chequamegon Formations, all belonging to the approximately 1 billion year old fluvial Bayfield Group (Nuhfer and Dalles 2004). Paleozoic and Mesozoic rocks are missing in the region. Therefore the other geologic units in the park are much younger (tens of thousands of years old) and are associated with the glacial history of the region. These units include the Jardine Creek, Hanson Creek and Douglas tills (Nuhfer and Dalles 2004). Nuhfer and Dalles (2004) provide a geologic guide to APIS, including excellent photos and a basic geologic map of the islands. Trace fossils were recently discovered within the Devils Island formation as described below (Havholm 2007). They are currently being analyzed. This is the first time fossils have been documented from the Bayfield Group within APIS. Fossils are not known from glacial deposits within APIS. Some enigmatic fossils are within park collections, however.

Potential Sources of Paleontological Resources

Bayfield Group (Proterozoic)

The Proterozoic Bayfield Group is comprised of three formations, from oldest to youngest: the Orienta Sandstone, Devils Island Formation (named for exposures on Devils Island within APIS), and the Chequamegon Formation. The Orienta is the oldest formation known in the park, and is exposed along the western edge of the Bayfield Peninsula (near Bark and Siskiwit Bays), and on Eagle and Sand islands. The Devils Island Formation is composed of sandstones that can be seen on Devils and Sand islands and along the western portion of the Bayfield Peninsula near Squaw Bay. The Chequamegon Formation dominates the majority of the islands within the Apostle Islands National Lakeshore and also consists of channel sandstone deposits (Nuhfer and Dalles 2004). These units are primarily fluvial (river) or lacustrine (lake) deposits associated with the Mid-Continent Rift (or Keweenawan) that occurred approximately 1.1 billion years ago. Rocks of the Bayfield Group, especially the Devils Island formation, form the dramatic sea cliffs, caves, and stacks the Apostle Islands are famous for. The Bayfield Group is also the source of the "brownstone" that is a popular building stone in the area and was used to construct the park's Bayfield visitor center (Nuhfer and Dalles 2004).

Units of the Bayfield Group display well-preserved sedimentary structures such as ripple marks, mudcracks, crossbeds, and soft sediment deformation (associated with settling of the wet sand after deposition) as photographed and described in Nuhfer and Dalles (2004). However, body fossils are not yet known from the Bayfield Group and are unlikely. Potential trace fossils were recently discovered within the Devils Island Formation of the Bayfield Group within APIS and sent to Dr. Steve Hasiotis (University of Kansas) for further identification (Havholm 2007; J. Van Stappen, APIS Natural Resources Branch Chief. pers. comm., April 2008). Interestingly, potential microbial fossils are known from outside of the GLKN but in rocks similar in age to those of Grand Portage National Monument (See GRPO section of this report).

Glacial and Postglacial Deposits (Upper Pleistocene-Holocene)

The Pleistocene ("Ice Age") and Holocene-aged tills known from the park are linked to the glacial advances which helped to sculpt the park's scenery. Tills are mixtures of variably sized material (clay, silt, sand, gravel, etc.) deposited directly by glaciers. There are three different tills within the park. From oldest to youngest, the tills are the Jardine Creek Till (approximately 14,000 years old), Hanson Creek Till (12,000 years old), and the Douglas Till (10,200 years old) (e.g. Need and Johnson 1984, Nuhfer and Dalles 2004). The Jardine Creek is part of the Copper Falls Formation while the Hanson Creek and Douglas tills are part of the Miller Creek Formation.

Need and Johnson (1984) studied the glacial deposits along Lake Superior shoreline immediately west of APIS, from Wisconsin Point to Bark Point. The Jardine Creek till directly overlies the Proterozoic bedrock in the area demonstrating the vast amount of geologic time missing from the rock record of APIS, and indeed much of the GLKN. Need and Johnson's (1984) reported ages for the various tills; however, they noted that the ages were not obtained from direct sampling of organic material but from regional correlations. Therefore, it is unlikely that fossils would be discovered within the Pleistocene glacial deposits of the park. However, as noted below, six fossils that may have been part of this glacial till are within park collections.

Davis et al. (1998) describe pollen history and paleoenvironmental changes recorded in sediment cores obtained within APIS at Stockton and Brander bogs, Hemlock Lake, and Lake Mary. These records date back approximately 9,500 years and record changes following retreat of the last major ice advance.

Park Collections

The only known fossils currently in AIPS collections are six pieces containing the remains of corals and brachiopods, of uncertain provenance. They are believed to have been transported into the park from glaciers that were once moving over the area (S. Mackreth, APIS Ranger, pers. comm. 2008). Three of these fossils are from the Bayfield Harbor, one from Oak Island, one from Sand Island, and one from Michigan Island. The largest of the fossils, a block of limestone (mostly likely Paleozoic in age) with visible fossil invertebrates (brachiopods), is not accessioned into the park collection due to the its uncertain provenance. It was left on the doorstep of the ranger cabin on Manitou Island in the off-season (S. Mackreth, APIS Ranger, pers. comm. 2008). Limestones with remnant fossils are occasionally found on the park's beaches, similar to those at Isle Royale National Park (see ISRO section of this report). Jim Nepstad (APIS Chief of Planning and Resource Management, pers. comm., April 2008) also indicated he has seen fossils within glacially transported material on Long Island. Other GLKN parks such as INDU, ISRO, PIRO, and SLBE also have documented occurrences of fossils washing up on their shorelines. The SLBE section of this report summarizes that park's efforts to manage this resource. The trace fossils from the Devils Island Formation mentioned above are currently on loan to University of Wisconsin (LaCrosse) for identification but will be added to the park's collection upon return (J. Van Stappen, pers. comm., April 2008).

Various American Indian tribes from the Midwest are known to have collected and/or traded paleontological resources (e.g. Mayor 2005). Such occurrences are documented in at least two NPS sites, Hopewell Culture National Historical Park in Ohio (Kenworthy and Santucci 2006) and near Effigy Mounds National Monument in Iowa. Similar occurrences are not yet known within APIS in association with the Ojibwe (J. Richner, MWAC Archeologist, pers. comm., January 2008)

Paleontological Resource Management, Preliminary Recommendations

- Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, have not yet been conducted for Apostle Islands National Lakeshore. Paleontological resources were recently discovered from the Devils Island Formation within the park. In addition, there are six fossils in

- If the provenance of the fossils from the collection can be determined, the practicality of a paleontological resource management plan can be evaluated. The NPS Geologic Resources Division would be able to assist with identification of fossils and developing management strategies. A forthcoming (2008) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management along hydrological features.
- Park staff should be encouraged to observe exposed cliffs, other erosional bedrock, and streams for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Many other GLKN parks (INDU, ISRO, PIRO, SLBE) have documented fossils washing up or being discovered along shorelines. The SLBE section of this report summarizes one park's methodology for management of fossil "beachcombing" which may be applicable to APIS.
- The NPS Geologic Resources Division is a source of assistance regarding paleontological resource management and/or interpretation at APIS.

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Data Sets

Apostle Islands National Lakeshore Paleontological Archives

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

Apostle Islands National Lakeshore Museum Collections

1971-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by APIS staff; status: Active.

Grand Portage National Monument

Grand Portage National Monument (GRPO) was established in 1958 to commemorate and preserve a premier site and route of the 18th century fur trade that led to pioneering international commerce and exploration in North America as well as cultural contact between Ojibwe and other native societies and the North West Company partners, clerks and canoe-men. The monument was also established to work with the Grand Portage Band of Lake Superior Chippewa (Ojibwe) in preserving and interpreting the heritage and lifeways of the Ojibwe people. Currently the monument protects 287 ha (710 acres) in northeastern Minnesota within an approximately 14 km (8.5 mile) corridor that extends from Minnesota's north shore of Lake Superior to the border of Canada.

Geologic Background

Like most parks in the GLKN, geologic units exposed within GRPO are from opposite ends of the geologic time scale (see Figure 2). Most of the bedrock in the park is the Paleoproterozoic ("Precambrian") Rove Formation, approximately 1.8 billion years old. Mesoproterozoic igneous (previously molten) rocks have intruded the Rove Formation. Paleozoic and Mesozoic rocks are missing in the region. Therefore, the other geologic units in the park are much younger (few hundred thousand years) and are associated with the glacial history of the region. Fossils are not known from within GRPO and given the age of the bedrock, are not likely. Nevertheless, the Rove Formation has produced interesting paleontological resources outside of the park and the paleoecological history of glaciations in the GRPO area is recorded in a number of publications. The Mesoproterozoic (approximately 1.1 billion years old) igneous dikes do not preserve fossils due to their intrusive (emplaced underground) and molten origin.

The geology of the park was recently (2001) studied by William Cannon and Laurel Woodruff of the USGS (bedrock geology) and Brian Phillips of Lakehead University (glacial geology) and detailed in reports to the park. This study formed the basis for the Geologic and Cultural History of Grand Portage field trip report (Cannon et al. 2007). Cannon et al. (2007) also included a larger scale geologic map of the park and surrounding area and highlight the connection between the "Grand Portage" and the underlying Proterozoic and glacial geology. Miller et al. (2001) produced a small scale (1:200,000) regional map of the Duluth Complex in northeastern Minnesota. Cannon et al. (2007) summarized previous geological work in the GRPO region by Grout and Schwartz (1933), Grout et al. (1959), and Morey (1969).

Potential Sources of Paleontological Resources

Rove Formation (Paleoproterozoic)

The Paleoproterozoic (approximately 1,800 million years old) Rove Formation forms the bedrock beneath nearly all of GRPO (Cannon et al. 2007; Miller et al. 2001). The formation is characterized by a variety of sedimentary rocks (greywacke, argillite, conglomerate, quartzite and carbonates) deposited in an ancient basin associated with the Keweenawan Rift. Interestingly, given the age of the rocks, a number of soft sediment deformation structures are preserved suggesting a significant slope and subaqueous deposition (Cannon et al. 2007 citing Morey 1969). Within GRPO, most of the Rove Formation is composed of the younger greywacke unit and it is well exposed along Highway 61 (Cannon et al. 2007). Many of the sedimentary structures have been obliterated by metamorphism (increased temperature and/or pressure).

Paleontological resources would not be expected within such an ancient rock unit. However, possible fossil evidence has been found within the Rove Formation outside of GRPO. Robbins et al. (1985) describe microfossils that resemble fecal pellets of microorganisms such as zooplankton from many Proterozoic-age localities across the globe. Rove Formation samples were studied from the Gunflint district in Canada and yielded examples of these fecal pellet microfossils. If these are indeed fossils of

zooplankton, they are among the earliest fossil evidence of metazoan (animal) life at about 1.9 billion years old (Robbins et al. 2001). Grout et al. (1959) mention "carbonaceous organic matter" in Rove Formation argillite, but there is no mention of identifiable fossils within the Rove. Grout et al. (1959) do note algal structures (probably stromatolites) in the underlying Gunflint Formation. In addition, Winter and Knauth (1989) used carbon isotopic signatures to suggest the presence of anaerobic bacteria in Rove Formation sediments surrounding Lake Superior.

Addison et al. (2005) mention microbial fossil evidence from the underlying (older) Gunflint Formation, which is not exposed within GRPO. They describe the Rove Formation as "fossil-absent" suggesting a possible bolide (extraterrestrial material such as a comet or asteroid) impact-caused extinction event. The Sudbury impact structure in Ontario is the second largest impact site on earth (Addison et al. 2005 citing Spray et al. 2004) and occurred just before deposition of the Rove Formation.

Glacial Deposits (Upper Pleistocene)

Glacial lake beds cover much of the bedrock mapped within GRPO (Miller et al. 2001 and Grout et al. 1959). Paleoecological material (fossils or ancient pollen) is occasionally preserved in such lake deposits as described in northeastern Minnesota by Huber (1992). However neither Sharp (1953) nor Grout et al. (1959) mention any paleontological resources from these glacial lake beds. Huber (1993) studied an archeological site at East Bearskin Lake approximately 56 km (35 miles) west of GRPO. Using algae and pollen preserved within the lake sediments, Huber was able to reconstruct a vegetational change from tundra to mixed conifer-hardwood forest following ice retreat some 10,500-7,000 years ago. Huber (1992) summarized additional paleoecological discoveries from 20 lakes and bogs in northeastern Minnesota. None are within Cook County or near GRPO, however. The pollen assemblages studied detail the biological response to ice retreat over the last 14, 000 years from tundra to conifer woodland.

Similar paleoecologial resources are not yet described near GRPO. Evidence for ancient shoreline variation is present within the park and has important implications for archeological discoveries since early Paleo-Indians lived along river mouths and shorelines (Cannon et al. 2007).

Park Collections

There are no known fossil specimens within GRPO park collections (D. Cooper, GRPO Park Ranger, pers. comm., November 2007; K. Byrne, HFC Curator, pers. comm. January 2008). Various American Indian tribes from the Midwest are known to have collected and/or traded paleontological resources (e.g. Mayor 2005). Such occurrences are documented in at least two NPS sites, Hopewell Culture National Historical Park in Ohio (Kenworthy and Santucci 2006) and near Effigy Mounds National Monument in Iowa. Similar occurrences are not yet known within GRPO in association with the Ojibwe (D. Cooper; J. Richner, MWAC archeologist, pers. comm., December 2007). Woolworth (n.d.) documented archeological items from the Northwest Trading Company within GRPO and noted a number of animal bones, but nothing definitively paleontological. Further research may uncover fossil material in cultural contexts.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division-sponsored geologic scoping sessions have not yet been held for GRPO. Paleontological resources are not known from within the park collections and are not yet known from the geologic formations mapped within the park. Future discoveries of fossils within GRPO are not likely, but fossils have been found in both the Proterozoic and glacial sediments in northeastern Minnesota.
- Due to the lack of documented fossil occurrences within the park, and the unlikelihood of macrofossil discovery within the park, establishment of a paleontological resource management plan is not necessary at this time. Further research may elucidate a connection between paleontological resources and the Ojibwe Indians in the GRPO area.

- As yet, there are no documented occurrences of paleontological material washing up along the shoreline of GRPO. However, this occurrence is documented at many GLKN parks (APIS, INDU, ISRO, PIRO, SLBE) and may be a potential source of fossil material.
- The NPS Geologic Resources Division is a source of assistance regarding paleontological resource management and/or interpretation at GRPO.

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Data Sets

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

Indiana Dunes National Lakeshore

On November 5, 1966, Indiana Dunes National Lakeshore (INDU) was established for the educational, inspirational, and recreational use of the public certain portions of the Indiana Dunes and other areas of scenic, scientific, and historic interest and recreational value along the southern shore of Lake Michigan. While the 1966 authorizing legislation included only 3,371 ha (8,330 acres) of land and water, four subsequent expansion bills for the park (1976, 1980, 1986, and 1992) have increased the park's size to more than 6,070 ha (15,000 acres).

Geologic Background

The Indiana Geological Survey (2008) maintains an online and interactive GIS Atlas for Indiana. One of the atlas' layers is geology, providing a basic geologic map of the park and surrounding area. As with most parks in the GLKN, rocks and sediments within INDU are found at two ends of the geologic timescale (see Figure 2). Paleozoic rocks (Silurian and/or Devonian; approximately 400 million years old) are overlain by much more recent (few thousand-few hundred thousand years old) glacial-lacustrine deposits and post-glacial dunes and sediments. The eponymous dunes and associated features within INDU are the park's primary resource. The three primary dune and beach complexes in the park were created in response to fluctuations in lake levels during and after retreat of the last ice sheet some 11,000 years ago. Glacial and post-glacial deposits completely cover the underlying bedrock of Silurian and/or Devonian age. As described below, fossils within INDU are known from both the Silurian and/or Devonian bedrock (as they occasionally wash up on park beaches) and the post-glacial deposits. The post-glacial deposits provide important paleoecological information detailing the re-establishment of flora and fauna to the region following the retreat of continental glaciers at the end of the last glacial advance.

Sources of Paleontological Resources

Wabash Formation, Muscatatuck Group, Antrim Shale, New Albany Shale (Silurian and Devonian)

The Silurian Wasbash Formation (Salina Group), Middle Devonian Muscatatuck Group, Upper (Late) Devonian Antrim Shale, and Upper (Late) Devonian New Albany Shale form the bedrock beneath the glacial and post-glacial deposits in northern Indiana along the shoreline of Lake Michigan (Indiana Geological Survey 2008). They are not well exposed in the area, although they may outcrop occasionally in headland bluffs in the area (B. Keith, Indiana Geological Survey Senior Scientist, pers. comm., April 2008.). Todd Thompson (Indiana Geological Survey Senior Scientist, pers. comm., April 2008) indicated that exposed bedrock is essentially absent along the Indiana shoreline, although it may have been exposed during Pleistocene high stands of the lake along the Illinois shoreline. (e.g. Chrzastowski and Thompson 1992). High stands of what is now Lake Michigan formed the Glenwood and Calumet (both glacial) shorelines. During these high stands, Paleozoic fossils may have been eroded from the Blue Island and Thornton areas of Illinois. Both are now approximately 17 km (10 miles) inland of Lake Michigan. The Silurian reef underlying Thornton is now a major aggregate mine with abundant fossils (e.g. Ingels 1963; Loydell et al. 2002). These Paleozoic fossils may have been eroded from the Illinois area during lake high stand and deposited in younger sediments that are eroding today to produce the fossils on INDU beaches (T. Thompson, pers. comm., April 2008).

The oldest bedrock formation mapped near INDU is the Silurian Wabash Formation. The Wabash Formation is primarily limestone and dolomite and represents extensive reef deposits from what is referred to as the Fort Wayne Bank. It is mapped west of Gary, Indiana, but reef deposits are also mapped beneath what is now INDU near Cowles Bog (Indiana Geological Survey 2008; Shaver 1974b). The Devonian units that underlie INDU include the Muscatatuck Group, the Antrim Shale and the New Albany Shale (Shaver et al. 1986). The middle Devonian Muscatatuck Group is composed of mostly fine-grained sandy dolomite, dolomitic quartz sandstone, vuggy dolomite, and limestones. The middle

Devonian Antrim Shale in Indiana consist of a noncalcareous shale, and in northern Indiana is the equivalent to the upper portion of the Traverse Group in Michigan (Schneider and Keller 1970). The late Devonian New Albany Shale overlies the Muscatatuck, which is correlative with the Antrim Shale of northern Indiana and Michigan, the Ohio Shale of Ohio and eastern Kentucky, the New Albany Shale of Kentucky, the New Albany Group of Illinois, and the Chattanooga Shale of Tennessee and south-central Kentucky. The Ellsworth Member of this unit is located in northern part of the Illinois Basin of Indiana and is composed of shale in its lower parts, with the upper consisting of a shale with limestone or dolomite lenses (Lineback 1968, 1970). All of these formations are better exposed in southeastern Indiana, particularly near the falls of the Ohio River. Fossils from these formations may wash up on the beaches of INDU, although this is likely a very rare occurrence (e.g. T. Thompson, pers. comm., April 2008). As described in the park collections section, crinoids have been collected within the park and accessioned into INDU collections.

The crinoids within the park's collections likely came from carbonate (limestone) layers and perhaps the reef facies, of the Silurian and/or Devonian bedrock via the erosive scenario described for the Thornton Reef/Blue Island area above. Further identification of the crinoids may allow assignment to a particular geologic unit. The Silurian Wabash Formation and Middle Devonian Muscatatuck Group are the most abundantly fossiliferous bedrocks units of the four mapped near INDU. For instance, the Middle Silurian reef deposits (most of which are included within the Wabash Group) in northern Indiana have produced more than 366 marine invertebrate taxa as reported by Shaver (1974b) including: receptaculitids (enigmatic algae-like fossils), sponges, conularids (another enigmatic fossil, not closely related to anything living today, probably a filterfeeder), stromatoporoids (sponge-like reef builders), corals, graptolites (hemichordates that look like "sawblades"), bryozoans, brachiopods, pelecypods (bivalves; "clams"), gastropods, cephalopods, crinoids, cystoid (echinoderms, similar to crinoids), and trilobites. The carbonates of the Muscatatuck Group are "conspicuously fossiliferous" with a variety of stromatoporoids, bryozoans, brachiopods, corals, crinoids and conodonts particularly useful for regional and global correlation (Shaver 1974a; Shaver et al. 1986; Leonard 1996).

The New Albany and Antrim shales are not nearly as fossiliferous as the carbonate Wabash and Muscatatuck Group with only a "meager" fossil record from the Antrim Shale including an early fossil plant (*Protosalvinia* (*Foerstia*)) and algal spores (e.g. Shaver et al. 1986; Harrell et al. 1991). The Antrim is also exposed in Sleeping Bear Dunes National Lakeshore (see SLBE section of this report).

Post-Glacial Deposits (late Pleistocene-Holocene)

While fossils may rarely wash up along INDU shorelines from the Paleozoic units described above, the park has a well documented and important Pleistocene fossils fauna that holds important information regarding post glacial floral and faunal changes in the area. Chrzastowski and Thompson (1992) described the large-scale and rapid lake level fluctuations along the southern Lake Michigan coast over the last 14,500 years.

Late Pleistocene (Lake Chippewa stage) post-glacial clays have yielded fossil remains from a site near Michigan City, likely within or immediately adjacent to INDU boundaries. The taxa include the fish *Lepisosteus* (gar), *Esox* (pike), *Ictalurus* (catfish), *Lepomis* (perch-like), *Micropterus* (bass), and *Stizostedion* (sauger). A painted turtle (*Chrysemys*) and a loon (*Gavia*) were also collected. These beds are between 5,500 and 6,300 years old based on radiocarbon dates from associated wood (Winkler 1962). It appears that these remains were preserved in a shallow lake or pond setting, and were also found in association with the fossilized remains of snails, clams, grasses and mosses (Bland and Bardack 1973; Teller and Bardack 1975). The fossils are curated at the Field Museum of Natural History in Chicago. Gutschick and Gonsiewski (1976) published a field guide to the Mt. Baldy area of the park, near Michigan City that mentions "matted vegetation," grasses, wood, *Chara* (algae), crayfish burrows, and clams in addition to the vertebrate fauna. Land (pulmonate) snails and small vertebrate remains (including pocket gopher) were also discovered in more recent (3,000-300 years old) paleosols near Mt. Baldy (Gutschick and Gonsiewski 1976).

Holocene post-glacial spruce forest pollen and wood are preserved in several localities within Indiana Dunes National Lakeshore, with radiocarbon dates falling between 12,000 and 11,600 years before present. Pollen sequences and buried wood suggest a shift from spruce-fir forest to jack pine forest about 11,000 years before present with white pine migrating into the area about 10,500 years before present. Oak forest became dominate around 8,300 years before present. (Cole 1987, 1989).

Paleoecological studies at Pinhook and Cowles bogs, within the park, have led to an increased understanding of environmental changes over the last few thousand years. At Pinhook Bog in Indiana Dunes the lake phase began around 8,000 years before present, with a floating mat of *Sphagnum* moss, sedges, heath shrubs, along with white pine and larch, expanded from the edge of the lake, covering most of its area by 2,000 years before present. No major vegetation changes have occurred in Pinhook Bog in the last 2,000 years (Futyma 1988). Pinhook Bog data is also synthesized by Davis et al. (1998) as part of a larger paleoecological study of Great Lakes region parks. At Cowles Bog, also in Indiana Dunes, the lake phase began approximately 7,000 years before present, dominated by floating-leaved aquatics and the algae *Pediastrum* before 1,700 years before present. The additional abundance of grass pollen may indicate the occupation of shallow areas of the lake by grassy marshes, which probably included some sedges. About 2,000 years before present the area was replaced by a grass dominated marsh, which contained *Sphagnum*, larch, and white pine. This was shortly followed by a conifer swamp that included *Larix laricina* (tamarack), *Pinus strobes* (eastern white pine), *Ilex verticillata* (winterberry), and/or *Nemopanthus mucronata* (mountain holly), *Alnus rugose* (speckled alder), Polypodiaceous ferns, *Osmunda* spp. (royal fern), and *Sphagnum* moss (Futyma 1988).

Mollusk fossils have been recovered from vibracores at Cowles Bog within INDU which reveal long and short term water-level fluctuations during the last 6,000 years (Miller and Thompson 1990; Miller et al. 1996). Dominant mollusk species include the terrestrial snails *Carychium exiguum*, *Gastrocopta tappaniana*, and *Vertigo milium*, along with the aquatic snails *Barkerilymnaea dalli*, *Amnicola walkeri*, *Amnicola limosa*, *Gyraulus parvus*, *Gyraulus deflectus*, *Marstonia decepta*, and *Valvata tricarinata* (Miller and Thompson 1990; Miller et al. 1996). T. Thompson (pers. comm., April 2008) noted planispiral (shell coils in one plane) snails from cores below a 3,800 year old peat layer beneath the Great Marsh.

Park Collections

There are 2 fossil specimens within INDU park collections (K. Byrne, HFC Curator, pers. comm. January 2008). INDU staff reported that fossils are likely crinoids washing up on the beaches (L. Van Auken, INDU RM Division Secretary, pers. comm., January 2008). The crinoids probably originated in the Silurian-Devonian carbonates of the Wabash Formation or the Muscatatuck Group mapped along the southern margin of Lake Michigan. This may not be a common occurrence (B. Keith, pers. comm., April 2008), but might indicate potential for unauthorized "beachcombing" collection of marine fossils along the beaches of INDU. Many GLKN parks (and NPS units outside the network) have documented similar occurrences of fossils washing up along the beach. The SLBE section of this report details that parks efforts to manage such resources.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division-sponsored geologic scoping sessions have not yet been held for INDU. Paleontological resources are known from the geologic formations within the park and within park collections. Paleozoic marine fossils may occasionally wash up along the shoreline of the park. The park's Pleistocene-Holocene deposits contribute to a better understanding of glacial advance and retreat along southern Lake Michigan.
- Fossils wash up along the shores of many GLKN parks (APIS, ISRO, PIRO, SLBE). The SLBE section of this report details that park's efforts to manage such resources.

- Park staff should be encouraged to observe exposed cliffs, other erosional bedrock, and streams for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- A field-based paleontological resource survey may yield additional fossils washing up along the shoreline, although this seems to be a rare occurrence. Further research or field surveys may demonstrate the practicality of a paleontological resource monitoring plan based on the frequency with which fossils wash up along the beaches. A forthcoming (2008) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management along hydrological features.
- The NPS Geologic Resources Division is a source of assistance regarding paleontological resource management and/or interpretation at INDU.

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Data Sets

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

Indiana Dunes National Lakeshore Museum Collections
1982-present. (museum specimen; associated specimen notes; collection records; maps; etc.). Originated by INDU staff; status: Active.

Isle Royale National Park

Isle Royale National Park (ISRO) was originally authorized on March 3, 1931 to preserve the largest forested island in Lake Superior. The park retains its wilderness character with an abundance of wildlife including moose and wolves. Pre-Columbian copper mines are preserved within the park. Boundary changes have occurred over the decades and today the park consists of 231,400 ha (571,790 acres). Nearly 99% of the land area administered by the park is designated Wilderness area.

Geologic Background

The geology of Isle Royale National Park is dominated by Keweenawan (Proterozoic, or "Precambrian" see Figure 2) volcanic rock. The Portage Lake Lava Series occupies much of the island, with the Copper Harbor Conglomerate found on the southwestern portion of the island (Huber 1971). As with most parks in the GLKN, the Proterozoic Keweenawan Rift is responsible for the bedrock in the park, while Pleistocene glaciations nearly one billion years later crafted the park's present landscape. The lithologic characteristics of the Copper Harbor Conglomerate consist of alternating beds of sandstone and conglomerate. The conglomerates are composed of reworked pebble to boulder/cobble size clast, with 50 to 75% derived from basalt, andesite, trachyte, latite, quartz latite, and rhyolite; 0-5% made up from claystones, arkosic sandstones, and quartzite. Thin shale layers are also present within this unit (Wolff and Huber 1973). The Portage Lake Volcanics record the Proterozoic rifting event where the upper Midwest-Great Lakes region began to pull apart. The Portage Lake Volcanics and Copper Harbor Conglomerate both contain the native copper mined by prehistoric peoples and settlers. The Copper Harbor Conglomerate resulted from deposition in the vast basin that formed during the earlier continental rifting.

Fossils are not likely to be found in ISRO's Proterozoic bedrock due to the high quantity of igneous rocks present in the park, lesser amounts of sedimentary units, and the extreme age of these rocks. In general, fossils are not commonly preserved in Proterozoic sedimentary rocks (see GRPO section). Fossils may be found in some of the glacial erratics, tills, boulders, and beach gravels on Isle Royale as described below. Holocene pollen was recovered from two lakes within the park, also described below. While not a fossil, the state gemstone Chlorastrolite is most commonly found on ISRO and may be subject to illegal "beachcombing" collection as fossils are at other GLKN parks (see Fossil Collecting in SLBE section in this report). Chlorastrolite occurs as amygdules and other cavity fillings in Proterozoic volcanic rocks, and as pebbles in certain beach gravels (Dietrich 1983).

Geologic scoping sessions, sponsored by the NPS Geologic Resources Division (GRD), were held for ISRO in June 2004 and summarized by Covington (2005). As part of the NPS GRD Geologic Resource Evaluation program, a digital geologic map and report will be produced for the park. The geology of the park was studied in detail during the mid-late 1900s by Norman King Huber (USGS) in a series of publications (Huber 1971, 1973a,b,c)

Sources of Paleontological Resources

Glacial, Beach, and Lake Deposits (Pleistocene-Holocene)

The extensive glacial deposits on Isle Royale record the advances and retreats of continental ice sheets throughout the Pleistocene. As glaciers sculpt the landscape they can remove large amounts of rock, transport them great distances and deposit them as glacial till or erratics. On Isle Royale, beach gravels include material from local bedrock and also glacial material. Some of these gravels contain limestone and cherts that preserve fossil marine invertebrates from as far away as Hudson Bay, Canada (Huber 1973, 1975). Typical fossils near Hudson Bay are Paleozoic in age (Ordovician-Silurian-Devonian) and are marine invertebrates not unlike those found in Paleozoic rocks in other parks of the GLKN. Further research may refine the provenance of these fossils. Their occurrence in loose beach gravel cobbles increases their transportability and potential for "beachcombing" collection. Valerie Bowen (ISRO West

District Interpreter, pers. comm., April 2008) indicated that fossils can be observed occasionally along the west end of the island.

Following Potzger (1954), Flakne (2003) analyzed cores from Lake Ojibway and Lily Lake for fossil pollen and spores to reconstruct the vegetation history of Isle Royale during the Holocene. The pollen and spores from Flakne's cores record the transition from spruce-dominated ecosystem (early Holocene, cooler than present) to pine-dominated (mid-Holocene, drier/warmer than present), and diverging histories at the two sites during the late Holocene. Overall the record extends back nearly 9,400 radiocarbon years before present in Flakne's (2003) study. Davis et al. (1998) incorporated paleoecological data from Lake Ojibway and Lily Lake as part of their larger paleoecological study of the Great Lakes region.

Park Collections

According to Harpers Ferry Center ANCS+ records, there are no fossils within ISRO park collections (K. Byrne, HFC Curator, pers. comm. 2008). Fossils are not yet known in association with any of the prehistoric sites in the area (J. Richter, MWAC archeologist, pers. comm., 2008).

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division-sponsored geologic scoping sessions have been held for ISRO (Covington 2005). Paleontological resources are not known from within the park collections and are not yet known from the bedrock geologic formations mapped within the park. However, fossils derived from sources outside the park may be found in the glacial tills, erratics, and/or beach gravels of Isle Royale. Fossil pollen from lakes within ISRO provide important paleoecological data for the Holocene (last 10,000 years). Further research may elucidate a connection between paleontological resources and the prehistoric peoples in the area.
- Fossils wash up along the shoreline of ISRO in beach gravels as documented by Huber (1975) and confirmed by park staff (V. Bowen, pers. comm., April 2008). Many other GLKN parks have also documented fossil occurrences along their shorelines including APIS, INDU, PIRO, and SLBE. This may be a potential source of additional fossil material at ISRO.
- Due to the paucity of documented fossil occurrences within the park, and the unlikelihood of extensive macrofossil discovery within the park, establishment of a paleontological resource management plan is not necessary at this time. However, further documentation of fossils along the shoreline may provide the basis for a field-based paleontological resource survey or paleontological resource management plan. A forthcoming (2008) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management along hydrological features.
- Park staff should be encouraged to observe exposed cliffs, other erosional bedrock, and streams for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- The NPS Geologic Resources Division is a source of assistance regarding paleontological resource management and/or interpretation at ISRO.

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Mississippi National River and Recreation Area

The Mississippi National River and Recreation Area (MISS) encompasses approximately 54,000 acres along 72 miles of the upper Mississippi River in southeastern Minnesota. The Park Service owns only 35 acres within the MISS corridor boundary. All the rest is owned and managed by partner agencies. This stretch of the river contains the only gorge and waterfall on the main course of the Mississippi River. The confluence of the Mississippi and Minnesota rivers was an important military and fur trading outpost, while St. Paul marked the northern-most extent of steamboat travel and became an important 'jumping-off' point for settlers.

Geologic Background

In the MISS corridor, the Mississippi River transitions from cutting through glacial sediments from the last glacial advance from Dayton to just north of Minneapolis, to eroding glacial terraces of the ancient Mississippi River near Minneapolis, to cutting though Paleozoic-aged (some 450 million years old and older) bedrock within and south of St. Paul. The Paleozoic sandstones, shales and limestones were deposited during the Late (Upper) Cambrian through the Late (Upper) Ordovician, during a time when the Twin Cities area was in the tropics, at a similar location to Rio de Janeiro today (e.g. Sloan 2005). The Keewenawan Rift, a unifying geologic feature in most GLKN parks, produced the Twin Cities Basin during the Paleozoic and facilitated extensive deposition of marine sandstones, shales, and limestones throughout southeastern Minnesota (e.g. Sloan 2005). Within MISS corridor, the Mississippi River cuts through a number of these sedimentary units, all of which are fossiliferous to varying degrees, in some cases with material being collected within the MISS corridor. The sedimentary units exposed within MISS corridor, and described below, include the Jordan Sandstone, Prairie du Chien Group, St. Peter Sandstone, Glenwood Shale, Platteville Limestone, Decorah Shale and the Cummingsville Limestone of the Galena Group (Madigan 2003). Fossils from these formations in the St. Paul area are very important in regional correlation and indeed North American stratigraphy for the Ordovician.

Bedrock (Paleozoic-aged rocks) and surficial (glacial-aged material covering the bedrock) geologic maps produced by the Minnesota Geological Survey (MGS) are available for many of the counties along the MISS corridor and can be downloaded from the MGS website for Hennepin (Olsen and Bloomgren 1989; Meyer and Hobbs 1989), Ramsey (Mossler and Bloomgren 1992; Patterson 1992), Dakota (Mossler 1990; Hobbs et al. 1990), Washington (Mossler and Bloomgren 1990; Meyer et al. 1990), and Goodhue (Runkel 1998; Hobbs and Setterholm 1998) counties. Eventually the MGS will complete county maps for the entire state.

Since there are extensive glacial sediments throughout the MISS corridor and southeastern Minnesota in general, exposures of the bedrock is generally limited to the bluffs along the Mississippi River within and south of the Twin Cities as mapped by Morey (1981). Exposures of the Paleozoic bedrock, both natural (bluffs) and man-made (quarries) are found in MISS corridor including, but not limited to St. Anthony Falls, Shadow Falls, Minnehaha Regional Park, Fort Snelling State Park, Hidden Falls-Crosby Farm Regional Park, Lilydale-Harriet Island-Cherokee Regional Park, near Wabasha Bridge, Indian Mounds Park, and Battle Creek Regional Park (e.g. Sloan et al. 2005; Campbell and Kirby 2005). Given the wide variety of city, county, and state lands within the MISS corridor, there are many different management strategies in use along the corridor as described in the Paleontological Resource Management section, below.

Sloan (2005) represents the most up-to-date syntheses of information regarding Minnesota's fossils, particularly those around the MISS corridor. It is highly recommended that the park obtain a copy of the report from the MGS. The manuscript includes basic information on fossils and paleontology as well as invaluable stratigraphic information, correlation charts, locality descriptions, figures, images, maps, biographical information regarding paleontologists working in Minnesota, a glossary, paleoenvironments from different time periods, and descriptions of all major fossil producing formations in the state from the

Upper Cambrian through the Pleistocene (Ice Age). Other field trip guidebooks to various fossil localities within the Twin Cities include Sloan et al. (1987a, 1987b, 2005), Sloan and Kolata (1987), and Campbell and Kirby (2005). Mossler (2008) contains the most recent summary of Paleozoic geologic units in Minnesota and is a great geological resource.

The MGS (Sloan 1987) published species lists and biostratigraphy for many middle-upper Ordovician groups compiled by Kolata et al. (1987, echinoderms), Brower (1987, crinoids), Sweet (1987, conodonts), Karklins (1987, bryozoans), Rice and Hedblom (1987, brachiopods and trilobites), Pojeta (1987, pelecypod bivalves), Catalani (1987, cephalopods), Sloan and Webers (1987, snails and monoplacaphorans), Swain (1987, ostracodes), and Dokken (1987, trace fossils). Within MISS, most of the middle-upper Ordovician groups are from the historical "Sardeson beds" 1-7.

Sources of Paleontological Resources

Jordan Sandstone (Upper Cambrian)

The Jordan Sandstone is the oldest bedrock unit outcropping within the park boundaries. Exposures are few, however, and occur only along the southern portion of the MNRRA corridor. Stauffer (1925) redescribed the Jordan Sandstone as the uppermost formation of the "St Croixan" series (an obsolete stratigraphic term referring to the Upper Cambrian) of rocks, which are "abundantly fossiliferous." The sandstone was named for exposures near the town of Jordan southwest of the Twin Cities. Cambrian section is exposed well south of MISS along the Mississippi River near Dresbach, MN near the Iowa state line. Stauffer (1925) mentioned the paucity of fossils within the Jordan, as to be expected in the loose quartz sands, but indicated fossils are known from the middle of the formation. These fossils are primarily trilobites as reported by Nelson (1949) among others. Some of these localities are along the Mississippi River, but outside of the MISS corridor (T. Runkel, Minnesota Geological Survey, pers. comm., April 2008).

Tape et al. (2003) utilized Mississippi River Valley exposures of the Jordan Sandstone to quantify tidal patterns in shallow epicontinental ("on continent") sea of the Upper Cambrian. They noted invertebrate burrows including *Skolithos* (worm), *Arenicolites* ("U" shaped), *Diplocraterion* ("U" shaped), *Chondrites* (highly branched), and a tentatively identified *Monocraterion* (vertical with a funnel-shaped top) were locally abundant in many beds of the Jordan in southeast Minnesota. Runkel (1994) also noted the presence of *Skolithos* and *Arenicolites* in many exposures of the lower beds of the Jordan near Minneapolis-St. Paul, but did not specifically mention any localities along the river. His Section 5 is located within MISS at the Army Corps of Engineers Lock and Dam Structure 2 near Hastings; however the abundantly burrowed lower beds are not exposed there. Stauffer (1940) described invertebrate fossils from the Van Oser Beds, assigned to the upper part of the Jordan Sandstone (see Runkel 1994), including brachiopods, gastropods, and trilobites near Merriam Junction (Louisville Township) in Scott County.

Prairie du Chien Group (Lower Ordovician)

The Prairie du Chien dolomites were deposited during the Lower (Early) Ordovician in a broad sea; they now are now found in bluffs along both the Mississippi and St. Croix rivers (Sloan 2005). The Prairie du Chien Group is divided into two formations, the lower (older) Oneota Dolomite and the upper (younger) Shakopee Formation (e.g. Runkel 1998, Mossler 2008). The Oneota Dolomite is characterized by dolostone (limestone chemically altered to the magnesium-carbonate mineral dolomite), sandstones, and shales and is exposed throughout southeastern Minnesota (Mossler 2008). The Oneota is further divided into the Coon Valley and the Hager City members. It outcrops along the MISS corridor near Hastings. The Shakopee Formation is characterized by dolostone, sandy dolostone, and sandstones. It is exposed extensively in Dakota County, where it crops out near the MISS corridor (Mossler 2008). The Shakopee is further divided into the New Richmond and Willow River members.

Marine invertebrate fossils are known from both the Oneota Dolomite and the Shakopee Limestone. Fossils from the Oneota Dolomite are only locally abundant, except for the common stromatolites (algal

mats) (Mossler 2008. Additional fossils include conodonts (tooth-like elements of enigmatic marine organisms; important for regional and global correlation), trilobites, brachiopods, cephalopods, gastropods (snails), pelecypods (bivalves), and cystoids (related to the echinoderm crinoids) (Furnish 1938; Smith and Clark 1996; Mossler 2008). Interestingly, the Oneota Dolomite is quarried extensively near Mankato, Kasota , and Winona for use as building stone ("Kasota Limestone"). If buildings in the MISS corridor were constructed with "Kasota Limestone," they may display similar fossils. Worm burrow trace fossils within the "Kasota Limestone" are visible in the blocks used during construction of the Smithsonian National Museum of the American Indian in Washington, D.C. (C. Barr, amateur paleontologist, pers. comm., 2007). The Shakopee Limestone fossils include stromatolites, conodonts (not as abundant as in the Oneota), and various trace fossils (Mossler 2008). Body fossils of gastropods and cephalopods are found but are neither abundant nor diverse (Webers 1972; Mossler 2008).

St. Peter Sandstone (Upper Ordovician)

The Upper (Late) Ordovician St. Peter Sandstone is a quartz sandstone, with multicolored beds of mudstone, siltstone and shale in its basal part. The upper, quartz sandstone part of the formation is frequently exposed in bluffs along the river, particularly in the northern MISS corridor and surrounding St. Paul (Madigan 2003). The St. Peter Sandstone was originally described (type section) from exposures at Fort Snelling State Park within the MISS corridor. Interestingly, the unit was formerly mined for glass sand for the Ford Motor Company near Hidden Falls Regional Park and Minnehaha Park, and contains a number of man-made caves once utilized to grow mushrooms (Mossler and Bloomgren 1992; Campbell and Kirkby 2005). Fossils are well known from the unit and are described from the Twin Cities area.

F.W. Sardeson collected fossil bryozoans, brachiopods, snails, nautiloid cephalopods, and clams as molds (no shell material) from the St. Peter Sandstone in the late 1800s and early 1900s (Sardeson 1892a, 1896). His localities included three within or near what is now MISS: Indian Mounds Park ("Dayton's Bluff") managed by St. Paul Parks and Recreation, Highwood (near Pig's Eye Lake in Battle Creek Regional Park), and across the river in South St. Paul near Minnesota Route 156 (Sloan et al. 1987b). The exposures in Battle Creek Regional Park (administered by Ramsey County) are not particularly fossiliferous but are some of the most accessible (Sloan et al. 1987b). The St. Peter Sandstone is also exposed at Shadow Falls ("Finns Glenn" or "Summit Avenue") along the Mississippi River within the MISS authorized boundary which is a popular fossil collecting locality for younger Ordovician formations (Sloan et al. 1987a, 1987b, 2005; Campbell and Kirkby 2005).

Glenwood Shale (Upper Ordovician)

The Upper Ordovician Glenwood Shale is a thin (~0.9-1.6 m; 3-5.5 ft thick) green sandy shale exposed in cliffs along the Mississippi River near St. Paul, and is mapped together with the overlying Platteville Limestone, described below (Mossler and Bloomgren 1992). The Glenwood Shale is exposed at many of the same sites listed above for the St. Peter Sandstone, including Shadow Falls (Sloan et al. 1987a, 1987b, 2005) and along the road to Hidden Falls Park (Crosby Farm Regional Park; St. Paul Parks and Recreation) (Mossler 2008).

Given the limited thickness of the Glenwood, extensive fossil resources may not be expected, however, some fossils are known from the Glenwood Shale. These fossils include "steinkerns" (internal casts of bivalves), brachiopods, and conodonts primarily of the *Chirognathus* genus (Sloan et al. 1987b, 2005; Sloan 2005).

Platteville Limestone (Upper Ordovician)

The Upper Ordovician Platteville Limestone is exposed in bluffs along the Mississippi River in/near St. Paul with thicknesses approaching 30 feet and down the river toward the Iowa state line where it is closer to 17 feet thick, but much farther away from the Mississippi River (Mossler and Bloomgren 1992; Sloan 2005). Historically, the Platteville Limestone was an important aggregate material and was extensively used for building stone (fossiliferous Mifflin limestone) in South St. Paul (Mossler and Bloomgren 1992). There are five members of the Platteville Limestone that may be referred to in the literature including

from oldest (bottom) to youngest (top): the Pecatonica dolomite, the Mifflin (or McGregor) limestone, the Hidden Falls shaly dolomite, the Magnolia dolomite, and the Carimona coarse-grained limestone (Sloan 2005). The Carimona is particularly interesting because it includes the Deicke ash bed near its base. This ash bed has been dated at 454 million years old and marks a volcanic eruption and a contemporaneous huge regional extinction event (Sloan 2005). The Platteville Limestone is exposed in a number of sites within or near MISS with the most accessible exposures at Shadow Falls (Sloan et al. 1987a, 1987b, 2005) and Lilydale-Harriet Island-Cherokee Regional Park (old Twin Cities Brick and Tile Company quarry; Sloan et al. 1987b, 2005). Hidden Falls Park (Crosby Farm Regional Park; St. Paul Parks and Recreation) is the place of original description (type section) for the Hidden Falls member of Platteville and likely preserves fossils characteristic of the member. The Platteville's resistance to erosion makes it a caprock for many of the waterfalls in the MISS corridor (e.g. Madigan 2003).

Various members of the Platteville Limestone are richly fossiliferous and have a long history of collection in the Twin Cities area. At Shadow Falls, for example, all five members are visible and produce fossils in varying amounts, including some layers of shell hash (rock composed almost entirely of broken fossil shell material). Fossils found at Shadow Falls, Hidden Falls Park, and/or Lilydale-Harriet Island-Cherokee Regional Park are all marine invertebrates including bryozoans, trilobites, ostracodes, clams, snails, monoplacaphorans (enigmatic mollusks with a rounded "droopy" conical shell), brachiopods, starfish and extensive conodonts (Sloan et al. 1987a, 1987b, 2005; Sloan 2005; Mossler 2008). Brower and Veinus (1978) described crinoids from a number of localities throughout the Twin Cities, including what is now Lilydale-Harriet Island-Cherokee Regional Park. Similar fossils might be found in other exposures of the Platteville along the MISS corridor. If historic structures within MISS corridor were built with Platteville Limestone (particularly the Mifflin limestone member), they may display fossils characteristic of the Platteville.

Trace fossils, especially the burrows *Chondrites* (highly branched, unknown maker) and *Planolites* are well known in the Platteville, where at least 18 different trace fossils have been discovered in addition to *Chondrites* and *Planolites* (Dokken 1987). Trace fossils are very important tools for paleoenvironmental reconstruction, even if actual body fossils are not found within them.

Decorah Shale (Upper Ordovician)

The Upper Ordovician Decorah Shale is naturally exposed in the southern MISS corridor, although it is also exposed along the river near South St. Paul and in quarries and roadcuts, including some within MISS (Mossler and Bloomgren 1992; Madigan 2003). The Decorah Shale is a green calcareous (calcium-rich) shale with some limestone beds (Mossler and Bloomgren 1992). The formation is best exposed within what is now Lilydale-Harriet Island-Cherokee Regional Park in the old Twin City Brick and Tile Company pit, where the thickest Decorah section is found (Sloan et al. 1987b, 2005).

The Decorah Shale is richly fossiliferous, especially at the Lilydale-Harriet Island-Cherokee Regional Park quarry exposure, and has been collected for more than 100 years. The Decorah is also exposed at the Shadow Falls locality (Sloan et al. 1987b, 2005). As with the other upper Ordovician formations, marine invertebrates such as brachiopods, ostracodes, bryozoans, trilobites, and conodonts are known from Lilydale and/or Shadow Falls (Sloan et al. 1987b, 2005; Sloan 2005). Stauffer (1935) also described the extensive conodont fauna from the Decorah.

Galena Group (Upper Ordovician)-Cummingsville Limestone

Above the Decorah Shale are exposures of the Cummingsville Limestone. The Cummingsville Limstone is the youngest Paleozoic formation exposed in the MISS corridor (Madigan 2003). The Cummingsville Limestone and the other two younger formations of the Galena Group (Prosser Limestone and Stewartville Dolomite) are exposed throughout southeastern Minnesota (Madigan 2003). Blocks of Cummingsville Limestone are found within Lilydale Park. Unfortunately, these blocks tumble down from above the Decorah Shale creating a rockfall hazard, and actually killed one researcher in 1953 (Sloan et al. 1987b, 2005; Sloan 2005).

The Cummingsville is richly fossiliferous in many localities within southeastern Minnesota; however fossils are not listed specifically from the Lilydale quarry (e.g. Sloan et al. 1987b, 2005). Nevertheless, fossils are likely present within the Cummingsville of the MISS corridor. Typical fossils, as described at the type section near the town of Cummingsville, include nearly two dozen genera of marine invertebrates such as brachiopods (see also Weiss 1955), bryozoans, trilobites, gastropods, rugose corals, and a calcareous algae (Sloan 2005).

River Terrace Deposits (Pleistocene)

Mississippi River terrace and other Pleistocene-age deposits are found throughout the MISS corridor and typically obscure the Paleozoic bedrock below. Northwest of Minneapolis, most of the MISS corridor cuts through these Pleistocene deposits, for example the dramatic ravine from Fort Snelling to St. Anthony Falls created as the falls retreated from Ft. Snelling to their present location (e.g. Wright 1972). However, there are extensive exposures of Pleistocene material within and surrounding the Twin Cities area (Sloan 2005; Wright 1972) frequently within gravel/aggregate quarries. These deposits are associated with the last Wisconsinan glacial advance, ancient Mississippi River terraces and Glacial Lake Agassiz (Wright 1972).

Fossils of beaver, badger, skunk, rabbit, elk, bison, horse, moose, reindeer, musk ox, giant beaver, mastodon, mammoths, and sloths are found within the Pleistocene deposits of Minnesota as described by Stauffer (1945) and Sloan (2005). The following list includes only those discoveries near the MISS corridor. Within MISS corridor, a partial skeleton of giant beaver (*Castoroides ohioensis*) was discovered in a "collapsed cave at Hidden Falls" in 1938 and is now curated at the Science Museum in St. Paul (Stauffer 1945). Stauffer (1945) reported a discovery of *C. ohioensis*) during an excavation at 15th Avenue N and Washington Avenue N in Minneapolis immediately adjacent to MISS corridor. Mammoth (historically *Elaphus* and other genera but now considered *Mammuthus*) finds are common in Minnesota, but with generally poor locality data. For example, a molar was discovered "in the drift [glacial deposits] of the city [Minneapolis]" but with no additional information (Stauffer 1945). Another mammoth ("*Parelephas* sp.") specimen was discovered in the "glacial gravel beds" of Minneapolis and is now in the Peabody Museum at Yale University (Stauffer 1945). More mammoth material from the MISS corridor is known from near Hastings (molar and femur), at the Coon Creek confluence with the Mississippi River (Coon Rapids Dam Regional Park, tooth and tusk), a fragmentary molar "dredged from the Mississippi River at St. Paul" now in the University of Minnesota collections, and a scapula near Inver Grove (Stauffer 1945). Sloan (2005) also reported a claw from the giant sloth *Megalonyx jeffersoni* from a Mississippi River terrace in Columbia Heights near the MISS corridor. Additional Pleistocene fossil material may have been observed by American Indians in what would later become the MISS corridor as described below in the cultural resource contexts section.

Fossils in Cultural Resource Contexts

Given the diversity of sites within the MISS corridor, there is high potential for paleontological resources to be found in a variety of contexts. As described in Kenworthy and Santucci (2006), fossils are found throughout the NPS in building stones and as archaeological resources in addition to ethnographic and historic accounts. While not specifically documented as yet, building stones (especially of the Oneota Dolomite or Platteville Limestone) used within MISS corridor may display fossils. Fort Snelling and the Clarence W. Wigington Pavilion at Harriet Island Park are just two examples of buildings faced with stone.

Mayor (2005) described interesting American Indian legends and associated fossil discoveries within MISS corridor. For example, a mound "near Fort Snelling" a mound apparently contained Unktehi ('water monster') bones according to American Indian legends. Such 'water monster' bones are commonly Pleistocene mammoth or mastodon bones. Interestingly one of the first the earliest written references to oral tales of these 'water monsters' was made in the 17th century by Father Hennepin, a French Franciscan captured by Dakota Sioux in Minnesota in about 1680 (Mayor 2005). Hennepin

observed the Dakota making offerings to a 'water monster' living under St. Anthony Falls. Apparently, Pleistocene mammoth teeth and tusks were recovered from St. Anthony Falls in 1874 (Mayor 2005).

The Hopewell Indians are known to include fossils as funerary items at Hopewell Culture National Historical Park in Ohio (Kenworthy and Santucci 2006). The Hopewell built the mounts at Indian Mounds Park within MISS corridor, and similar fossils might be found in archaeological investigations, although none are currently documented.

Park Collections

There are no fossils in MISS park collections (K. Byrne, HFC Curator, pers. comm., 2008). However, fossils collected from localities within or near the MISS corridor (Lildydale Park, Shadow Falls, Hidden Falls, etc.) are located in collections ranging from the Smithsonian National Museum of Natural History to the Minnesota Geological Survey, the Department of Geology and Geophysics (Bell Natural History Museum) of the University of Minnesota, and Science Museum of St. Paul.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division-sponsored geologic scoping sessions have not yet been held for MISS. Paleontological resources are known from within the park and have been collected and observed for nearly 100 years. Future discoveries of fossils within MISS are likely and may also occur in cultural resource contexts such as building stones or archaeological items. Marine invertebrate fossils are common in southeastern Minnesota and Pleistocene fossils are also known from the area surrounding the MISS corridor.
- The unique management situation between the National Park Service and the various cooperative agencies within the MISS corridor yields a variety of resource management strategies. While NPS lands are not open to fossil (or any other resource) collection, fossils apparently can be collected within the city parks of MISS corridor, some requiring a permit. Lilydale-Harriet Island-Cherokee Regional Park (St. Paul Parks and Recreation) contains the paleontologically significant Twin Cities Brick and Tile Plant quarry locality and has a permitting process in place for groups (http://www.stpaul.gov/depts/parks/userguide/lilydale.html). Shadow Falls Park (also a St. Paul city park) located near, if not within MISS corridor, is another common site for fossil collectors but no permit is required (e.g. Mossler and Benson 2006).
- An field-based inventory of bedrock exposures along the MISS corridor could yield additional data regarding fossiliferous exposures within the authorized boundary of the park
- The field work could be accomplished by establishing a cooperative agreement with one or more of the local natural history museums with paleontological expertise, local universities, or the Minnesota Geological Survey. Graduate students could be hired non-competitively using the STEP hiring authorities and supervised by a partnership of a faculty advisor and a park natural scientist. The NPS Geologic Resources Division can help advertise, recruit, and provide technical assistance for these positions.
- Given the small amount of Federal land and the array of other park jurisdictions within MISS corridor, any paleontological resource monitoring plan should account for the different management goals. A forthcoming (2008) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management along hydrological features.
- Park staff should be encouraged to observe exposed cliffs, other erosional bedrock, and streams for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.

- The NPS Geologic Resources Division is a source of assistance regarding paleontological resource management and/or interpretation at MISS.

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Pictured Rocks National Lakeshore

Pictured Rocks National Lakeshore (PIRO) was established on October 15, 1966, "for the benefit, inspiration, education, recreational use, and enjoyment of the public a significant portion of the diminishing shoreline of the United States and its related geographic and scientific features." Pictured Rocks National Lakeshore is located on the southern shore of Lake Superior in Michigan's Upper Peninsula, and now protects a total of 29,674 ha (73,325 acres). The Shoreline Zone is federally-owned and includes 13,731 ha (33,929 acres). The Inland Buffer Zone is a mixture of lands in State of Michigan, Forestland Group, and other private ownership and encompasses 15,907 ha (39,306 acres).

Geologic Background

The dramatic exposures of Proterozoic and Paleozoic sandstones along the shore of Lake Superior give the park its name. The Proterozoic (informally known as the "Precambrian") Jacobsville Formation is the oldest rock formation exposed in the park and is composed of red sandstone. Sediments were deposited in a lacustrine environment during the late Proterozoic in the northern Michigan Basin (Milstein 1987) following continental rifting associated with the Keweenawan Rift. The Late Cambrian Munising Formation lies unconformably above the Jacobsville Formation and consists of two members: the Chapel Rock Sandstone and the Miners Castle Sandstone. The early Ordovician Au Train Formation lies unconformably above the Munising Formation (Blewett 1994; Milstein 1987; Miller et al. 2006). During the Cambrian and early Ordovician periods, sediments were deposited in shallow marine environments that covered the same portion of the northern Michigan Basin (Milstein 1987). Fossils from PIRO from the Munising and Au Train formations are summarized below. Fossils also wash up occasionally on the shoreline from an offshore source as described in the "Park Collections" section below.

Like many of the other GLKN parks, rocks within PIRO encompass two ends of the geologic time scale (see Figure 2). The Proterozoic, Cambrian, and Ordovician rocks described above are hundreds of millions of years old and were laid down before terrestrial plants had evolved. Younger Paleozoic and Mesozoic rocks are missing from the region. Deposits of gravel and sand were left by the last retreating glacier and are millions of years younger than the ancient bedrock on which they lie.

Sources of Paleontological Resources

Jacobsville Formation (Proterozoic)

The oldest formation exposed within PIRO is the feldspar-rich, quartz sandstones of the Jacobsville Formation. This formation was formed from material that eroded and was carried by streams flowing northward from the northern Michigan highlands. The Jacobsville Formation is composed of a mixture of materials that range in size from fine grained siltstones to coarser conglomerates. Minor amounts of basalt and iron can be found throughout the formation (Regis and Anderton 1999; Milstein 1987). No fossils have been found in the Jacobsville Formation (Haddox and Dott 1990).

Munising Formation (Upper Cambrian and Ordovician)

The Munising Formation makes up most of the dramatic shoreline cliffs at PIRO. Two members are present in the Munising Formation, which lies unconformably above the Jacobsville Formation. Both of these members, the lower (older) Chapel Rock and the upper (younger) Miners Castle, were deposited in near-shore marine beach environments which are well described by Haddox and Dott (1990). The Chapel Rock member is characterized by a lower (non-fossiliferous) conglomerate section and a medium-grained, well sorted quartz-rich sandstone with large scale cross-bedding. Sedimentary structures including mud cracks, ripple marks, clastic dikes, clay pebbles, and sand concretions can also be found in this member. They paint a picture of the depositional environment some 490 million years ago. In addition to these inorganic structures, fossils are known from the Munising Formation within PIRO.

Haddox and Dott (1990) list a number of body fossils from the Miners Castle Member throughout northern Michigan, including the trilobites *Prosaukia*, *Briscoia*, *Idioniesis*, *Idahoia*; the brachiopod *Linqulepus;* and the nautiloid cephalopod *Michelinoceras*. Within the Miners Castle Member exposed within the park, the trilobite *Prosaukia curvicastata* is found roughly 1.5 m (5 ft) below the uppermost extent of the formation. In the Upper Miners Castle member at the Sand Point section, Robert Rose (retired geologist, pers. comm., April 2008) found an inarticulate (no "teeth" along shell margin) brachiopod. The Miners Castle Member is a poorly sorted silty-shaley quartz sandstone (Milstein 1987). Early Ordovician conodonts (enigmatic marine animals, whose tooth-like fossils are important biostratigraphic correlation tools) from the *Rossodus manitouensis* biostratigraphic zone have been recovered from the upper Munising Formation and the lower part of the Au Train Formation (Miller et al. 2006). Miller et al. (2006) used these fossils from within the park to demonstrate that the boundary between the Cambrian and Ordovician epochs does not necessarily correlate with the lithologic (rock-type) boundary between the Munising and Au Train formations. Trace fossils observed by Haddox and Dott (1990) include *Planolites* and *Skolithos*.

Trilobite trace fossils are also known from within the park. *Cruziana* (tracks with a central groove bordered by a two-lobed structure that are interpreted as trilobite "furrowing" traces) and *Rusophycus* (trilobite resting traces) are also known from the Chapel Rock Member (Haddox and Dott 1990; see Fig. 7). These trace fossils were discovered in the mid 1800s (see Foster and Whitney 1851, cited by Haddox and Dott 1990) near Grand Portal and Mosquito Harbor within what is now PIRO. They may still be found there today along with circular cross-section trace fossils similar to *Planolites* (a meandering burrow) (Haddox and Dott 1990). In November 1985, PIRO ranger Fred Young discovered fossil *Cruziana* tracks in mudstone from the upper Miners Castle Member. They are now on display in the Munising Falls Interpretive Center (Gregg Bruff, PIRO Chief of Heritage Education, Visitor Services, and Cultural Resources, pers. comm., April 2008).

Au Train Formation (Lower Ordovician)

The Au Train Formation is composed of a hard dolomitic sandstone that contains a high amount of glauconite. This formation often forms a hard cap rock over the softer Miners Castle member of the Munising Formation resulting in the many waterfalls within the park. Two trilobites (probably representing the *Symphysurina* Zone) from the lower Au Train confirm the early Ordovician age. Other fossils include ostracoderm fish armor, brachiopod fragments, and gastropod internal molds (Miller et al. 2006). Robert Rose (pers. comm., April 2008) noted inarticulate brachiopods, gastropods, solitary coral, trilobites, and hyoliths in the Au Train Formation at the Sand Point section. Conodonts are also well known from the Au Train Formation within upper Michigan, and particularly within PIRO as described by Miller et al. (2006) from Sand Point. As described in the Munising Formation section, Miller et al's (2006) conodont collections from the park provided important biostratigraphic information regarding the Cambrian-Ordovician time boundary and its relationship to the boundary between the Munising and Au Train formations.

According to Haddox and Dott (1990), the Au Train formation underlies the Ordovician fossiliferous Black River Formation in the region around PIRO, but it has not been observed as an outcrop at the park.

Glacial and Postglacial Features (Pleistocene-Holocene)

During one of the last sub-stages of the Wisconsinan glacial period (~12,000 years before present), the area was "wiped clean" by retreating glaciers, with a brief readvancement of the ice in Northern Michigan around 10,000 years before present. Between the towns of Wetmore and Seney along the south edge of PIRO a sheet of outwash was deposited by a southward flowing braided stream. This material now underlies the Kingston Plains, with Kingston and Nevins Lakes being kettle lakes formed on this outwash plain. Around 5,000 years before present, the Grand Sable Banks were destabilized as lake levels rose, consisting of a steep, north-facing exposure of glaciofluvial sediments (Marsh and Marsh 1987). To the south the banks form a high terrace, which is covered by the Grand Sable Dunes. These dunes sit upon the glaciofluvial deposit that was reworked by wind. These dunes contain evidence of buried soils, with *in situ*

trees and other organic remains preserved (Anderton and Loope 1995). These organic remains, along with the presence of eolian sediments lead some to believe that the high terrace was a stable, forested environment from deglaciation to about 5,000 years before present and now destabilize with rising lake levels as proposed by Marsh and Marsh (1987). Radiocarbon dates are available to date burial events as early as 4,500, 3,500, 1,500, and 700 years before present and a more recent burial event about 100 years before present (Larsen 1985; Marsh and Marsh 1987; Anderton and Loope 1995; Regis and Anderton 1999). Fossil pollen from sediment of Twelvemile Bog near Lake Superior was analyzed to reconstruct vegetation history of the area (Futyma, 1987). Davis et al. (1998) also summarized the late Pleistocene-Holocene paleoecological history of PIRO from Buck Lake (just outside of the park) and Spirit Lake as part of their larger study of ecological change throughout the Great Lakes region. Fisher and Whitman (1999) utilized lake sediments from cores within PIRO's Beaver Lake to develop a deglaciation history for the Upper Peninsula. Their study did not yield any fossils, but layers of peat and organic material were found in the cores and provided dateable material.

Park Collections

Conodont remains from the Miller et al. (2006) study, along with trilobite fossils from within the park are reposited in the PIRO collections (accession #344, catalog #7250-7275) The *Cruziana* tracks are also held within the park's collections (accession #154, catalog #787; Gregg Bruff, pers. comm., 2007). Trilobite specimens from PIRO are also held in the Invertebrate Collections at Museum of Paleontology, University of Michigan.

Gregg Bruff (pers. comm., 2007) indicated that horn coral fossils are known to wash up along the lakeshore from an off-shore source, which may have even been on the Canadian side of the lake. "Loose" fossils such as these may be subject to unauthorized collection by beachcombers. Fossils wash up on the shores of many GLKN parks including APIS, INDU, ISRO, and SLBE. The Sleeping Bear Dunes National Lakeshore section of this report describes some of the resource management issues and SLBE approaches to managing these resources. ISRO also has documented uncommon fossiliferous limestone or chert boulders that originated from as far away as Hudson Bay and were transported by the one of the glaciers.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division-sponsored geologic scoping sessions have not yet been held for PIRO. Paleontological resources are known from within the park collections and are known from the geologic formations mapped within the park.
- The fossil remains of horn corals are known to wash onto the lakeshore from an off-shore source (most likely located in Canada (Gregg Bruff, pers. comm. 2007). Due to their interest to collectors, the park may want to make certain efforts to instruct visitors as to their importance and encourage visitors not to collect them. Many other GLKN parks have also documented fossil occurrences along their shorelines including APIS, INDU, ISRO, and SLBE. The SLBE section of this report details that park's efforts to manage this resource.
- Given the diversity of paleontological resources in PIRO, as well as the potential for unauthorized collection, a field-based inventory of paleontological resources of the park is recommended.
- The field work could be accomplished by establishing a cooperative agreement with one or more of the dominant natural history museums with paleontological expertise, such as the University of Michigan Museum of Paleontology. Graduate students could be hired non-competitively using the STEP hiring authorities and supervised by a partnership of a faculty advisor and a park natural scientist. The NPS Geologic Resources Division can help advertise, recruit, and provide technical assistance for these positions.
- Interviews with the dominant specialists within each discipline who have worked in the park would provide considerable background. These interviews should be documented and archived by the park.

- The park would benefit from an effort to locate specimens that have already been retrieved and are currently stored in other repositories. Molds of the holotypes and/or other significant specimens could be made and casts placed in the park museum collection. Scientifically significant material that might be threatened in the field should be stabilized *in situ* or retrieved and curated into dedicated storage.
- Park staff should be encouraged to observe exposed cliffs, other erosional bedrock, and streams for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- The establishment of a study collection of fossils from the local area could be beneficial. A field-based inventory could provide specimens for such an endeavor.
- Results of a field inventory could lead to development of paleontological resource monitoring prescriptions. A forthcoming (2008) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management along hydrological features.
- The NPS Geologic Resources Division is a source of assistance regarding paleontological resource management and/or interpretation at PIRO.

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Data Sets

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

Pictured Rocks National Lakeshore Museum Collections
1982-present. (museum specimen; associated specimen notes; collection records; maps; etc.). Originated by PIRO staff; status: Active.

University of Michigan Museum of Paleontology Collections
1980s-present. (museum specimens; associated specimen notes; collection records; maps, etc.). Originated by Invertebrate Collections staff; status: Active.

Saint Croix National Scenic Riverway

Saint Croix National Scenic Riverway (SACN) preserves 406 km (252 miles) of the Namekagon and Saint Croix rivers as part of the National Wild and Scenic Rivers System. The Saint Croix National Scenic Riverway, which includes the Namekagon River, was established on October 2, 1968 as one of the original eight rivers under the National Wild and Scenic Rivers Act. The Lower Saint Croix National Scenic Riverway was added to the system on October 25, 1972. The total size for both the upper and lower riverway (including water surface, backwater & islands) is 39,486 ha (97,573 acres).

Geologic Background

The Saint Croix National Scenic Riverway is located in eastern Minnesota and northwestern Wisconsin and forms the boundary between these states for many of its miles. The riverway includes 248 km (154 miles) of the Saint Croix River from Gordon, Wisconsin to its confluence with the Mississippi River and the entire 158 km (98 miles) of its Namekagon tributary. As with all parks of the GLKN, SACN contains rocks from opposite ends of the geologic time scale with bedrock of Proterozoic (known informally as the "Precambrian"; up to one billion years old, see Figure 2) and Upper Cambrian rocks capped by Pleistocene ("Ice Age") or Holocene rocks a few thousand to few hundred thousand years old. The Proterozoic Keweenawan Supergroup, consisting of lavas, tuffs, and interflow sedimentary rocks of the Oronto Group, Bayfield Group, and Chengwatana Volcanic Group are present in the Taylor Falls and Saint Croix Falls areas. These rocks represent the one billion year old failed Keweenawan Rift, when the North American Plate began to split apart. Abundant geological evidence for the rift is found throughout Minnesota and Wisconsin. In addition, the border between the two states very roughly parallels the axis of this ancient rift. These Proterozoic rocks are not fossiliferous. However, an interesting trace fossil was recently discovered in the Proterozoic Bayfield Group in Apostle Islands National Lakeshore (see APIS section).

There is much greater potential for fossil discovery within the Upper Cambrian and Lower Ordovician rocks exposed along the St. Croix River valley. In fact the name "St. Croixian" was a geologic term referring to any rocks of the uppermost (latest) Cambrian. This term came into use during the late 1800s and early 1900s because of the exposure of these latest Cambrian rocks along the St. Croix River valley, especially in the southern reaches. Likewise, the terms "Dresbachian," "Franconian," "Trempealeauan" are obsolete nomenclature for the Upper Cambrian that are found in the historic literature. The Upper Cambrian rocks of the Saint Croix valley formed during a Late Cambrian increase in sea level (transgression) when what would become Minnesota and Wisconsin was in a tropical setting near the equator (e.g. Sloan 2005). A shallow epicontinental (on-continent) sea spread across a land surface of low relief, cutting into mostly Middle Proterozoic clastic sedimentary rocks.

These fossiliferous formations include the basal coarse-grained Mt. Simon sandstone, the fine-grained Eau Claire sandstone and shale, and the overlying medium-grained Wonewoc Sandstone (formerly the Galesville sandstone; Mossler 2008). Above theWonewoc are the glauconitic sandstones of the Tunnel City Group (see Mossler 2008 for nomenclatural history of this unit). Formed during a second Late Cambrian transgression (sea level rise), a shallow epicontinental sea spread across an area of subdued relief and surrounded by islands of the Chengwatana Volcanic Group (at what is now Taylor Falls). The Saint Lawrence Formation, which overlies the Tunnel City Group, is composed of sandy dolomite, dolomite siltstones, and fine-grained dolomitic sandstone. The Jordan Sandstone overlies the St. Lawrence Formation and is comprised of two unofficial 'members': the basal Norwalk, and the Van Oser (Cavaleri et al. 1987). As described below fossils may be found in many of these formations within SACN and are similar to fossils from the same formations exposed in southeastern Minnesota along MISS (see MISS section for more information). Fossils might also be found within SACN in Pleistocene-Holocene sediments (primarily glacial) or within cultural resource contexts, as described below.

Small-scale (regional or county) geologic maps have been published for much of the SACN, especially the by the Minnesota Geological Survey (in St. Paul) and the Wisconsin Geological and Natural History Survey (Madison). For Minnesota, Washington County bedrock (Proterozoic-Cambrian-Ordovician) and surficial/glacial (Pleistocene-Holocene) maps were published by Mossler and Bloomgren (1990) and Meyer et al. (1990). Similar maps have been produced for Pine County Minnesota (Boerboom 2001; Patterson and Knaeble 2001) and Chisago County maps will be completed within two years (A. Runkel, pers. comm., April 2008). The West-Central sheet of the Bedrock Geology of Wisconsin provides regional geologic map for the Pierce and southern St. Croix county sections of SACN (Brown 1988). The Northwest Sheet (Mudrey et al. 1987) provides regional bedrock geologic map for northern St. Croix, Polk, and Burnett counties. The Pleistocene geology of Polk County is further detailed by Johnson (1998). Separate bedrock mapping does not exist for the northern reaches of SACN, as much of the region is buried under thick glacial deposits. Mudrey et al. (1982), however, published the bedrock geologic map for the state of Wisconsin which can be used as a general reference. The Pleistocene geology of the northern portion of SACN (Burnet, Washburn, Sawyer, Douglas, and Bayfield counties) was mapped by Clayton (1985) and includes areas where Paleozoic bedrock is exposed.

The bedrock geology of the region is primarily exposed along the southern portions of the SACN corridor, particularly along "The Dalles" in the Interstate Park/Taylor Falls/St. Croix Falls area. Bedrock might also be visible along the uppermost reaches of SACN along the St. Croix River in Douglas County (e.g. Clayton 1985). There are small outcrops of Cambrian bedrock) along the St Croix River in northernmost Chisago and southern Pine County on the Minnesota side of the river, and across the river in Wisconsin (Burnett County). Fossils might be visible in any of the exposures of the formations listed below. However, some localities are known to produce fossils including the Taylor Falls and St. Croix Falls areas and exposures near the Soo Line Drawbridge (aka Cedar Bend Drawbridge).

The Cambrian and Ordovician formations described below are also detailed in guidebook for southwestern Wisconsin (Ostrom et al. 1970). Nehm and Bemis (2002) describe common Paleozoic fossils of Wisconsin and include detailed line drawings of various specimens in an accessible, non-technical format. Conodonts (tooth-like elements of enigmatic marine organisms) are exceptionally important biostratigraphic fossils and are used for both regional and global correlation. Southern Wisconsin (outside of SACN) contains many important conodont localities for the same formations mapped within the park (Clark 1971). Runkel et al. (2007) utilized more than three dozen localities throughout Minnesota, Wisconsin, and Iowa in a detailed study of the Middle Cambrian-Lower Ordovician sequence stratigraphy of the area. Localities 1-12 are along or near the Saint Croix River valley. The supplemental material (see Literature Cited) for their paper describes fossil localities and collections made during their study.

Sources of Paleontological Resources

Mt. Simon, Eau Claire and Wonewoc formations (Upper Cambrian)

From lowest (oldest) to highest (youngest), the Mt. Simon Formation, Eau Claire Formation, and the lower Wonewoc Formation were historically referred to as the "Dresbachian" Sequence, a now obsolete Upper Cambrian stratigraphic term. The Mt. Simon Formation (or Mt. Simon Sandstone) is exposed in upper reaches of the St. Croix River in Pine County Minnesota (Mossler 2008) and southern Burnett-northern Polk counties Wisconsin (Mudrey et al. 1987). The Eau Claire Formation is not well exposed in Minnesota (Mossler 2008) but is mapped in small areas along St. Croix River in Polk and St. Croix counties Wisconsin (Mudrey et al. 1987) and is well exposed at Willow Creek State Park (Little Falls) near Hudson Wisconsin, just east of SACN (Mossler 2008). The Wonewoc Formation (or Wonewoc Sandstone) is exposed primarily south of SACN and MISS, but a "few outcrops" are found in Chisago County Minnesota south of Taylor Falls (Mossler 2008). Likewise, Mudrey et al. (1987) mapped the Wonewoc in Polk and St. Croix counties, Wisconsin, but did not indicate many exposures. Where these formations are exposed however, fossils can be found as all are known to produce fossils in the St. Croix Valley (e.g. Nelson 1949) and St. Croix Falls, for example (Cavaleri et al. 1987).

Inarticulate brachiopods are the most common fossils known in the Mt. Simon Sandstone, near the top of the formation where they are sometime so abundant, they form "coquina" or shell hash layers; *Skolithos* (worm burrow trace-fossils) are also present (Driese 1979; Cavaleri et al. 1987; Mossler 2008). Trilobites of the *Cedaria* assemblage zone are present, but not abundant (Runkel et al. 1998). The Eau Claire Formation is the most fossiliferous unit in the Dresbachian sequence, containing numerous inarticulate brachiopods (forming coquinoid layers and lenses), worm burrows (especially *Planolites*), and a diversity of trilobites (Mossler 2008). These trilobites are known to occur in the *Cedaria, Crepicephalus, Aphelaspis,* and *Dunderbergia* faunal zone (Nelson 1951; Runkel et al. 1998, Mossler 2008). Hyolithids and a variety of acrotretid and other inarticulate brachiopods, such as *Dicellomus,* are also common within the Eau Claire Formation (Nelson 1949; Mossler 2008). The Galesville Sandstone member of the Wonewoc Sandstone contains sparse amounts of fossils, including trilobites of the *Aphelaspsi, Crepicephalus,* and *Dunderbergia* zones (Runkel et al. 1998; Mossler 2008). Fragments of inarticulate brachiopods, hyolithids, and monoplacophorans are also observed (Berkey 1897, 1898; Stauffer and Thiel 1941; Nelson 1949; Cavaleri et al. 1987; Mossler 2008). The Ironton member is dominated by trilobite faunas of the *Elvinia* zone (Nelson 1951). *Elvinia* zone trilobites, are known from coarse conglomerates in the Taylor Falls area, as is an uncommon molluscan fauna collected at Interstate Park from a basalt boulder conglomerate that accumulated near the Upper (Late) Cambrian shoreline, not in an intertidal zone (Yochelson and Webers 2006). Invertebrate burrow trace fossils are also known from the Ironton (Mudrey et al. 1987).

Tunnel City Group (Upper Cambrian)

The Tunnel City Group is mapped, and exposed extensively, along the Saint Croix River in Chisago and Washington counties in Minnesota and Polk and St. Croix counties in Wisconsin (Mudrey et al. 1987; Brown 1988; Mossler and Bloomgren 1990; Mossler 2008). The Tunnel City Group was formerly known as the Franconian Formation in Minnesota, and along with the Ironton Member of the Wonewoc Formation (summarized above) was part of the "Franconian Stage", a now-obsolete Upper Cambrian stratigraphic term. All of the Tunnel City Group formations are potentially fossiliferous in the SACN corridor.

The Tunnel City Group consists of three formations, the Lone Rock Formation, the Davis Formation (not exposed near SACN), and the Mazomanie Formation. The Tunnel City Group (formerly the Franconian Formation; Mossler 2008) is dominated by trilobites of the *Elvinia* and *Conaspis* zones, the *Prosaukia* and *Ptychaspis* subzones, and the basal part of the *Saukia* zone (Mossler 2008, Cavaleri et al. 1987, Nelson 1951). This formation is interpreted as shallow inner marine environment. The Lone Rock contains three members: the Birkmost, Tomah, Reno. The Birkmost member contains worm-burrows and trilobites from the *Elvinia* zone in its fine-grained feldspathic sandstones (Cavaleri et al. 1987). The top of the Birkmost member also contains the earliest known articulate brachiopods in Minnesota ("*Eorthis* beds"; Berg 1951; Mossler 2008). The Tomah Member is only very rarely exposed as it is quite thin and frequently covered by vegetation, however it does outcrop near Hudson in St. Croix County (Mossler 2008). Mossler (2008) also reported that the Tomah almost always preserves fossils, particularly trilobite molds, when it is exposed. The Reno Member is fine grained, glauconitic, feldspathic sandstone with interclast of dolostone, containing numerous worm-burrows, inarticulate brachiopods, gastropods and conodonts (rare) from the uppermost part of the member (Cavaleri et al. 1987, Stauffer and Thiel 1941, Runkel unpublished data, Mossler 2008). The Mazomanie Formation rarely contains body (generally trilobite) fossils in Minnesota (Mossler 2008). Runkel et al. (2007) collected trilobites from "Boom Hollow" (near Stillwater, Minnesota) along the west bank of the St. Croix River.

St. Lawrence Formation (Upper Cambrian)

The St. Lawrence Formation is mapped in Washington County Minnesota with the underlying Tunnel City Group (Franconia Formation) (Mossler and Bloomgren 1990). However in Wisconsin, the formation is mapped with the overlying Jordan Formation (Mudrey et al. 1987; Brown 1988). Nomenclature aside, the only exposures of the St. Lawrence are possible in the southern reaches of SACN (southern Chisago

and Washington counties, Minnesota and southern St. Croix County, Wisconsin) where the siltstone facies is common (e.g. Mossler 2008). Fossils are known from the St. Lawrence Formation.

The St. Lawrence Formation is dominated by trilobites of the *Osceolia* and *Saukia* subzones (Raasch 1951, Hughes 1993 and 1994, Mossler 2008). Aglaspid arthropods (Hughes and Hesselbo 1997; Raasch 1939; Hesselbo 1992), trace fossils (commonly burrows along bedding planes), inarticulate and articulate brachiopods, gastropods, dendroid graptolites (Ruedemann 1933), phyllocarids, rare hyolithids, "serpulids," possible primitive conulariids (Raasch 1939), and echinoderm columnals are also known from the St. Lawrence Formation. This formation contains two recognized members in Wisconsin, the Lodi, a dolomitic siltstone and very fine sandstone (dolostone lithofacies, Mossler 2008), and the Black Earth, a glauconitic dolostone (siltstone lithofacies, Mossler 2008). The Black Earth member, interpreted as a tidal flat deposit, is known to contain stromatolites (Byers 1978; Cavaleri et al. 1987).

Graptolites were described by Prout (1851) from "lower Silurian Rocks" near the falls of the Saint Croix River near Osceola. Prout's 1851 description of the rock's as "lower Silurian" came before the Ordovician Period was named in 1879, so "lower Silurian" refers to Upper Cambrian. Therefore these fossils might be from the St. Lawrence Formation, which is well exposed at Osceola and is known to contain graptolites (A. Runkel, Minnesota Geological Survey Chief Geologist, pers. comm., April 2008; Hughes and Hesselbro 1997).

Jordan Sandstone (Upper Cambrian)

As mentioned above, the Jordan Sandstone in Wisconsin is commonly mapped with the St. Lawrence Formation (Mudrey et al. 1987; Brown 1988). It crops out in numerous places in the southern St. Croix River Valley, but is only sparingly fossiliferous. This formation is also exposed in the MISS-corridor (see MISS section).

The Jordan Sandstone in the St. Croix River Valley is composed of two unofficial members: the Norwalk and the Van Oser. A meager trilobite fauna of the *Saukia* Assemblage Zone, brachiopods, and abundant conodonts are known from the Jordan Formation (Nelson 1956, Webers 1972, Runkel et al. 1999, Mossler 2008). The Norwalk 'member' is a very fine to fine-grained sandstone that is known to be extensively burrowed, with *Planolites* identified at many outcrops (feldspathic lithofacies, Mossler 2008). It was deposited in an offshore shelf environment (e.g. Runkel 1994, Runkel et al. 2007) The Van Oser 'member' is characterized by cross-bedded fine- to coarse-grained quartz sandstone with *Skolithos* and *Arenicolites* burrows common (quartzose lithofacies, Mossler 2008). Fossils assigned to the Jordan by Stauffer (1925) are known from the middle of the formation near the Soo Drawbridge in Washington County, and at Osceola, Wisconsin. Nelson (1949) reported several Jordan Sandstone trilobite localities, and Hughes and Hesselbo (1997) and Runkel et al. (2007) have confirmed them.

Prairie du Chien Group (Lower Ordovician)

The Lower Ordovician Prairie du Chien Group contains the youngest Paleozoic rocks mapped along SACN (Brown 1988; Mossler and Bloomgren 1990) in Washington County Minnesota and St. Croix and Pierce counties Wisconsin. The Prairie du Chien Group is divided into the older (lower) Oneota Formation and the upper (younger) Shakopee Formation as described in greater detail in the MISS section of this report. The Prairie du Chien Group is sparingly fossiliferous with generally low abundance and low diversity (Mossler 2008). However, stromatolites (cyanobacterial mats) and thrombolites (another type of cyanobacterial cluster) are well known from the Prairie du Chien Group.

The Coon Valley was formerly a member of the Jordan Sandstone but is now recognized to be the lowermost member of the Oneota Dolomite in the Prairie du Chien Group (Lower Ordovician, Cavaleri et al. 1987, Mossler 2008). A widespread but obscure regional unconformity beneath the Coon Valley Member beds represents a major hiatus and justifies its revision (Runkel et al. 1999, Mossler 2008). The Coon Valley Member is fine- to medium-grained quartz sandstone with sandy to cherty dolostone, with minor fine grained feldspathic sandstone. This member is known to contain stromatolite beds, common and occasional abundant conodonts, along with the trilobite *Saukia* zone (Odom and Ostrom 1978,

Nelson 1951, Cavaleri et al. 1987, Furnish 1938, Smith and Clark 1996, Mossler 2008). The Shakopee Formation fossil record includes abundant stromatolites and much less abundant gastropods and cephalopods (Mossler 2008).

Glacial and Recent Deposits (Pleistocene-Holocene)

Most of the SACN bedrock north of Burnett County, Wisconsin is obscured by extensive glacial or more recent fluvial deposits. In the northernmost SACN (both St. Croix and Namekagon rivers) these deposits include spillway sediments (from proglacial lakes approximately 11,500-9500 years before present) of the Miller Creek Formation and proglacial streams of the Copper Falls Formation (approximately 16,000-11,500 years before present) as mapped by Clayton (1985). Modern marshes, wetlands, floodplains, steep scarps of unlithified sediments, and postglacial terraces are also mapped along St. Croix River in Polk County (Johnson 1998). Fossils are not common within these deposits in the SACN corridor. However, one occurrence of Pleistocene vertebrate fossils at Interstate Park (Polk County) deserves special mention, and is described below.

As described by West and Dallman (1980), the Late Pleistocene and Holocene vertebrate fossil record in Wisconsin has been sporadically studied since the 1860s and unfortunately many early specimens and locality information has been lost. Nevertheless, mammoth, mastodon, bison, muskox (*Ovibos* and *Symbos*) peccary, beaver (*Castoroides* and *Castor*), deer (*Odocoileus*, *Cervus*), caribou (*Rangifer*) and fish are known from Wisconsin. Within Interstate Park, immediately adjacent to SACN in Polk County, Wisconsin, some 300 bison specimens were discovered in 1936 (West and Dallman 1980 reporting results from Palmer 1954) in a postglacial peat bog. This is one of the larger samples of postglacial bison. In addition, the fossils were found in direct association with American Indian artifacts (West and Dallman 1980). As the park has developed, the site is apparently no longer available.

Fossils in Cultural Resource Contexts

As described in Kenworthy and Santucci (2006), fossils are found throughout the NPS in building stones and as archaeological resources in addition to ethnographic and historic accounts. Although none are yet documented, structures along the southern reaches of SACN might display fossils if local fossiliferous building stones were used in their construction. The Interstate Park example given above by West and Dallman (1980) described bison bones in direct association with American Indian artifacts. Further research may shed additional light on these occurrences or reveal new instances.

Park Collections

While no fossils are specifically noted from park collections (K. Byrne, HFC Curator, personal commun., 2008), Nelson acknowledges the University of Minnesota as the repository for the trilobites used in his 1951 study (unless otherwise specified: University of Wisconsin, American Museum of Natural History, and the U.S. National Museum).

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division-sponsored geologic scoping sessions have not yet been held for SACN. Paleontological resources are not known from within the park collections but are known from the geologic formations mapped within the park.
- Given the diversity of paleontological resources in SACN, as well as the potential for unauthorized collection, a field-based inventory of paleontological resources from the park is recommended.
- The field work could be accomplished by establishing a cooperative agreement with one or more of the dominant natural history museums with paleontological expertise, such as the University of Minnesota or the University of Wisconsin at Madison. Graduate students could be hired non-competitively using the STEP hiring authorities and supervised by a partnership of a faculty

advisor and a park natural scientist. The NPS Geologic Resources Division can help advertise, recruit, and provide technical assistance for these positions.

- Interviews with the dominant specialists within each discipline that have worked in the park would provide considerable background. These interviews should be documented and archived by the park.
- The park would benefit from an effort to locate specimens that have already been retrieved and stored in other repositories. Molds of the holotypes and/or other significant specimens could be made and casts placed in the museum collections. Scientifically significant material encountered in the field should be stabilized *in situ* or retrieved and curated into dedicated storage if threatened.
- Park staff should be encouraged to observe exposed cliffs, other erosional bedrock, and streams for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- The establishment of a study collection of fossils from the local area could be beneficial. A field-based inventory could provide specimens for such an endeavor.
- Results of a field inventory could lead to development of paleontological resource monitoring prescriptions. A forthcoming (2008) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management along hydrological features.
- The NPS Geologic Resources Division is a source of assistance regarding paleontological resource management and/or interpretation at SACN.

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Sleeping Bear Dunes National Lakeshore

Sleeping Bear Dunes National Lakeshore (SLBE) was established on October 21, 1970 by President Richard M. Nixon. "Be it enacted…That the Congress finds that certain outstanding natural features, including forests, beaches, dune formations, and ancient glacial phenomena, exist along the mainland shore of Lake Michigan and on certain nearby islands in Benzie and Leelanau Counties, Michigan, and that such features ought to be preserved in their natural setting and protected from developments and uses which would destroy the scenic beauty and natural character of the area." The park now protects 28,813 ha (71,199 acres), including 105 km (65 miles) of Lake Michigan shoreline.

Geologic Background

Sleeping Bear Dunes National Lakeshore is located in Northwestern Lower Michigan along the shores of Lake Michigan. The lakeshore is covered by recent (Holocene) alluvium, dune sand, and Pleistocene glacial deposits (Handy and Stark 1984). There are two levels of sand dunes that occur in the park: dunes near the modern level of Lake Michigan and dunes on morainal plateaus above the lake.

Glacial deposits, primarily moraines and outwash areas, in the park range from 150 m to 213 m (500-700 ft) thick (Handy and Stark 1984). Glacially derived sediments from Pleistocene retreat are characterized by westward sloping drumlinized till plains, moderately buried by crevice-fill and outwash deposits, as well as lacustrine and eolian sediments (Milstein 1987; Wallbom and Larson 1999). Limestone belonging to the Traverse Group (Devonian) and shale from the Antrim Shale (Devonian) underlie the glacial deposits within SLBE. "Petoskey Stones", rugose coral fossils, are known from within the park as they wash up on the beaches. Their source may be the Traverse Group and/or an offshore geologic unit. Other marine invertebrates commonly wash up along the beaches of SLBE and have been subject to unauthorized collection along with the Petoskey Stones. The "Fossil Collecting in SLBE: Management Strategies" section below outlines efforts by SLBE staff to mitigate this impact. Important fossils are also known from the Pleistocene-Holocene glacial deposits of SLBE.

Sources of Paleontological Resources

Traverse Group (Middle Devonian)

"Petoskey Stones," the colonial rugose coral *Hexagonaria percarinata* (also the State stone of Michigan), have been found in SLBE, but appear to wash in from a different source. It is also possible that these corals occur locally in the Traverse Group within the Alpena Limestone, as they do elsewhere in the state, and wash ashore as Petoskey Stones within the park. Fossils of many other corals most notably the solitary coral genus *Heliophyllum* and the tabulate coral genus *Favosites* may also wash up along the beach. Brachiopods, bryozoans and stromatoporoids (sponge-like reef builders) are also found in beach washed gravels (S. Wilson, Michigan Geological Survey, pers. comm., April 2008). The Alpena Limestone contains both limestone and shales, and is limited in exposure to the Traverse Bay area near Petoskey (S. Wilson, Michigan Geological Survey, pers. comm., 2007).

Antrim Shale (Upper Devonian)

Uplift in the Appalachian region during the late Devonian swept great amounts of muds into the Michigan Basin area, which formed the Antrim Shale. While no fossils are known from the Antrim Shale within the park, fossilized wood fragments have been found from this unit in other parts of the state (Dorr and Eschman 1970).The Antrim Shale also forms some of the bedrock beneath Indiana Dunes National Lakeshore (see INDU section of this report).

Glacial and Postglacial Deposits (Pleistocene-Holocene)

Gates (1939) initially described a unique fossil occurrence within the Pleistocene (Ice Age) dunes of SLBE. The Sleeping Bear Dunes fauna is an important part of the Pleistocene vertebrate record of Michigan listed by Wilson (1967). While Gates (1939) and Pruitt (1954) do not give any date for the fossil remains they identify, Wilson (1967) identifies the fossil remains in his paper as being Pleistocene in age. Taxa identified by Gates, Pruitt and Wilson include six species of mollusk (UMMP 171835-171841) and twenty three species of mammals (UMMP 29391-29406, 30088-30092, 30107-30109, 30115-30117, & 30158) including woodchuck, chipmunk, squirrels, beaver, mouse, muskrat (first record in Michigan), voles, raccoon, marten, fox, dog and deer. Wilson (1967) lists a catfish from the Sleeping Bear Dunes locality as well. Wilson illustrated that the presence of the prairie vole *Microtus ochrogaster* supported the idea of climatic reversal prior to historic time. A radiocarbon date on this particular specimen (UMMP 29399) was 730 ± 250 years before present. Davis et al. (1998) summarized the pollen and paleoecological history from Green and Tamarack lakes over the last 12,500 years as part of a paleoecological study of the Great Lakes region.

Park Collections

Twenty-nine fossil species have been collected at Sleeping Bear Dunes National Lakeshore and include. While these collections are not reposited in the park's collections, they are curated at the Museum of Paleontology at the University of Michigan. Gates (1939), Pruitt (1954), and Wilson (1967) have all noted the presence of fossils within SLBE.

Fossils do not yet appear to be associated with American Indian activities within the park (J. Richner, MWAC Archeologist, pers. comm., January 2008). Nevertheless, fossils are known in association with many American Indian tribes of the Midwest and Minnesota (e.g. Mayor 2005) and many of the tribes had extensive trade networks throughout North American. Fossils were common trade and funerary items as documented at Hopewell Culture National Historical Park in Ohio and near Effigy Mounds National Monument in Iowa, as two examples. Kenworthy and Santucci (2006) presented an overview of NPS fossils found in cultural resource contexts.

Fossil Collecting in SLBE: Management Strategies along GLKN Shorelines

The following section was written by SLBE assistant superintendent Tom Ulrich and law enforcement ranger Patrick Schad (written commun., 2007). We include it here in its entirety as a resource for all GLKN parks and other NPS units that manage fossils washing up on beaches and associated "beachcombing" type activities. While all GLKN parks include some shoreline and potential for paleontological material to wash up along the beaches, APIS, INDU, ISRO, and PIRO, in addition to SLBE have documented such occurrences. Outside of GLKN, NPS units with similar resource management issues include George Washington Birthplace National Monument in Virginia (Kenworthy and Santucci 2003), Curecanti National Recreation Area in Colorado, Colonial National Historical Park in Virginia (Kenworthy and Santucci 2003), Gateway National Recreation Area in New York and New Jersey (Kenworthy and Santucci 2003), and Padre Island National Seashore (Kenworthy, Santucci, and Visaggi 2007).

> "It is the opinion of Law Enforcement Rangers at SLBE that the most popular fossil collected within the park are Petoskey Stone, with other fossils, such as trilobites, horn corals, chain corals, and bi-valve species, being easily found along the beaches. From an enforcement standpoint, is usually easy to discern whether or not a visitor is committing a violation by collecting fossils and/or other rocks when beachcombing. Beach patrols are a normal part of a Ranger's daily/nightly procedures. If a violation is believed to have been observed, the Ranger(s) will survey the area, note behavior and activity, contact the possible suspect(s), and conduct an investigation that typically involves interviews. Based on the interview and observations, the Ranger will rely on discretion and Regulations to take the appropriate enforcement action. Appropriate enforcement actions may range from simply educating the people involved and

letting them go with a verbal warning or written Warning Notice, or Violation Notices may be issued along with equipment and evidence seizure

The types of fossil-collectors/rock-collectors Law Enforcement Rangers encounter can be classified as personal-use and commercial-intent collectors. The first type of personal-use collector is a person who has no idea that collecting fossils/rocks within SLBE is illegal and who is genuinely surprised to learn that fossils/rocks are protected. This person will actively and willingly comply with the regulations after an educational contact. This person is usually in possession of one or just a few stones and simply educating him/her and relying on a verbal warning will ensure compliance with the regulations. The second type of personal-use collectors are the people who suspect they shouldn't be collecting but will do it anyways. These people are not surprised to learn their activity is illegal, rather they are surprised that someone is actually taking the time to contact them about it. Amounts of collected stones might range from pockets-full to small bucket-loads. In these cases Warning Notices and/or Violation Notices may be issued.

People with commercial-intent are collectors who remove resources from the park for personal gain/profit. Whether it is someone who is collecting gem-stone quality rocks or is avoiding the purchase of bulk rocks from a retail outlet, some sort of profit will be made by removing these resources from public land. Some examples are rock-gardens, landscaping, stone-masonry, souvenir sales, and sales to curio shops and rock dealers. Removal of fossils/rocks may be select and discriminating or the value may be in the quantity taken. People who fall in this category may have specialized equipment for collecting: examples may include rock-hammers, identification manuals, five-gallon buckets, retrieval hooks, underwater viewing boxes, pickup trucks, etc. Law Enforcement Rangers may encounter collectors who, while engaged in collecting, are also actively trying to avoid detection by law enforcement and who might use deceit when confronted in an effort to avoid penalties. The totality of the circumstances will make commercial-intent collectors stand out from the casual visitor who happens to pocket one or two interesting-looking stones. Enforcement action takes into consideration the severity of the violation, the investigation, and the intent of the regulation that protects the fossils/rocks: Commercial-intent collectors are usually issued Violation Notices, their equipment may be seized, and all fossils/rocks are seized as evidence."

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division-sponsored geologic scoping sessions have not yet been held for SLBE. Paleontological resources are known from within the park collections (but are reposited outside SLBE) and are known from the geologic formations mapped within the park.
- Given the diversity of paleontological resources in SLBE, as well as the potential for unauthorized collection, a field-based inventory of paleontological resources from the park is recommended.
- The field work could be accomplished by establishing a cooperative agreement with one or more of the dominant natural history museums with paleontological expertise, such as the Museum of Paleontology at the University of Michigan. Graduate students could be hired non-competitively using the STEP/SCEP hiring authorities and supervised by a partnership of a faculty advisor and a park natural scientist. The NPS Geologic Resources Division can help advertise, recruit, and provide technical assistance for these positions.
- Interviews with the dominant specialists within each discipline that have worked in the park would provide considerable background. These interviews should be documented and archived by the park.

- The park would benefit from an effort to locate specimens that have already been retrieved and stored in other repositories. Molds of the holotypes and/or other significant specimens could be made and casts placed in the museum collections. Scientifically significant material encountered in the field should be stabilized *in situ* or retrieved and curated into dedicated storage if threatened.
- Park staff should be encouraged to observe exposed cliffs, other erosional bedrock, and streams for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- The Petoskey Stones that wash ashore have presented a collection problem in the past as described above. Due to their interest to collectors, the park may should continue efforts to instruct visitors as to their importance and encourage visitors to not collect them.
- The establishment of a study collection of fossils from the local area could be beneficial. A field-based inventory could provide specimens for such an endeavor.
- Results of a field inventory could lead to development of paleontological resource monitoring prescriptions. A forthcoming (2008) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management along hydrological features.
- The NPS Geologic Resources Division is a source of assistance regarding paleontological resource management and/or interpretation at SLBE.

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Data Sets

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

Sleeping Bear Dunes National Lakeshore Museum Collections
1982-present. (museum specimen; associated specimen notes; collection records; maps; etc.). Originated by SLBE staff; status: Active.

University of Michigan Museum of Paleontology Collections
1980s-present. (museum specimens; associated specimen notes; collection records; maps, etc.). Originated by museum staff; status: Active.

Voyageurs National Park

Voyageurs National Park (VOYA) preserves 88,300 ha (218,200 acres), with 40% of this area covered by four large lakes. VOYA was established on April 8, 1975 to "preserve, for the inspiration and enjoyment of present and future generations, the outstanding scenery, geological conditions, and waterway system which constituted a part of the historic route of the Voyageurs who contributed significantly to the opening of the Northwestern United States."

Geologic Background

Voyageurs National Park is located in northern Minnesota along the Canadian border. It is the only park unit in which surface waters drain entirely northward to Hudson Bay. The bedrock is well exposed along lake shores and consists of 2.7 billion year-old (Archean) igneous and metamorphic rocks, 2 billion year-old (Proterozoic) diabase dikes, and glacially derived sediments. The Archean rocks include a greenstone belt exposed in the northwest corner of the park, where a gold mine operated from 1894-1897 on Little America Island. South and east of the greenstone belt, major rock types include biotite schist of sedimentary origin, and igneous rocks that are part of the Vermilion Granitic Complex. A bedrock geologic map of the park area (Hemstad and others 2002) is available as a free PDF file from the Minnesota Geological Survey website (ftp://mgssun6.mngs.umn.edu/pub2/m-125/). Graham (2007) produced a geologic resource evaluation report summarizing the geology, geologic features and processes within VOYA. The project, sponsored by the NPS Geologic Resources Division also resulted in the compilation of a geologic map for the park, based on the Hemstad et al. map. Copies of the report are available from the GRD website (http://www.nature.nps.gov/geology/inventory/gre_publications.cfm.). No fossils have been reported from the park's bedrock, which is some of the oldest in North America. However, fossils have been discovered within sediment cores at Cayou Lake there are two fossils within the park's collections.

Potential Sources of Paleontological Resources

Postglacial Deposits (Pleistocene-Holocene)

While fossils are not known from the park's bedrock, important paleoecological data is contained within sediment cores from Cayou Lake as described by Davis et al. (1998) and Winkler and Sanford (1998). Both of these reports detail the transition in pollen type from cold and dry spruce-poplar parkland (more than 10,600 years before present) to a colder steppe environment (sparse spruce) likely associated with glacial Lake Agassiz at approximately 9,900-10,000 years before present. Following the draining of Lake Agassiz, a boreal forest with spruce, jack pine, alder and willow existed by approximately 9,000 years before present. A very warm period (compared to the rest of the last 10,500 years) existed from approximately 8,000 and 4,000 years before present. From approximately 4,000 years before present until pre-European settlement, the area was cooler and wetter. Over the last hundred or more years, anthropogenic impacts are well documented in pre-logging and logging time periods (Winkler and Sanford 1998). Winkler and Sanford (1998) also describe potential vegetation changes due to global warming.

Park Collections

There are only two known fossil specimens within VOYA park collections (catalog numbers 6104 and 6107) which were identified during archeological investigations conducted in 1978 and 1979. (Mary Graves, VOYA Lead Resource Specialist, pers. comm., April 2008). Both are a species of coral, with one (catalog number 6104) appearing to be a variety of tabulate coral. The specimens were both discovered on eroding beaches. The site that produced 6107 is one of the best examples of a paleosol (ancient soil layer) preserved in the park (M. Graves, pers. comm., April 2008). A planned geomorphological survey of VOYA will study the correlation between soil benches and archeological resources, and might be a source of additional material. Fossils do not appear to be commonly associated with American Indians or

Voyageurs within the park (J. Richner, MWAC Archeologist, pers. comm., January 2008). Nevertheless, fossils are known in association with many American Indian tribes of the Midwest and Minnesota (e.g. Mayor 2005). Kenworthy and Santucci (2006) presented an overview of NPS fossils found in cultural resource contexts.

The Ellsworth Rock Garden is a unique resource within VOYA. The more than 200 original rock sculptures were crafted from "local material" (e.g. Graham 2007). All of the rock within the garden was apparently collected in what is now the park (M. Graves, pers. comm., April 2008). Therefore, fossils would not be expected within the rock sculptures.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division-sponsored geologic scoping sessions have been held for VOYA and a geologic resource evaluation report was completed (Graham 2007). Paleontological resources are not known from the geologic formations mapped within the park. However, fossils were utilized from the park for paleoecological studies and are known within park collections.
- Future discoveries of fossils within VOYA are not likely but fossils have been found in both the Proterozoic and glacial sediments in northeastern Minnesota. Additional fossils may be found in subsequent archeological excavations or further sediment core studies. Further research into the fossils in the collection may elucidate a connection between paleontological resources and the American Indians and/or Voyageurs in the VOYA area.
- Due to the lack of documented *in situ* fossil occurrences within the park, and the unlikelihood of extensive macrofossil discovery within the park, establishment of a paleontological resource management plan is not necessary at this time.
- The NPS Geologic Resources Division is a source of assistance regarding paleontological resource management and/or interpretation at VOYA.

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

Voyageurs National Park Museum Collections
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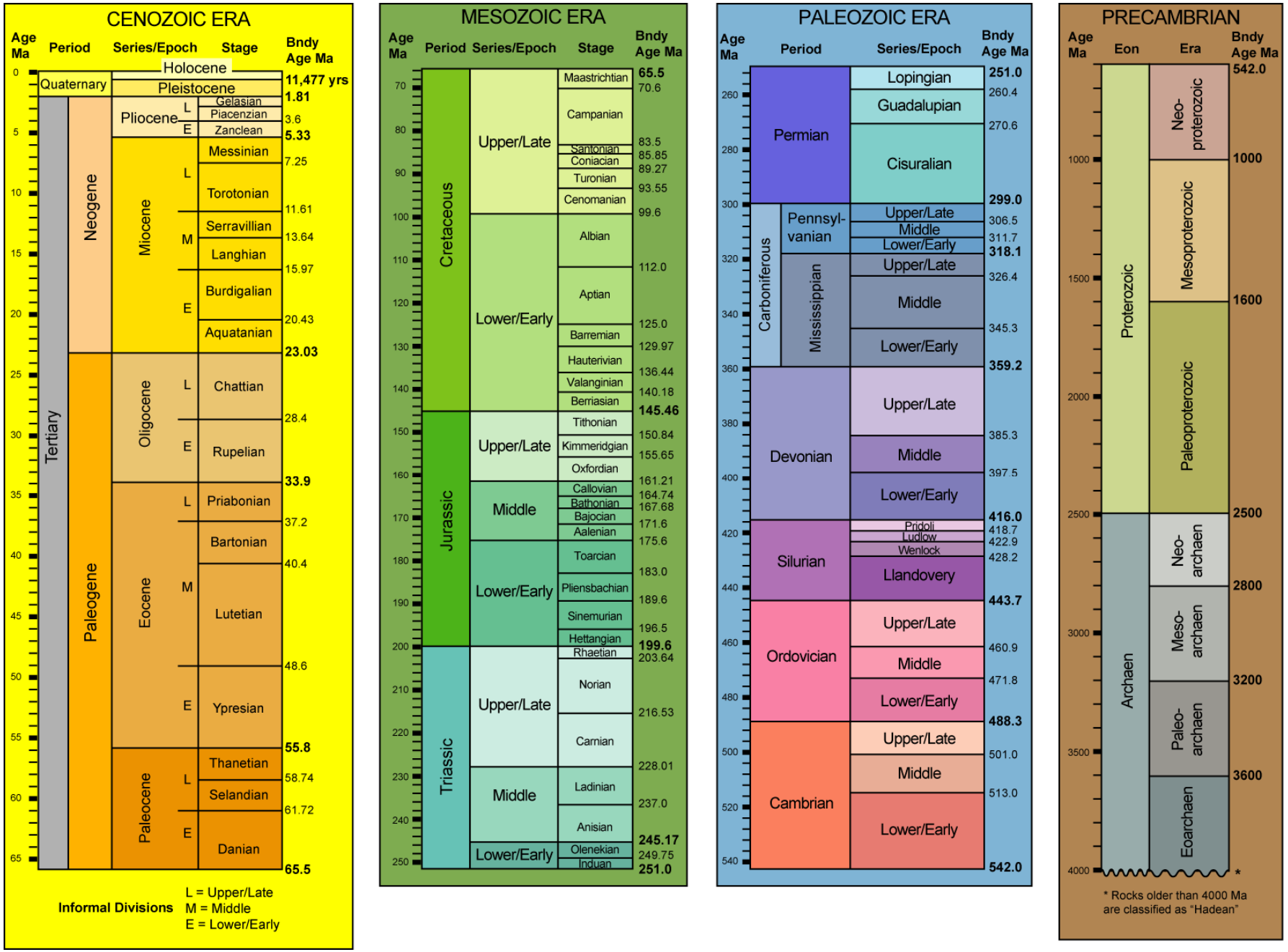


Figure 2. Geologic Time Scale. *Ma = Millions of years old. Bndy Age = Boundary Age*. Colors are USGS standard colors found on geologic maps. Modified from 1999 Geological Society of America Time scale (www.geosociety.org/science/timescale/timescl.pdf). Boundary dates and additional information from 2004 International Commission on Stratigraphy (www.stratigraphy.org/gssp.htm) and U.S. Geological Survey Fact Sheet 2007-3015 (http://pubs.usgs.gov/fs/2007/3015/).

The Great Lakes Network (GLKN) is one of 32 similar networks across the United States and part of the NPS strategy to improve park management through greater reliance on scientific information. The GLKN consists of nine national park units in the upper Midwestern United States. The nine units extend from the boreal forests of northern Minnesota to the sand dunes of southern Lake Michigan. Together they represent the major freshwater ecosystems and terrestrial landforms of the Upper Midwest.

The purpose of the inventory and monitoring (I&M) program is to design and implement long-term ecological monitoring and provide results to park managers, science partners, and the public. The intent is to provide periodic assessments of critical resources to evaluate the integrity of park ecosystems and better understand ecosystem processes.



www.nature.nps.gov/im/units/glkn

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS D-65, May 2008

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