National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Paleontological Resource Inventory and Monitoring

Arctic Network

Natural Resource Technical Report NPS/NRPC/NRTR—2009/276



ON THE COVER
Mammoth and mastodon tusks are commonly discovered in surficial deposits in the Beringia and in the Arctic region. As a source of ivory for artists and collectors, fossil tusks are subject to unauthorized collection from public lands in Alaska. Historic photo from what is now Bering Land Bridge National Preserve. Photo from NPS files.

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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

The National Park Service, Natural Resource Program Center publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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

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

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

This report is available from the Arctic Network intranet (http://www1.nrintra.nps.gov/im/units/ARCN/index.cfm; NPS access only) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/NRPM).

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Abstract

Paleontological resources (fossils) are any remains of past life preserved in a geologic context. Paleontological resources are non-renewable resources found in at least 221 National Park Service units. Despite the abundance and diversity of these resources throughout the NPS, until recently few parks have adequate baseline paleontological resource data.

The NPS National Inventory and Monitoring Program and the NPS Geologic Resources Division have developed various strategies to provide parks with the baseline paleontological resource data necessary for greater understanding and appropriate management of these resources. This report presents a paleontological resource summary for the parks of the Arctic Network. The summary was compiled through extensive literature reviews and interviews with park staff and professional geologists and paleontologists. Preliminary paleontological resource management recommendations are also included for each park. Including this report, summaries have been prepared for 28 NPS Inventory and Monitoring Networks. The National Inventory and Monitoring Program provided funding to complete these paleontological resource summaries for each of the networks.

In general, the paleontological resources known from the parks of the Arctic Network are of Paleozoic age, with far lesser numbers of fossils coming from the early Mesozoic and Cenozoic. The network parks include Bering Land Bridge National Preserve (BELA), Cape Krusenstern National Monument (CAKR), Gates of the Arctic National Park and Preserve (GAAR), Kobuk Valley National Park (KOVA), and Noatak National Preserve (NOAT). These parks are all predominately underlain by Paleozoic basement rocks of the Arctic Alaska Terrane, and with the exception of BELA, lie in or adjacent to the Brooks Range of Alaska, which contains an extensive area of uplifted and deformed Paleozoic rocks surrounded by Mesozoic sediments. Although many of these rocks are comprised of fossiliferous Paleozoic carbonate sediments, they display various degrees of metamorphism that frequently makes fossil identification difficult or impossible. In general, fossils known from the rocks include conodont, radiolarian and lesser numbers of foraminifer microfossils, and invertebrates that include brachiopods, rugose corals, trilobites, graptolites, stromotoporoids, bryozoans, echinoderms (including many types of crinoids), gastropods, bivalves, and cephalopods. There are few vertebrate remains other than conodonts elements known from rocks of this age. Early Paleozoic fossils of the Brooks Range are of tropical aspect. The area moved north to cooler mid-latitudes by the Late Paleozoic. The Mesozoic rocks primarily contain radiolaria and bivalves. Although there is probably a rather rich Quaternary and Holocene fossil record in the parks, little is known from these deposits with a few exceptions. The most common vertebrate fossils from these more recent surficial deposits include mammoths, bison, horses, dogs, deer, and rodents. Several rich insect localities are known from Cenozoic deposits in BELA as well. The Pleistocene and Holocene fossils may have considerable significance in understanding early human migration and culture in the area.

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Finally, this report would not have been possible without the funding from the National Inventory and Monitoring Program and the support of the North Coast and Cascades Network and Geologic Resources Division. The enthusiasm and support of Bert Frost (Associate Director; NPS Natural Resource Stewardship and Science) and Steve Fancy (National Inventory and Monitoring Program Leader) is acknowledged. We extend a sincere thanks to Bert and Steve for providing the means upon which this work, and similar work, can be accomplished.



Dedication

We dedicate the Arctic Network Paleontological Resource Inventory and Monitoring report to Steve Fancy, National Inventory and Monitoring Program Leader, National Park Service Inventory and Monitoring Division. Steve's interest in and direct support of a Servicewide inventory for paleontological resources has enabled a greater understanding of the fossil record preserved throughout the National Park System.

Introduction

Paleontological resources, or fossils, are any remains of past life preserved within a 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 221 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 Inventory Strategies and Methodology section of this report. This report presents paleontological resource inventory and monitoring data compiled for the parks of the Arctic I&M Network (ARCN).

The Arctic Network is one of four networks in Alaska. It includes five National Park Service areas as shown in Figure 1. These include Gates of the Arctic National Park and Preserve (GAAR), Noatak National Preserve (NOAT), Kobuk Valley National Park (KOVA), Cape Krusenstern National Monument (CAKR), and Bering Land Bridge National Preserve (BELA). The network contains some of the nation's largest national parks, with GAAR being the second largest national park covering 3,428,702 ha (8,472,506 acres), and NOAT being not far behind at 2,660,598 ha (6,574,481 acres). The smallest park in the network is CAKR, which encompasses 267,014 ha (659,807 acres) along the northwestern coast of Alaska. Largely inaccessible by road, and encompassing nearly a quarter of all National Park Service public lands, few places on earth offer visitors a greater wilderness experience than the parklands of the Arctic Network. All of these parks, with the exception of BELA, lie north of the Arctic Circle and are in or directly adjacent to the Brooks Range, a broad area of uplifted Paleozoic bedrock that forms an east-west trending mountain range across northern Alaska. The pristine natural areas of this range contain abundant wildlife as well as extensive exposures of the rocks beneath.

Because of the remoteness of ARCN, most of the geologic research has been conducted by governmental agencies. Over a half century of geologic investigations (primarily by U.S. Geological Survey scientists, but also by Alaska Division of Geological and Geophysical Surveys, university and industry scientists) have yielded a fairly detailed understanding of the network's geology and paleontology, and indicate that most of the rock units contain considerable paleontological resources, and that there is potential for continued discovery.

The Arctic parks are found in a number of distinct physiographic provinces. Bering Land Bridge National Preserve lies south of the other parks in the northern section of the Seward Peninsula in western Alaska. BELA can be divided into the following physiographic zones: Northern Coastal Plain, Rolling Stream-dissected Uplands, Imuruk Lava Plateau, Kuzitrin Flats, and the Bendeleben Mountains. Prominent features of the northwestern coast are barrier bar and lagoon systems, and a series of relict beach ridges at Cape Espenberg contain significant archeological sites. Although BELA was mostly unglaciated during Wisconsin times, substantial deposits of glacial loess, gravels, silts, and a few moraines within the preserve reflect the effects of glacial advances and retreats in surrounding areas. BELA is located in what was once the interior of Beringia, a large land mass connecting North America and Asia during the last glacial maximum about 20,000 years ago, and perhaps more than 40 times during the Cenozoic Era. During the most recent connection, humans traversed this land mass, most likely in pursuit of big game. Potential big game included mammoth (*Mammuthus*), caribou (*Rangifer*), horses (*Equus*), camels (*Camelus*), and bison (*Bison*).

Cape Krusenstern National Monument protects a series of beach ridges located along the southern coast of Cape Krusenstern. The beach ridges, built up over thousands of years, contain evidence of prehistoric human populations. While Kotzebue Sound makes up CAKR's southern shore, the Chukchi Sea forms its western shore. The Noatak River separates CAKR from the NOAT along its eastern border. The monument contains two sets of low, rolling hills that reach heights of up to 610 m (2,000 ft) above sea level. The Mulgrave Hills to the north, and the Igichuk Hills to the south (which extend eastward into NOAT) are separated by a broad plain of coastal lowlands. These hills are composed of Paleozoic bedrock.

Noatak National Preserve lies in the mountainous regions adjacent to the Noatak River. The Noatak River originates in Gates of the Arctic National Park and Preserve to the east, and flows westward through the central portion of the NOAT preserve, before exiting at its western border and turning south to empty into Kotzebue Sound. Sandstone, shale, chert, and limestone make up the bedrock geology of both the De Long Mountains to the north of the Noatak River, and the Baird Mountains to the south of the river; all are part of the Brooks Range and are primarily composed of Paleozoic sedimentary rocks with subsidiary amounts of early Mesozoic sedimentary rocks. Intrusions of basaltic igneous rocks and klippen of oceanic gabbro and basalt occur as well. The lowland areas of the Noatak drainage are made up of sedimentary materials, including siltstones, sandstones and limestones. Unconsolidated deposits of gravel, clay, silt and sand are concentrated in the lower areas of the Noatak drainage, yet few Cenozoic fossils are known from these units.

Kobuk Valley National Park lies south of NOAT and is divided into three physiographic areas: the Baird Mountains, the Waring Mountains, and the Kobuk Valley (floodplains and terraces). The Baird Mountains, north and east of the Kobuk River, are a western extension of the Brooks Range and separate the Kobuk and Noatak rivers. They range in height from 760 m to 1,450 m (2,500 to 4,760 ft). The Baird Mountains are composed of Paleozoic rocks. On the south side of the Kobuk River lie the Waring Mountains, which are northeast-trending mountains that generally are less than 610 m (2,000 ft) high, and which contain Cretaceous sedimentary rocks. The Kobuk River runs through the lowland between these two sets of mountains. This lowland area is largely covered by glacial drift and alluvial deposits, including clayey till, outwash gravel, sand, and silt.

Gates of the Arctic National Park and Preserve lies east of the other parks and can be divided into four major physiographic zones. The Arctic Foothills at the northern boundary are characterized by east-west trending ridges, rolling hills, and irregular buttes with interspersed tundra plains. The foothills contain Paleozoic rock on their south margin and Mesozoic bedrock to the north. The Brooks Range Mountains form the largest physiographic zone in the park. These mountains are east-west trending and rise to heights of 2,440 m (8,000 ft) in the north and 1,830 m (6,000 ft) in the south, and are primarily composed of Paleozoic limestone and shale. The third physiographic region, the Ambler-Chandalar Ridge and Lowlands crosses the southern portions of the preserve. Large lakes such as Selby, Narvak, and Nutuvukti are located in this zone. The last region, the Kobuk-Selawik Lowlands zone encompasses the southernmost part of the preserve part of GAAR. Bedrock metamorphism in the southern part of the Brooks Range largely has destroyed any fossils present in much of GAAR. Pleistocene and Holocene fossils are known from surficial deposits scattered around GAAR.

Overall, the area covered by ARCN can be divided into eight east-west trending geologic provinces. These are defined by structural character, degree of metamorphism, and stratigraphy. They primarily reflect the deformational history related to the formation of the Brooks Range. In general, the network is bounded to the north and south (east for BELA) by relatively undeformed Cretaceous sedimentary rocks of the Colville and Koyokuk basins, respectively. In between are the geologic provinces of the Brooks Range, which generally increase in metamorphic grade to the south. The northern boundary of the northern network parks lies in the disturbed belt province, or near the boundary of that province and the crestal belt province to its south. The disturbed belt consists of complex, structurally broken and imbricated Mesozoic and Paleozoic rocks at the northern front of the mountain range. The crestal belt forms the northern part of the Brooks Range and consists of folded and thrusted Devonian to lower Cretaceous

rocks. Much of the southern part of the Brooks Range lies in the central belt, which forms the geographic core of the Brooks Range. This province is composed of ductilely deformed Paleozoic slate, phyllite, schist, carbonate rocks and gneiss. These sedimentary rocks mostly retain their primary textures. The southern parts of network parks may cross the following provinces: 1) the schist belt, which is mostly composed of schistose metasedimentary and metavolcanic rocks, 2) the phyllite belt composed of strongly deformed metasedimentary rocks, and 3) the greenstone belt with resistant metamorphosed basalt and chert. The southernmost extension of some network parks may lie within the Cretaceous sediments of the Koyokuk basin shed off of the uplifting Brooks Range. Because of the increase in metamorphic grade southward within the Brooks Range, the best potential for well preserved fossils in bedrock deposits, other than in the Cretaceous sediments to the north and south, is in the crestal belt province.

The geology of the Arctic Network records a long period of Paleozoic platform deposition, first associated with rift tectonics and then a passive margin that adjoined ocean crust to the south beginning in the Devonian (Moore et al. 1997). Convergence in the adjacent ocean led to collision of an island arc with the passive margin in the middle Mesozoic. Bedrock of the Arctic Network parks can be placed in two terranes: the Arctic Alaska terrane, which consists of the passive margin deposits, underlies most of the park areas. The less extensive Angayucham terrane represents the remnants of the ocean basin and island arc rocks to the south (Moore et al. 1994). Terranes are fault bounded geologic bodies of rock that have been moved and deformed by tectonic forces. The Arctic Alaska terrane was divided into a number of subterranes or allochthons by Moore et al. (1994). Subsequently, the subterrane nomenclature has been replaced by allochthon nomenclature for the Brooks Range geology, as the character of these structural blocks has become better understood (Moore et al. 1997, 2004). Although allochthons more accurately place the stratigraphic units of the area into their structural position and context, this paper utilizes subterrane nomenclature for the most part, since it simplifies the nomenclature to some degree. The subterranes and/or allochthons used here for the network parks are from north to south: North Slope, De Long Mountains, Endicott Mountains, Hammond, Coldfoot, and Slate Creek. These roughly coincide with the geologic provinces of the Brooks Range noted above.

The geologic and deformational history of northern Alaska is complex and difficult to decipher due to superposed deformation, but sediments of the Arctic Alaska terrane largely record an extensive period of continental to marine deposition on a platform developed along a passive continental margin during the late Paleozoic and into the Early Mesozoic (see the appendix for a geologic time scale). The main land mass associated with this platform was situated to the present day north of the parks. Prior to the Permian, the platform included a highland situated to the present day south, and the deposition recorded in the parks occurred in a shallow sea between the two highlands (Moore et al. 1994). During the Permian, the highlands to the south subsided, and fine-grained sediments deposited on a passive margin platform blanketed the entire region. The platform continued to subside into the early Mesozoic, resulting in deeper water deposition through time. In the Jurassic, rifting in the northern landmass started to occur and eventually led to formation of the present day Canada Basin in the Early Cretaceous (Arctic Ocean). To the south, convergent tectonics and associated southward dipping subduction of the Arctic Alaska terrane beneath an island arc in the adjacent ocean basin also began in the Jurassic and continued into the Early Cretaceous. This convergence caused northward thrusting and emplacement of ocean crust and island arc rocks on platform rocks to the north. The Angayucham terrane represents island-arc and other rocks of the oceanic plate that developed adjacent to continental platform, and that are now found as highly allochthonous klippen at the highest structural levels of the Brooks Range. The thrusted and folded platform rocks of the Arctic Alaska terrane in the Brooks Range in the area of the parks are outer parts of the platform that were detached and thrust northward below, but with, the Angayucham terrane during the thrusting in a “thin-skinned” style of deformation (Moore et al. 1994).

The contact between the upper thrusted and underlying undeformed platform sequence is visible in the Mt. Doonerak area in GAAR and is probably the most geologically important outcrops in northern Alaska. After a period of regional extensional deformation in the southern Brooks Range and development of a major normal fault along the southern edge of the Brooks Range, the region was

tectonically quiet during the Late Cretaceous (Miller and Hudson 1991; Moore et al. 1997). In the early Tertiary, northward convergence again occurred in the Brooks Range, driven by subduction far to the south in southern Alaska (Moore et al. 2004). This resulted in a "thick-skinned" style of thrust faults that resulted in formation of the modern Brooks Range in the area of the parks.

The marine sedimentary rocks of northern Alaska have produced an abundance of fossils and many are almost entirely composed of fossil material. These fossils include conodont, radiolarian and foraminifer microfossils, and macrofossils including trilobites, graptolites, corals, stromatoporoids, bryozoans, brachiopods, echinoderms, gastropods, bivalves, and cephalopods. In particular, the Late Paleozoic Kayak Shale and carbonates of the Lisburne Group, the Triassic limestone member of the Otuk Formation, and a Cretaceous coquinoid limestone unit contain significant marine fossil resources. In addition, terrestrial deposits occur and have produced a variety of plant fossils.

Although this report draws of a number of published sources for the fossil resources in the ARCN, it relies very heavily on unpublished U.S. Geological Survey reports that have been made available on the Alaska Paleontological Database website (http://www.alaskafossil.org/). There are two caveats that must be recognized with the information gleaned from this web source: 1) The fossil identifications and assigned stratigraphic units have not been vetted through the formal write-up, peer review and publication process, and 2) the database currently contains only about half of the total U.S. Geological Survey fossil reports from Alaska.

Collectively, the paleontological resources of the ARCN contribute to a greater understanding of the history of the Arctic and life on earth as a whole. Continued paleontological resource inventories will serve to expand this ever-widening base of paleontological knowledge represented throughout the National Park Service. Although 221 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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Figure 1. Map of Arctic Network parks. Courtesy Scott Miller (ARCN).

Paleontological Resource Inventory Strategies and Methodology

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

Comprehensive Park-Specific Paleontological Resource Inventories

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

Servicewide Thematic Paleontological Resource Inventories

Servicewide thematic paleontological resource inventories compile data regarding specific types of paleontological resources that occur in parks throughout the NPS. The first thematic paleontological resource inventory identified 19 NPS units that preserve fossil vertebrate tracks (Santucci et al. 1998). Subsequent discoveries have increased the number of parks identified with fossil vertebrate tracks to 25 and warranted an updated publication (Santucci et al. 2006). Another thematic inventory identified paleontological resources associated with NPS caves in 35 parks (Santucci et al. 2001). Cave fossils occur in two contexts: first, fossils can be preserved in the marine limestones in which caves develop; second, the remains of Pleistocene/Holocene animals and plants that lived, died or were transported into caves after death are common types of cave fossils. Servicewide thematic inventories have also been initiated for fossil fish (Hunt et al. 2006) and fossils found in cultural resource contexts (Kenworthy and Santucci 2006).

Inventory and Monitoring Network 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 28 of the 32 I&M networks including: Appalachian Highlands, Arctic, Chihuahuan Desert, Cumberland Piedmont, Eastern Rivers and Mountains, Great Lakes, Greater Yellowstone, Gulf Coast, Heartland, Klamath, Mediterranean Coast, Mid-Atlantic, Mojave Desert, National Capital Region, North Coast and Cascades (this report), Northeast Coastal and Barrier, Northern Colorado Plateau, Pacific Island, Rocky Mountain, San Francisco Bay Area, Sierra Nevada, Sonoran Desert, Southeast Coast, Southeastern Alaska, Southern Colorado Plateau, Southern Plains, Southwestern Alaska, and Upper Columbia Basin networks. Research for summaries of the Central Alaska, Northeast Temperate, Northern Great Plains, and South Florida/Caribbean networks are currently underway. NPS I&M Program funding is targeted to complete paleontological resource summaries for the remaining networks in FY2010. Citations for the completed reports are in the Additional References section.

I&M Network Paleontological Resource Inventory Methodology

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

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

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

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

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

Organization of the Reports

Information from these various sources is compiled into a narrative report for each park. Each park report includes an executive summary of the park's significance and a brief description of the geologic background. Geologic formations mapped within the park that are known to preserve fossils within the park are described in the "Sources of Paleontological Resources" section. Geologic formations mapped

within the park that potentially preserve fossils (based on fossil discoveries outside the park) are listed in the section "Potential Sources of Paleontological Resources." Field investigations could determine whether these "Potential Sources" do preserve fossils within the park. The park narratives also include a summary of paleontology specimens in park museum collections and, where applicable, highlight fossils that occur in cultural resource contexts (see Kenworthy and Santucci 2006).

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

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

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

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

Given the tremendous diversity of past life, the existence of life for over a billion years, and the range of environments to which life has adapted, there is a broad spectrum of research interests in paleontology. It is not surprising that most of what is to be learned about the history of life remains to be discovered. Through research, more than 219 NPS areas have been identified as containing paleontological resources. However, the paleontological research for a particular park may vary widely from an incidental fossil discovery, to over a century of intensive paleontological investigations. Therefore, the inventory reports include information on the history of paleontological research, identification of any museums or universities serving as repositories for park fossils, and a complete bibliography.

Paleontological Resource Management Legislation and Guidance

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

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

> §6302 calls for the management and protection of paleontological resources using scientific principles and expertise. The NPS should develop plans for inventory, monitoring, and the scientific and educational use of paleontological resources. Planning should emphasize interagency coordination and collaboration and where possible include non-federal partners, the scientific community and the public.
>
> §6303 calls for the establishment of education programs to increase public awareness about the significance of paleontological resources.
>
> §6304 calls for the development of a specific permit for the collection of NPS paleontological resources. The new legislation and other existing authorities clarify and reaffirm issues of property ownership, accountability, access and confidentiality of locality information associated with the management of NPS paleontological resources.
>
> §6305 calls for the curation of NPS paleontological resources, along with any associated data or records, in approved repositories.
>
> §6306 provides clarity regarding prohibited acts involving paleontological resources and specifies criminal penalties associated with these prohibited acts.
>
> §6307, along with other existing authorities, enables the NPS to seek civil penalties and restitution for the violation of any prohibited activities involving paleontological resources.
>
> §6308 provides the NPS a confidentiality provision with an exemption from the disclosure of any information associated with the nature and specific location of NPS paleontological resources.
>
> §6310 directs the Secretaries of the Interior and Agriculture to issue regulations appropriate to carry out the Act

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

Paleontological resource management issues were the subject of a Report of the Secretary of the Interior in May 2000, prepared in response to a Congressional request for an assessment of the need for a unified federal policy on the collection, storage and preservation of fossils and for standards that would maximize the availability of fossils for scientific study. That report, an "Assessment of Fossil Management on Federal and Indian Lands," summarized a number of principles relating to paleontological resources and their management. The Paleontological Resources Management section of Natural Resource Management Reference Manual 77 provides guidance and additional information regarding the

implementation and continuation of paleontological resource management programs. Links to the above documents are listed in the "Additional References" section.

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

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

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Smithsonian Institution National Museum of Natural History (Department of Paleobiology; Washington, DC): http://paleobiology.si.edu/

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

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

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

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

National Park Service Paleontology Program Sites
NPS Geologic Resources Division: http://www.nature.nps.gov/geology/

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

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Bering Land Bridge National Preserve

In 1980, Congress passed the Alaska National Interest Lands Conservation Act, redesignated the original national monument as Bering Land Bridge National Preserve (BELA). The national preserve encompasses 1,100,000 ha (2,700,000 acres). Of this acreage, 1,015,000 ha (2,509,000 acres) are in federal ownership. There are 38,400 ha (95,000 acres) of non-federal land within the boundaries, as well as 72,800 ha (180,000 acres) selected by Native groups to fill their land entitlement under ANCSA.The purposes of the preserve are to: "protect and interpret examples of arctic plant communities, volcanic lava flows, ash explosions, coastal formations, and other geologic processes; protect habitat for internationally significant populations of migratory birds; provide for archeological and paleontological study of the process of plant and animal migration, including man, between North America and the Asian Continent; protect habitat for fish and wildlife including, but not limited to, brown/grizzly bears, moose, and wolves; to continue reindeer grazing use; and to protect the viability of subsistence resources."

The modern-day physiographic zones in BELA include: the Northern Coastal Plain with barrier bar/lagoon systems and relict beach ridges; Rolling Stream-dissected Uplands including higher elevation areas of limestone, marble, quartz, and slate conducive to cave formation, including Trail Creek Caves at 560 m (1,800 ft) above sea level; Imuruk Lava Plateau with lava flows ranging in age from 5 million years to the 2,000 year old Kuzitrin Flats with Kuzutrin Lake bordered by relict lacustrine beach terraces; and the Bendeleben Mountains. Although BELA was mostly unglaciated during Wisconsinan (last glacial maximum) times, substantial deposits of glacial loess, gravels, silts, and a few moraines within the preserve boundary reflect the effects of glacial advances and retreats in surrounding areas. Aeolian deposits in the area, dating to Pleistocene times, include dunes as well as blanket deposits up to several meters thick.

BELA is unique because it is a reserved area representing what was once the interior of Beringia, a large land mass connecting North America and Asia during the last glacial maximum approximately 20,000 years before present and perhaps more than 40 times throughout the Cenozoic Era. During the most recent connection and after, humans traversed this land mass most likely in pursuit of big game resources vital to survival in the harsh climate of such northern latitudes. Potential big game included mammoth (*Mammuthus*), caribou (*Rangifer*), horses (*Equus*), camels (*Camelus*), and bison (*Bison*). Musk ox (*Ovibos moschatus*), once extinct on Seward Peninsula. were reintroduced in 1970 and have been growing in numbers.

Geologic Background

Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held May 8-10, 2007. A formal paleontological resource survey has not been conducted, but geologic investigations in the park and the surrounding area, primarily by university, U.S. Geological Survey, and Alaska Division of Geological and Geophysical Surveys scientists indicate that some of the rock units found in the park contain paleontological resources, and there is potential for continued discovery.

The bedrock geology of BELA largely consists of Precambrian and Paleozoic Era marine sediments (see the appendix for a geologic time scale). The Paleozoic sediments are largely carbonate platform deposits that were subsequently metamorphosed to varying degrees during the Mesozoic (Ross 1965; Rohr 1988; Vinson 1988; Till and Dumoulin 1994; Santucci et al. 2001). Many fossils have been recovered in Paleozoic carbonate rocks on Seward Peninsula, most notably in the York Mountains.

Rocks of the eastern and southern Seward Peninsula in the Kigluaik, Bendelden, and Darby mountains underwent high- and low-pressure metamorphism during the Mesozoic. In contrast the rocks of the York Mountains in the western Seward Peninsula experienced brittle deformation and thrusting faulting and was heated only to low temperatures (Till and Dumoulin 1994). In the Cretaceous Period, a magmatic belt formed from the U.S. Cordillera through to the Russian Far East (Amato et al. 2003). At this time, granitic plutons and associated contact metamorphism developed across the Seward Peninsula.

During the Cenozoic, volcanism in the region from the late Oligocene to the present resulted in basalt flows, cinder cones, and maar-rim deposits (Lawver et al. 2002). Under one late Miocene lava flow dated at 5.7 ± 0.2 million years old, paleosols at the Lava Camp Mine preserve a fossil forest with many associated insects (Hopkins et al. 1971; Elias et al. 2006). Finally, Quaternary marine and windblown loess sediments have blanketed much of the bedrock in the BELA area (Lawver et al. 2002).

Terranes

Terranes are fault bounded geologic bodies of rock that have been moved and deformed by tectonic forces. A terrane has an internally similar sequence of sedimentary units (stratigraphy) and deformational history that differs significantly from neighboring terranes. Various terrane names have been applied to the bedrock blocks of the Seward Peninsula in the vicinity of BELA including the York and Seward terranes (e.g., Till and Dumoulin 1994; Dumoulin et al. 2002) and the Arctic Alaska terrane (e.g., Colpron et al. 2007).

The York terrane of the York Mountains area of the western Seward Peninsula consists of Ordovician through Mississippian limestone, dolostone and fine-grained clastic rocks deposited in a shallow water platform environment (Till and Dumoulin 1994; Dumoulin et al. 2002). These rocks have received little metamorphism and may be locally fossiliferous. Some exposures of these rocks may occur near the southern edge of the western extension of BELA in the Teller quadrangle.

The Seward terrane is dominated by low- to high-grade metamorphic rocks. Of importance for fossils in this terrane is the Nome Group, which consists of Paleozoic and Precambrian sedimentary clastic and carbonate rocks that undergone blueschist facies metamorphism (Till and Dumoulin 1994; Dumoulin et al. 2002). Areas of BELA in the northwestern part of the Bendeleben quadrangle, particularly east of the Serpentine Hot Springs area, as well as possibly along the southern edge of BELA along the northwestern edge of the Solomon quadrangle, may contain fossil resources in Nome Group rocks of the Seward terrane (Till et al. 1986).

Sources of Paleontological Resources

Fossils have been documented from the following geologic formations and museum collections within BELA. These fossils present opportunities for resource management (including field surveys, inventory, and monitoring), education, interpretation, and continued or future scientific research in the park.

Nome Group (Upper Precambrian–Middle Paleozoic)

One part of the Nome group contains two schist layers with a limestone between. Ordovician conodonts have been recovered from this metamorphosed part. A second part contains dolostones containing Cambrian to Devonian fossils, including some shallow water invertebrates (Till et al. 1986; Till and Dumoulin. 1994). Fossils from these rocks in BELA include several locations in the Bendeleben C-5, C-6, D-5, D-6 quadrangles, where mostly conodonts of Ordovician, Silurian and Devonian age have been recovered. However, one locality in the C-6 quadrangle contains corals and stromatoporoids of Silurian or Devonian age (Till et al. 1986). Recrystallized radiolarians and Ordovician conodonts have also been reported from marble of the Nome Group at Trail Creek Caves on the eastern margin of BELA (Santucci et al. 2001), and conodonts have been recovered from a limestone unit on the north coast at Sullivan Bluffs. Nome Group rocks have also produced fossils just south of BELA in the Solomon D-3 and D-5 quadrangles. These fossils include conodonts, corals, and stromatoporoids of Ordovician to Devonian age, and *Lapworthella*, a phosphatic fossil of Cambrian age from the D-5 quadrangle (Till et al. 1986).

Ordovician rocks of the York terrane

Ordovician rocks of the York terrane are composed of shallow water facies that include bioclastic sandstone, limestone, lime mudstone, wackestone and packstone (Till and Dumoulin 1994). These rocks are locally fossiliferous and may contain diverse invertebrate assemblages. One particular area in the Don River vicinity, south of the western panhandle of the park. Papers published on the faunal elements of this area include: cephalopods (Flower 1941, 1946, 1968a, 1968b; Miller and Kummel 1945); trilobites

(Ormiston 1978; Ormiston and Ross 1979); brachiopods (Potter 1984), corals (R.J. Elias *in* Blodgett et al. 2002), gastropods (Rohr and Potter 1987; Rohr et al. 2003), and graptolites (Ross 1967). In addition, ostracodes, and conodonts are known from this unit. This unit may outcrop along the southern edge of the western panhandle of BELA, and thus similar fossils may occur there. It is also possible that a small area of Silurian rocks of the York terrane may outcrop in BELA; these are also known to contain fossils (see Till and Dumoulin 1994).

Pleistocene to Holocene deposits

Pleistocene to Holocene deposits have produced a variety of fossils in the vicinity of BELA. Although mainly representing megafauna, including mammoths, mastodons, reindeer, elk, horse, and wolf, these sediments have also yielded insects and ostracodes. These fossils have been found in surficial deposits at a number of localities particularly along the coastal bluffs of the Kotzebue Quadrangle, but also in the interior of BELA (see locations listed in www.alaskafossil.org).

Several Pleistocene localities are of particular importance. A significant insect fauna is present just east of BELA at Cape Deceit in rocks dated at 1.8 million years old (Elias et al. 2006). Here, 86 insect and arachnid taxa have been uncovered. These insects were excavated from peat deposited in fens and bogs (Elias et al. 2006 and references therein). Elias et al. (2006) concluded that the fauna indicates that tree line was at least 100 km (62 miles) further north in the Pleistocene than it is today. In addition, some of the Cape Deceit insect and arachnid taxa record their earliest occurrence in North America (Elias et al., 2006).

Also at Cape Deceit east of BELA, Pleistocene mammal fossils have been recovered from the Cape Deceit, Inmachuk, and Deering Formations on the south shore of Kotzebue Sound approximately 3 km (2 miles) northwest of Deering. The fossils uncovered from these formations are considered to be early Pleistocene in age (Guthrie and Mathews 1971). Fossil mammals excavated include voles (*Predicrostonyx hopkinsi*, *Microtus deceitensis*, *Pliomys deeringgensis*, and *Lemmus* cf. *sibericus*), marmots (*Marmot* sp. and *Citellus* sp.), pika (*Ochotona whartoni*), shrew (*Sorex* sp.), horse (*Equus* sp.), elk (*Cervus* cf. *elephas*), reindeer (*Rangifer* sp.), and wolf (*Canis* sp.).

More importantly, Trail Creek Caves in BELA have produced many vertebrate fossils from test excavations in five of the thirteen caves (Caves A, B, C, D, and F; Schaaf 1985; Vinson 1988; Santucci et al. 2001). These fossils have been dated as the latest Pleistocene to earliest Holocene (Kurtèn and Anderson 1980; Schaaf 1985; Vinson 1988). Two thousand five hundred and eighty one elements (bone fragments, etc.) were collected (Vinson 1988) and many forms identified (Vinson 1988, 1993, and references therein). Identified taxa include voles (*Dicrostonyx torquatus*, *Lemmus sinbiricus*, *Microtus oeconumus*, *M. gregalis*, *M. pennsylvanicus*, and *Clethrionomys rutilus*), rabbit (*Lepus* sp.), ground squirrel (*Spermophilus* sp.), reindeer (*Rangifer* sp.), sheep (*Ovis* sp.), bison (*Bison* sp.), horse (*Equus* sp.), mammoth (*Mammuthus* sp.), fox (*Vulpes* sp.), bear (*Ursus* sp.), and birds (Aves). Many small and medium to large elements were collected but are presently unidentifiable. Dixon and Smith (1986) also wrote about purported dog teeth at Trail Creek Caves. These deposits provide an exceptional opportunity for multiple analytical studies, including population, predator-prey, eco-climatological, taphonomic, and time series analyses. Additionally, comparisons might be possible with the Cape Deceit fauna if persuasive dates can be collected from both sites.

Several other vertebrate sites of importance are listed in the Alaska paleontological database (www.alaskafossil.org). These include a collection of bones from an intertidal mudflat along the north shore of Nuglungnugtuk Estuary in the Kotzebue A-5 quadrangle. Bones collected include phasianoid fowl, seal (*Pusa hispida*), fox (*Vulpes* sp.), wolf (*Canis* sp.), horse (*Equus* sp.), and sheep (*Ovis* sp.). A second site in the interior in the Bendeleben B-6 quadrangle was collected during excavation of the 1967 pit of the Houston Alexander Mine on Dahl Creek. This locality produced bones from Wisconsinan (last glacial period) and Holocene colluvium and loess. Taxa represented include horse (*Equus* sp.), reindeer (*Rangifer tarandus*), and musk ox (*Ovibos* sp.)

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within BELA. However, future field investigations within the park may yield fossils from one or more (or none) of the following geologic units. Fossils may be documented from these units outside of the park.

Miocene deposits in BELA vicinity

Just east of BELA, south of Cape Deceit, a forested Miocene floodplain was buried beneath a lava flow dated at 5.7±0.2 million years old in the vicinity of Lava Camp Mine. Hopkins et al. (1971) reported on fossil insects associated with 10 species of conifers found there, including Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*). Beetles from this assemblage indicate that temperatures were approximately 2°C (~3.6°F) warmer in the late Miocene than today. Elias et al. (2006) described and listed 83 insect and arachnid taxa from the Lava Camp Mine. Scattered Cenozoic volcanic activity around BELA may have led to similar yet undiscovered deposits in the park.

Park Collections

The BELA museum collections include nine specimens listed as paleontology under natural history and an additional four specimens listed as fossil under cultural resources. Two plant fossils are curated into the collections including a fossil leaf (BELA 598) and a specimen listed as a liverwort (BELA 7958). In 1987 Rich Harris collected a leg bone (BELA 1444) tentatively identified as proboscidean (either mammoth or mastodon)(R. Harris, BELA, pers. comm., 1992). The specimen was collected on a beach within BELA and the locality data is maintained by the NPS. Five additional catalog records indicate mammoth or mastodon bone, tooth and tusk (BELA 25109–25112, 30007, 30009). Three ivory artifacts produced from mammoth tusk (BELA 399, 2940, 6785) and a horse tooth (BELA 14757) were collected from the Trail Creek Caves and are cataloged as archeological objects (E. Devinney, Western Arctic National Parklands, pers. comm., November 2009). Kenworthy and Santucci (2006) present an overview and cite selected examples of other NPS fossils discovered in cultural resource contexts. BELA museum collections are summarized online (http://www.museum.nps.gov/splashsearch.htm)

Paleontological Resource Management, Preliminary Recommendations

- Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held for BELA on May 8-10, 2007. These meetings and the corresponding scoping summary includes recommendations related to the paleontological resources for BELA and other ARCN parks.
- Park staff should continue to be made aware of the potential for discovery of fossil material during other field work, particularly along river bluffs, caves, sink holes, road cuts, streams, creeks, gullies, and erosional 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 photodocument and potentially monitor any occurrences of paleontological resources.
- The park should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils. The park may consider a formal site documentation and condition assessment for significant fossil localities.
- 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.
- 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. Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist.

- Paleontological field inventories may indicate the need for long-term monitoring of in situ fossil resources. The NPS has developed a strategy for paleontological resource monitoring and has been published by the Geological Society of America in a special publication on Geological Monitoring (Santucci et al. 2009). Site specific paleontological resource monitoring prescriptions should be considered for significant fossil localities.
- BELA should seek technical assistance from the NPS Geologic Resources Division regarding issues related to paleontological resource management, protection and/or interpretation.

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

Bering Land Bridge National Preserve.
1980-present. (museum specimens; associated specimen notes; collection records; maps; etc.).
Originated by BELA staff; status: Active.

Alaska Paleontological Database.
1990s–present. (electronic paleontological resource data: locality information, specimen lists, maps, etc.).
Originated by MDIRA staff; status: Active. Online: www.alaskafossil.org.

University of California Museum of Paleontology (Berkeley)
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Originated by USGS staff and other researchers; status: Active.

Smithsonian Institution National Museum of Natural History (Washington, D.C.)
~1960s–present. (USGS museum specimens; associated specimen notes; collection records; maps; etc.).
Originated by USGS staff and other researchers; status: Active.

Cape Krusenstern National Monument

Cape Krusenstern National Monument (CAKR) was established in 1978 to protect a series of beach ridges located along the southern coast of Cape Krusenstern. The beach ridges developed over a series of thousands of years, and contain evidence of prehistoric human populations. The monument was established to protect these cultural remains and to provide an area where human migration and population processes could be studied; in this case the process of moving from the Asian continent to the American continent via the Bering Land Bridge. The monument also was established to provide habitat protection for seals, other marine mammals, birds and other wildlife, to protect fish resources, and to protect the viability of subsistence resources. The entire monument lies within the Cape Krusenstern National Historic Landmark boundaries. These landmark boundaries were defined in 1973 with the placement of Cape Krusenstern on the National Register of Historic Places as an Archaeological District. CAKR encompasses 267,014 ha (659,807 acres) along the northwestern coast of Alaska. Kotzebue Sound makes up its southern shore, while the Chukchi Sea makes up its western shore. The Noatak River, emptying southward along its eastern border into Hotham Inlet, separates CAKR from the Noatak National Preserve. The monument is made up of two sets of low, rolling hills that reach a maximum height of 610 m (2,000 ft) above sea level. The Mulgrave Hills to the north, and the Igichuk Hills to the south (which extend eastward into the Noatak National Preserve) are separated by a broad plain of coastal lowlands. This area exhibits classic thermokarst topography, with thaw lakes and ponds, ice wedge polygons, pingos and the like. To the south, the cape from which the monument takes its name consists of a series of relict beach ridges and intervening swales with numerous ponds and lakes. The entire shoreline is made up of barrier bars, lagoons and spits.

Geologic Background

Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, have been held (need date). A formal paleontological resource survey has not been conducted, but geologic investigations in the park and the surrounding area, primarily by U.S. Geological Survey scientists but also by Alaska Division of Geological and Geophysical Surveys, and university and industry scientists indicate that some of the rock units found in the park contain paleontological resources, and there is potential for continued discovery.

The web site http://www.alaskafossil.org/ contains a recent compilation of paleontological data based primarily on extensive U.S. Geological Survey paleontological reports, but also containing many other sources and helpful links to sites with geologic maps and other information. This resource, coupled with some additional literature sources, provide the basis of this report. Moore et al. (1994, 1997) provided a helpful overview of the complex geology of northern Alaska that can be used to place the paleontologic information in context and was used extensively for the framework geology used in the report. Other important bodies of work with information relevant to the framework geology and paleontology of CAKR include Tailleur and Weimer (1987), and Gryc (1988).

The bedrock geology of the inland areas of CAKR consists of limestone, dolomite, chert and phyllite of Precambrian to Devonian age (see the appendix for a geologic time scale). The southern end of the Mulgrave Hills also contains a collection of marine sediments: dolomite, sandstone, shale, and limestone from the Devonian to Mississippian periods. This geology has been divided onto several geologic provinces and tectonostratigraphic terranes, as well as stratigraphic units. These will be discussed briefly below.

Geologic Provinces

Three east-west trending geologic provinces are found within the boundaries of CAKR. These are defined by structural character, degree of metamorphism, and stratigraphy. The geologic provinces primarily reflect the deformational history related to the formation of the Brooks Range and generally increase in metamorphic grade to the south. Two-thirds of CAKR lie in the disturbed belt province. The disturbed

belt consists of complex, structurally broken and imbricated Mesozoic and Paleozoic rocks found in the northern part of the Brooks mountain range. Most of the southern third of the monument lies in the central belt province, which forms the core of the Brooks Range. This province is composed of ductilely deformed Paleozoic slate, phyllite, schist, carbonate rocks and gneiss. The sedimentary rocks mostly retain their primary textures in this province. The southernmost part of the park lies in the schist belt, which contains schistose metasedimentary and minor metavolcanic rocks.

Terranes

Terranes are fault bounded geologic bodies of rock that have been moved and deformed by tectonic forces. A terrane has an internally similar sequence of sedimentary units (stratigraphy) and deformational history that differs significantly from neighboring terranes. Subterranes or allochthons are fault bounded blocks or thrust sheets whose stratigraphies can be linked, but that are different enough to indicate significant amounts of tectonic displacement between them.

Alaska was divided into a number of tectonostratigraphic terranes by Jones et al. (1987). Using additional information for northern Alaska, Moore et al. (1994, 1997) modified this terrane scheme to create a terrane and subterrane and/or allochthon scheme. Basement rocks of CAKR can be assigned to the Arctic Alaska terrane.

In CAKR, the Arctic Alaska terrane is primarily represented by the Endicott and De Long Mountains subterranes, the latter of which has been divided into four allochthons and is the structurally highest subterrane of the Arctic Alaska terrane. These subterranes share a similar Devonian through Lower Cretaceous stratigraphy. The Devonian to Pennsylvanian rocks are mostly marine carbonates, and siliceous sediments occur above. The carbonate rocks may contain both macro- and microfossils, whereas the siliceous rocks tend to contain mostly microfossils as will be discussed in detail in the Formations section below. A small band of the Hammond subterrane is found in the far south of the park. It has a lower Paleozoic marine section as well as the Carboniferous carbonate section.

Sources of Paleontological Resources

Paleontological resources have been documented from the following geologic units at CAKR and are cataloged into the park's museum collection. These fossils present opportunities for resource management, education, interpretation, and continued or future scientific research in the park.

Baird Group (Cambrian–Upper Devonian)

Rocks of the Baird Group apparently represent remnants of a once widespread Cambrian to Devonian carbonate platform or platforms (Moore et al. 1994). Only one locality containing fossils is potentially assigned to the Baird Group in the Noatak C-3 quadrangle of CAKR. It contains corroded and broken conodonts of middle Devonian age from a massive limestone unit from near top of a carbonate unit that conformably underlies an Upper Devonian Endicott Group sandstone. This is reported to be the only area in the Noatak region where the base of the Endicott Group is exposed.

Endicott Group (Upper Devonian–Lower Mississippian)

The Endicott Group is composed of time-transgressive units that represent a transgressive-regressive (sea level advance and retreat) sequence across northern Alaska. The lowest unit consists of marine prodelta deposits of the Hunt Fork Shale. Above this lie the regressive marginal marine deposits of the Noatak Sandstone, overlain by delta plain and fluvial deposits of the Kanayut Conglomerate. The overlying marginal marine to shelf deposits of the Kayak Shale represent the next transgressive period.

In CAKR and the surrounding area, fossils have only been found in the Noatak Formation and Kayak Shale. Within the park, fossils are only known from the Noatak Formation in the Noatak C-4 quadrangle. These include indeterminate fenestrate bryozoan impressions, rhynchonelloid brachiopods, and several valves of *Punctospirifer* cf. *P. subtexta* (White). The latter species indicates an early Mississippian age.

Lisburne Group (Lower Mississippian–Lower Permian)

In the De Long Mountains subterrane in and around CAKR, the Lisburne Group is represented by carbonate units of the Utukok and Kogruk formations (Moore et al. 1994). These formations represent progressive onlap of a slowly subsiding shallow platform. Throughout northern Alaska, Lisburne Group rocks tend to be highly fossiliferous, but in CAKR published reports of fossils definitively from this unit are not known. One sample from the Noatak A-3 quadrangle in CAKR may have come from this unit. It contains "ghosts" of crinoids and brachiopods of indeterminate age.

Pleistocene Deposits

The entire northwest coast of Alaska from at least Cape Krusenstern south to Norton Sound is rich in Pleistocene fauna and large mammal fossils from the Late Pleistocene (J. Rasic, YUGA archeologist, pers. comm., 2009). Most of the material is reworked and is now out of original context, but may be of value in archeological studies such as those conducted on these types of transported materials by Guthrie (2006) and Gelvin-Reymiller (2006). However, no Pleistocene fossils are present in NPS collections from CAKR. Nevertheless, there is good potential for the discovery of Pleistocene material along river banks, and coastal areas with further field investigations.

Holocene Beach Ridges

The series of Holocene beach ridges along the southern coast of Cape Krusenstern, contain material that could be classified as fossil. This includes fossil wood discussed by Mason and Ludwig (1990).

Park Collections

There are no specimens cataloged as paleontological specimens in the CAKR collections under natural history. There are six specimens (CAKR 977, 978, 980, 7334, 7656, 7707) listed within cultural resources which could be cross-referenced as fossil material. These specimens are pieces of mammoth ivory that were found within an archeological context and exhibit some evidence of human modification or use (E. Devinney, Western Arctic National Parklands, pers. comm. November 2009). Kenworthy and Santucci (2006) present an overview and cite selected examples of other NPS fossils found in such cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held for CAKR on May 8-10, 2007. These meetings and the corresponding scoping summary includes recommendations related to the paleontological resources for CAKR and other ARCN parks.
- Park staff should continue to be made aware of the potential for discovery of fossil material during other field work, particularly along river bluffs, caves, sink holes, road cuts, streams, creeks, gullies, and erosional 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 photodocument and potentially monitor any occurrences of paleontological resources.
- The park should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils. The park may consider a formal site documentation and condition assessment for significant fossil localities.
- 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.
- 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. Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist.

- Paleontological field inventories may indicate the need for long-term monitoring of in situ fossil resources. The NPS has developed a strategy for paleontological resource monitoring and has been published by the Geological Society of America in a special publication on Geological Monitoring (Santucci et al. 2009). Site specific paleontological resource monitoring prescriptions should be considered for significant fossil localities.
- CAKR should seek technical assistance from the NPS Geologic Resources Division regarding issues related to paleontological resource management, protection and/or interpretation.

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Originated by Santucci, Vincent; status: Active.

Cape Krusenstern National Monuent Museum Collections.
1980-present. (museum specimens; associated specimen notes; collection records; maps; etc.).
Originated by CAKR staff; status: Active.

Alaska Paleontological Database.
1990s–present. (electronic paleontological resource data: locality information, specimen lists, maps, etc.).
Originated by MDIRA staff; status: Active. Online: www.alaskafossil.org.

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Originated by USGS staff and other researchers; status: Active.

Smithsonian Institution National Museum of Natural History (Washington, D.C.)
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Originated by USGS staff and other researchers; status: Active.

Gates of the Arctic National Park and Preserve

Gates of the Arctic National Park and Preserve (GAAR) was established in 1980 when Gates of the Arctic National Monument (established 1978) was combined with Gates of the Arctic Preserve. It is the nation's second largest national park covering 3,428,702 ha (8,472,506 acres). It was established to "maintain the wild and undeveloped character of the area, including opportunities for visitors to experience solitude, and the natural environmental integrity and scenic beauty of the mountains, forelands, rivers, lakes, and other natural features; to provide continued opportunities, including reasonable access, for mountain climbing, mountaineering, and other wilderness recreational activities; and to protect habitat for and the populations of, fish and wildlife, including, but not limited to, caribou, grizzly bears, Dall sheep, moose, wolves, and raptorial birds."

The entire park lies north of the Arctic Circle, primarily in the Endicott Mountains of the central Brooks Range, although small portions at the northern boundary lie within the Arctic Foothills at the south edge of the Arctic coastal Plain, and along the southern boundary, portions are in the lowlands of the Kobuk River Valley. The park is bordered on the west by Noatak National Preserve. Four major physiographic zones run across the park and preserve. The Arctic Foothills at the northern boundary are characterized by east-west trending ridges, rolling hills, and irregular buttes with interspersed tundra plains. The Brooks Range mountains form the largest physiographic zone in the park. These mountains are east-west trending and rise to heights of over 2,130 m (7,000 ft) in the north and 1,830 m (6,000 ft) in the south. The third physiographic region, the Ambler-Chandalar Ridge and Lowlands crosses the southern portions of the preserve. Large lakes such as Selby, Narvak, and Nutuvukti are located in this zone. The last region, the Kobuk-Selawik Lowlands zone encompasses the southern most part of the preserve part of GAAR. Bedrock in the park and preserve is primarily composed of Paleozoic conglomerate, sandstone, shale, limestone, phyllite, metagranitic and metavolcanic rocks and schist. See the appendix for a geologic time scale.

Geologic Background

Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, have not been held. A formal paleontological resource survey has not been conducted, but over a half century of geologic investigation in the park area primarily by U.S. Geological Survey scientists, but also by Alaska Division of Geological and Geophysical Surveys, and university and industry scientists have indicated that most of the rock units found in the park contain considerable paleontological resources, and that there is potential for continued discovery.

The Alaska Paleontological Database web site http://www.alaskafossil.org/ contains a recent compilation of paleontological information based primarily on extensive U.S. Geological Survey paleontological reports, but also contains many other sources and helpful links to sites with geologic maps and other information. This resource, coupled with some additional literature sources, provides the basis of this report and is the source of the information for the fossils listed below unless otherwise indicated. Moore et al. (1994, 1997) provide a very helpful overview of the complex geology of northern Alaska that can be used to place the paleontologic information in context and was used extensively for the framework geology used in the report. Other important bodies of work with information relevant to the framework geology and paleontology of GAAR include Gryc (1988) and Mull and Adams (1989).

The geology of GAAR has been divided onto several geologic provinces and tectonostratigraphic terranes, as well as formations. Each of these will be discussed briefly below.

Geologic Provinces

Eight geologic east-west trending geologic provinces are found within the boundaries of GAAR. These are defined by structural character, degree of metamorphism, and stratigraphy. They primarily reflect the deformational history related to the formation of the Brooks Range. In general, the park is bounded to the

north and south by relatively undeformed Cretaceous sedimentary rocks of the Colville and Koyokuk basins, respectively. In between are the geologic provinces of the Brooks Range, which generally increase in metamorphic grade to the south. The northern boundary of the GAAR at most places coincides with the boundary between the disturbed belt province to the north and the crestal belt province. The disturbed belt consists of complex, structurally deformed and imbricated Mesozoic and Paleozoic rocks at the northern front of the mountain range; small portions at the northern boundary of the park may lie in the disturbed belt. The crestal belt forms the northern half of GAAR, and consists of folded and thrusted Devonian to lower Cretaceous rocks. Much of the southern half of GAAR lies in the central belt, which forms the geographic core of the Brooks Range. This province is composed of ductilely deformed Paleozoic slate, phyllite, schist, carbonate rocks, metavolcanic rocks, and granitic gneiss. The metasedimentary rocks commonly retain their primary sedimentary textures. Southern extensions of GAAR also cross the following provinces: 1) the schist belt, which is mostly composed of schistose metasedimentary and metavolcanic rocks, 2) the phyllite belt composed of metasedimentary phyllites in a regional zone, and 3) the greenstone belt consisting of resistant metamorphosed basalt and chert. The southernmost extension of GAAR encompasses the Cretaceous sediments of the Koyokuk basin which were shed off of the uplifting Brooks Range while it was being formed. Because of the increase in metamorphic grade southward within the Brooks Range, the best potential for well preserved fossils, other than in the Cretaceous sediments to the north and south, is in the crestal belt province.

Terranes

Terranes are fault bounded geologic bodies of rock that have been moved and deformed by tectonic forces. A terrane has an internally similar sequence of sedimentary units (stratigraphy) and deformational history that differs significantly from neighboring terranes. Subterranes are fault bounded blocks whose stratigraphies can be linked to other nearby terranes, but that are different enough to indicate significant amounts of tectonic displacement between the subterranes.

Alaska was divided into a number of tectonostratigraphic terranes by Jones et al. (1987). Using additional information for northern Alaska, Moore et al. (1994, 1997) modified this terrane scheme to create a terrane and subterrane and/or allochthon scheme. The rocks of GAAR can be assigned to two tectonostraigraphic terranes: the Arctic Alaska terrane and the Angayucham terrane.

Only a small band of the southern part of GAAR lies in the Angayucham terrane. This narrow band is called the Narvak panel (Moore et al. 1994) and is primarily composed of pillow basalt and diabase with small amounts of inter-pillow chert, siliceous shales, and limestone that range from Late Devonian to Early Jurassic in age as dated by radiolarian fossils found in rocks near the park (Murchey and Harris 1985; Jones et al. 1988).

The rest of GAAR is underlain by subterranes/allochthons of the Arctic Alaska terrane. The subterrane nomenclature utilized in this paper includes from north to south: the North Slope, De Long Mountains, Endicott Mountains, Hammond, Coldfoot, and Slate Creek subterranes. The bulk of the park is underlain by the Endicott Mountain and Hammond subterranes. Most of these subterranes share some common stratigraphy between them which will be discussed in the Formations section to follow. However, more southernly Coldfoot and Slate Creek subterranes are more metamorphosed and deformed, and they do not share stratigraphic units with the other subterranes. Their paleontologic potential will be discussed at the end of this section.

The North Slope subterrane contains the most complete stratigraphic sequence in northern Alaska, with primarily shallow marine rocks ranging in age from the Proterozoic, lower and upper Paleozoic, Mesozoic, through the Tertiary. Most of these rocks are fossiliferous. In GAAR, the North Slope subterrane is only exposed in an area around Mt. Doonerak in the east-central part of the park called the Doonerak fenster (a window through the Brooks Range thrust sheet). This is one of the most important geologic features in all of northern Alaska because it demonstrates that Endicott Mountains and other structurally higher subterranes were thrust onto the North Slope succession over a distance at least 90 km (Mull and Adams 1989). The Endicott and De Long Mountains terranes generally display a similar

Devonian through Lower Cretaceous stratigraphy. The Mississippian and Pennsylvanian rocks are mostly marine carbonates, and siliceous sediments occur above. The carbonate rocks commonly contain both macro- and microfossils, whereas the siliceous rocks tend to contain mostly microfossils as will be discussed in detail in the Formations section below. The Hammond subterrane has a Paleozoic marine section that may constitute the stratigraphically lower part of the Endicott Mountains succession (Moore et al. 1997).

Finally, the narrow band of Coldfoot terrane in the southern part of GAAR is mainly comprised of lower Paleozoic metasedimentary rocks that have occasionally yielded rare megafossils and conodonts (Hitzman et al. 1986; Moore et al. 1994). The band of Slate Creek subterrane is a fault zone mélange of metasedimentary rocks that have occasionally yielded palynomorphs (Gottschalk 1987), radiolaria (Dillon et al. 1986) and conodonts at a few locations (Murphy and Patton 1988).

Sources of Paleontological Resources

Fossils have been documented from the following geologic formations and museum collections within GAAR. These fossils present opportunities for resource management (including field surveys, inventory, and monitoring), education, interpretation, and continued or future scientific research in the park.

Unnamed Cambrian unit (Middle Cambrian)

The Doonerak fenster exposes a Precambrian to Paleozoic sequence of metasedimentary and metavolcanic rocks of the North Slope subterrane around Mt. Doonerak in the Wiseman quadrangle. A poorly mapped unit of metasedimentary rocks of this sequence in the Wiseman C-3 quadrangle has yielded Middle Cambrian conodonts, trilobites, brachiopods, and hyoliths. Dutro et al. (1984) report that Cambrian fossils collected near Wolf Creek include trilobites and paraconodonts. Trilobites date the strata as early Middle Cambrian, correlative with the Amgan Stage of Siberia. The assemblage includes: *Kootenia* cf. *K. anabarensis* Lermontova, cf. "*Parehmania*" *lata* Chernysheva, and *Pagetia* sp. Specimens of the paraconodont genus *Westergaardodina*, from the same sample as the megafossils, record the earliest known occurrence of this taxon. These fossils, the first to establish an age for part of the sedimentary sequence in the Doonerak Anticlinorium, are the oldest fossils yet taken from the central and western Brooks Range.

Baird Group (Cambrian to Upper Devonian)

The Hammond Subterrane in the park contains rocks of the Baird Group, which in the park consists of the Skajit Limestone and other unnamed carbonate units. Rocks of the group apparently represent the metamorphosed and deformed remnants of a once widespread Cambrian to Devonian carbonate platform (Dumoulin and Harris 1994). Conodonts have been recovered from massive beds of fossil hash (crinoid ossicles recognizable) in medium-light-gray, recrystallized packstone in the Hughs D-4 and D-6 quadrangles. In the Ambler River B-1 quadrangle rugose and tabulate coral and conodonts are present in units containing bryozoan limestone, black chert, and phyllitic mudstone. Till et al. (2008) provided a comprehensive list of conodont localities in the southern Brooks Range, including parts of GAAR.

Unnamed Unit? (Silurian)

A unit in the Wiseman D-1 quadrangle submitted as the Hunt Fork Shale for paleontological analysis produced conodonts of Silurian age, no younger than Ludlovian (early Late Silurian). This sample was submitted as Hunt Fork Shale, which is otherwise dated as being Late Devonian to Mississippian, therefore these fossils would either have to be redeposited or they came from a Silurian unit misidentified as the Hunt Fork Shale. The sample may have taken from a block of Baird Group-type metacarbonate rock that lies in or near the Amawk thrust on which the Endicott Mountains allochthon was emplaced onto the Mt. Doonerak succession in the Cretaceous (T. Moore, USGS, pers. comm., 2009).

Beaucoup Formation (Middle to Upper Devonian)

The Beaucoup Formation in the Hammond Subterrane was characterized by Dillon (1989) as having complex facies changes from phyllite, metasandstone, and metaconglomerate. Purple and green phyllite

and orange-weathering limestones are two characteristic rock types found in that formation (Moore et al. 1994). The formation contains lenticular bodies of fossiliferous limestone or marble containing brachiopods, echinoderms, rugose corals in the Survey Pass B-1, D-1, and D-2 quadrangles. Moore et al. (1997) suggested that the Beaucoup is a structural rather than stratigraphic unit (a duplex) composed of post-Skajit Limestone units and the lowest part of the Hunt Fork Shale. The limestone unit of the Beaucoup from which most of the fossils are taken, lies at or near the base of the Hunt Fork.

Endicott Group

The Endicott Group is composed of time-transgressive units that represent a transgressive-regressive clastic wedge sequence across northern Alaska. The lowest unit consists of marine prodelta deposits of the Hunt Fork Shale. Above this lie the regressive marginal marine deposits of the Noatak Sandstone, overlain by delta plain and fluvial deposits of the Kanayut Conglomerate. The overlying marginal marine to shelf deposits of the Kayak Shale represent the next transgressive period.

Endicott Group: Hunt Fork Shale (Upper Devonian to Mississippian)

The Hunt Fork Shale is mapped in both the Endicott Mountains subterrane and the Hammond subterrane. Fossils are only known from the former subterrane (Moore et al. 1994). The unit consists mostly of thin-bedded dark gray shale with lesser amounts, increasing upwards, of siltstone and quartzose sandstone that are the product of mud-rich turbidites in a prodelta setting. In the Endicott Mountain subterrane the deposits contain shallow marine fossils, typically in thin limestone beds deposited in shelfal settings in the upper part of the Hunt Fork. A fine-grained echinodermal limestone is known from the Survey Pass D-2 quadrangle. Most of the fossil material consists of indeterminate fragments of echionderm ossicles and plates. There are a few fragments with small pores that could be bits of algae. One or two circular sections may be pieces of brachiopod spines, and there are several small fragments of indeterminate shells. In the Survey Pass C-6 quadrangle, a crinoidal limestone is present in a black slate that could belong to either the Hunt Fork or Kayak Shale. The Hunt Fork Shale of the Killik River A-3 quadrangle has produced plant material, including one slab of sandstone containing a 6 cm (2.4 in) wide fragment ornamented with coarse, longitudinal ribbing suggestive of a calamarian.

Limestone wacke in the Killik River A-5 quadrangle contains conodonts and brachiopods, indicating an early Frasnian age (early Late Devonian, *Asymmetricus* Zone). A sample questionably assigned to the Hunt Fork Shale in the Killik River B-3 quadrangle has yielded Mississippian brachiopods, echinoderms, and crinoids. Finally, a sample from the Hunt Fork Shale in the Philip Smith Mountains A-5 quadrangle contains Frasnian rugose corals and stromatoporoid material and may come from strata assigned to the Hunt Fork from a klippe of the Picnic Creek allochthon of the De Long Mountains subterrane (Mull et al. 1987).

Endicott Group: Noatak Sandstone (Upper Devonian to Lower Mississippian)

The Noatak Sandstone of the Endicott Mountains subterrane is a succession of sandstone with minor shale and conglomerate beds that represent marginal marine deposits developed between the marine Hunt Fork Shale and the terrestrial Kanayut Conglomerate prograding into the basin from the east. The Noatak is known to contain brachiopods, gastropods, bivalves and echinoderms of Late Devonian age outside the park (Nilsen et al. 1980). West of the northwest edge of the park, in the Killik River B-5 quadrangle, brachiopods, echinoderms, blastoids and a cephalopod of Early Mississippian age are known from strata questionably assignable to the Noatak Sandstone or a related marine clastic facies. A ferruginous marine sandstone of typical Noatak facies also contains a rhynchonellid brachiopod-dominated assemblage and fragments of plant stems. This assemblage is also known to occur in the park to the south in the Killik River and northern Survey Pass quadrangles. The fossils indicate a very nearshore, possibly intertidal, environment.

Endicott Group: Kanayut Conglomerate (Upper Devonian to Lower Mississippian)

The Kanayut Conglomerate of the Endicott Mountains subterrane is a largely nonmarine succession of interbedded sandstone, conglomerate, and shale and is interpreted to represent the fluvial portion of a coarse-grained fluvial-dominated delta that prograded into the basin from the north and east (Nilsen

1981). Shale of the Kanayut contains plant material of Late Devonian to Early Mississippian age. Plant material from the Wiseman D-3, Chandler Lake B-5 and A-3 quadrangles, have been examined, revealing fossils of *Lepidodendron*. The Kanayut Conglomerate in the Killik River B-3 has produced nine cartons of fossil plants from four localities, but the coarse character of the sediment they are in only allowed preservation of stems and roots. The fossils are nearly all lycopod, except for a few that show evenly spaced parallel ribbing suggesting a calamarian affinity. Finally, a Devonian brachiopod from the southern facies of the upper Kanayut Conglomerate, probably in the northern Wiseman quadrangle, has been in identified as Fammenian (Late Devonian) in age (T. Moore, USGS, pers. comm., 2009).

Endicott Group: Kayak Shale (Lower Mississippian)

The Kayak Shale is present in both the Endicott Mountains and Hammond subterranes. In its type area, in the Endicott Mountains subterrane near Shainin Lake, adjacent to the GAAR Preserve in the Chandler Lake B-2 quadrangle, the Kayak Shale has been divided into five members including a basal sandstone member and two black shale members with intervening bioclastic carbonate members. The Kayak records the northwestward transgression of the sea across the Kanayut delta in the early Mississippian (Moore et al. 1994). The black shales represent shallow to deep marine sedimentation with massive fossiliferous debris flows forming limestone units (Nilsen 1981).

The Kayak Shale has produced abundant fossils throughout much of the park and rocks of this unit should be considered paleontologically sensitive. A number of collections have been made in the Chandler Lake quadrangle, including brachiopods, bryozoa, blastoids, and other echinoderms from limestone clasts in volcanic rocks associated with black shale in the A-4 and A-5 quadrangles. The occurrence of the brachiopod *Orbinaria*, along with the other fossils, strongly indicates an Early Mississippian age. In the Chandler Lake A-3 quadrangle, *Lepidodendropsis*-like plant fossils have been found. Finally, Yochelson and Dutro (1960) discussed gastropods from an argillaceous (mud-rich) limestone member of the Kayak Shale that indicate the Lower Mississippian *Leptaena analoga* zone in a sample from the Chandler Lake B-2 quadrangle.

In the Wiseman D-1 quadrangle, a thin-bedded limestone with scattered lenses of fossil hash has yielded early Early Mississippian (Kinderhookian) conodonts including *Ozarkodina crassidentata* (Branson and Mehl) and *Polygnathus inornatus* Branson. A crinoid-bryozoan packstone in the Wiseman D-2 quadrangle has produced encrusting algae. In the Philip Smith Mountains A-5 quadrangle, the Mississippian plant genus *Lepidodendropsis* was collected from a black shale unit that contained a fair abundance of lycopsid stem fragments. A collection from the Killik River A-1 quadrangle contains *Unispirifer*, a smooth brachiopod similar to *Actinoconchus*, indeterminate echinoderm debris and fenestrate bryozoans, a small fragment of a horn coral, a loxonematid gastropod steinkern, and a small bellerophontid gastropod characteristic of the upper Kayak Shale. In the Survey Pass D-5 quadrangle, the Kayak has produced ostracodes, brachiopods, cephalopods, bryozoa, and echinoderms, all most likely Early Mississippian in age.

Lisburne Group (Lower Mississippian–Lower Permian)

The Lisburne Group occurs in the North Slope, Endicott Mountains, and Hammond subterranes, and consists primarily of carbonate units of Mississippian and Pennsylvanian age. In the central Brooks Range, Bowsher and Dutro (1957) subdivided the Lisburne into the Wachsmuth and Alapah Limestones based on a section in the Endicott Mountains subterrane near Shainin Lake, adjacent to the GAAR Preserve in the Chandler Lake B-2 quadrangle. These shallow water carbonate platform deposits thin and grade westward into a thin sequence of shale, limestone and chert of the more basinal facies of the Kuna Formation outside of GAAR. The Kuna occurs in GAAR, however, in a few isolated klippen in the Chandler Lake quadrangle. The carbonate platform rocks of the Lisburne Group tend to be highly fossiliferous but fossils in the Kuna are largely restricted to siliceous microfossils.

Because the formations defined by Bowsher and Dutro (1957) are commonly difficult to distinguish outside the type area, fossils have been found at numerous localities in a strata assigned only to the Lisburne Group with no formational assignment. In the Wiseman D-1 quadrangle, limestone containing

crinoid, bryozoan, and brachiopod debris has also yielded the Early Pennsylvanian conodonts Declinognathodus noduliferus and Idiognathoides or Idiognathodus. Also in the Wiseman D-1 and D-2 quadrangles, foraminifers, algae, and rugose corals have been recovered from bryozoan-echinoderm packstone. Conodonts of Early Pennsylvanian age have also been recovered from a crinoid limestone of the Lisburne Group in the Chandler Lake A-1 quadrangle. Mississippian brachiopods *Quadratia* cf. *A. hirsutiformis* (Walcott) and *Leiorhynchoidea* aff. *L. carboniferum* (Girty), from rocks that correlate with the black chert-shale member of the Alapah of the type section. Lisburne rocks of the Killik River B-3 quadrangle have produced crinoids, bryozoa, echinoderms, conodonts, and ichthyoliths. Dumoulin et al. (1997) showed that most of the Lisburne in GAAR is Mississippian with only the uppermost few meters consisting of Pennsylvanian deposits.

Lisburne Group: Wachsmuth Limestone (Lower Mississippian)

At its type locality in the Chandler Lake B-2 quadrangle, the Wachsmuth Limestone lies conformable on the Kayak Shale and consists of four informal members from bottom to top: 1) shaly limestone, 2) crinoidal limestone, 3) dolomite, and 4) banded chert-limestone (Bowsher and Dutro 1958). Yochelson and Dutro (1960) identified gastropods from the crinoidal limestone member in the Chandler Lake B-1 and B-2 quadrangles and the Phillip Smith B-5 quadrangle. These included the new species *Straparollus* (*Euomphalus*) *brooksensis* and *Anematina rockymontanum* (Shimer) indicative of Lower (Early) Mississippian strata. Early Mississippian-aged gastropods have also been recovered from the shaly limestone member in the Chandler Lake A-2 quadrangle, and from the banded limestone member in the Chandler Lake B-5 quadrangle, including *Naticopsis* (*Naticopsis*) *suturicompta* Yochelson and Dutro.

Lisburne Group: Alapah Limestone (Upper Mississippian–Lower Pennsylvanian?)

The Alapah Limestone is probably the most fossil-rich unit in the park. At its type area in the Chandler Lake B-2 quadrangle, the Alapah is characterized by abundant fossils and gray to black chert beds, nodules and veins. The base of the formation is composed of shaly limestone that grades upward to interbedded massive limestone, black chert and shale, and limestone with abundant chert nodules. Silica for the chert was probably mostly supplied from dissolved sponge spicules.

Yochelson and Dutro (1960) reported on Upper Mississippian gastropods from the Alapah Limestone in the Chandler Lake B-1, B-4 and B-5 quadrangles. These included *Naticopsis* (*Naticopsis*) *suturicompta* Yochelson and Dutro (new species), *Anematina rockymontanum* (Shimer), *Bembexia? inumbilicata* Yochelson and Dutro (new species), and *Nodospira ornata* Yochelson and Dutro (new species). The lower part of the Alapah Limestone in the Chandler Lake B-1 quadrangles has produced a large collection of fossils, including corals, bryozoans, brachiopods, mollusks, and ostracodes. A single orthoconic nautiloid from this locality was identified as *Dolorthoceras?* sp. by Gordon (1957).

Ammonoids, nautiloids, gastropods, and bivalves have been found in the Chandler Lake B-3 quadrangle in a black chert and shale member of the Alapah limestone. Gordon (1957) reported the following ammonoids and nautiloids from USGS loc. 12084-PC in this quadrangle: *Cypricardella* sp., *Adnatoceras alaskense* Gordon (new species), *Endolobus* sp., Nautiloid fragment, *Bollandites bowsheri* Gordon (new species), and *Girtyoceras endicottense* Gordon(new species). Also on the border of the Chandler Lake A-4/B-4 quadrangles, the black chert and shale member of the Alapah limestone has yielded the following cephalopods at USGS loc. 11804: *Euloxoceras* sp., *Sudeticeras alaskae* Gordon (new species), *Eothalassoceras aurorale* Gordon (new species) (Gordon 1957). This collection is of special interest because it combines the first records of the genera *Euloxoceras* and *Eothalassoceras* in rocks earlier than Pennsylvanian age with the first record of *Sudeticeras* in the western hemisphere.

The Alapah Limestone in the Chandler Lake B-4 quadrangle has produced foraminifers from a bryozoan-echinoderm packstone. This poorly preserved microfauna includes *Brunsia* sp., *Archaediscus* sp. and possibly *Planoarchaediscus* sp. The presence of *Archaediscus* in the samples indicates Late Mississippian (Meramecian) or slightly younger beds. Finally, tabulate and rugose coral have been reported from the Ambler River B-1 and Wiseman D-1 quadrangles. Armstrong et al. (1970), Armstrong (1972), and

Armstrong and Mamet (1977) have extensively reported on and illustrated the foraminiferal and coral faunas of this and other Lisburne units in the Brooks Range.

Lisburne Group: Kuna Formation (Lower Mississippian–Lower Pennsylvanian)

The Kuna Formation is a deep water unit composed of phosphatic black shale and dolomite with lesser amounts of black radiolarian- and spiculite-bearing chert (Mull et al. 1982). Although fossils are known from other localities outside the park in this unit, few fossils are known in the park. In the Chandler Lake A-5 quadrangle, an external mold probably of the goniatite ammonoid *Cravenoceratoides* indicates an Early Mississippian age. Brachiopods are also known from the Kuna in the Chandler Lake B-4 quadrangle.

Nuka Formation (Mississippian–Pennsylvanian)

The Nuka Formation occupies the position of the Lisburne Limestone in an allochthonous succession of the De Long Mountains subterrane and is locally found in fault slivers near the northern edge of GAAR. It consists of limestone, arkosic limestone, arkose, and quartz sandstone and appears to represent both marine and non-marine deposits (Moore et al. 1994). Fossils are locally abundant in the Nuka. In the Chandler Lake B-5 quadrangle, an arenaceous crinoid, bryozoan packstone has yielded poorly preserved fragments of recrystallized foraminifera suggestive of plectogyral *Endothyra* sp. Rugose coral also is known from the Nuka just north of the park boundary in the Killik River B-3 quadrangle.

Sadlerochit Group (Lower Permian)

The Sadlerochit Group is primarily composed of non-marine to shallow marine clastic rocks that overlie a regional unconformity above the Lisburne Group in the North Slope subterrane. It has been divided into the Echooka and Ivishak formations (Moore et al. 1994). In GAAR, fossils are known from this unit in the North Slope subterrane and are restricted to the Mt. Doonerak area in the Wiseman D-1 and D-2 quadrangles. Fossils include scyphozoans, worm burrows, brachiopods, cephalopods, and gastropods from red-brown calcareous limestone and sandstone.

Etivluk Group (Permian–Jurassic)

The Etivluk Group overlies the Lisburne Group in the Endicott Mountains and De Long Mountains subterranes. In GAAR, it consists predominantly of relatively nonresistant siliceous shale and siltstones divided into the Siksikpuk and Otuk formations.

Etivluk Group: Siksikpuk Formation (Permian)

The Siksikpuk Formation is mostly composed of shale and siltstone that can be cherty, calcareous or ferruginous. Yochelson and Dutro (1960) and Rowett (1975) identified rugose corals, cephalopods, gastropods, echinoderms, brachiopods, as well as fish bone and teeth from this unit in the Chandler Lake B-4 and B-5 quadrangles. This is a characteristic assemblage found at many localities, usually in the lower part of the Siksikpuk Formation. The Siksikpuk in the Chandler Lake B-1 quadrangle has produced a similar Early Permian assemblage. The fauna contains relatively few taxa, probably the most pervasive being the smooth-shelled brachiopod Martinia which occurs abundantly in shelly accumulations, in some places. Another characteristic form is the small gastropod *Straparollus* (*Euomphalus*) *alaskensis* Yochelson and Dutro. Also included in this assemblage are *Attenuatella*, *Anidanthus* and *Spiriferella*. Occasionally, small horn corals are found including *Ufimia*, *Sochkineophyllum* and *Tachylasma* (Rowett 1975). Brachiopods have also been found in this unit in the Chandler Lake A4 quadrangle.

Etivluk Group: Otuk Formation (Upper Triassic–Middle Jurassic)

The Otuk Formation is characterized by thinly bedded sequence of chert, shale, silicified mudstone, and silicified limestone. The upper part of the Otuk consists of the Jurassic Blanckenship Member containing black laminar shales that reflect low oxygen conditions though much of the time of its deposition. The limestone member in the lower part of the Otuk is typically very fossiliferous, containing an Upper Triassic pectinid dominated fossil assemblage which in the Chandler Lake B-2 quadrangle contains several species of *Halobia*, *Monotis* (*Eomonotis?*) sp., and *?Otapiria* cf. *O. tailleuri* Imlay. The Otuk in the Chandler Lake B-1 quadrangle has also produced *Monotis* (*Monotis*) *subcircularis*. The Blankenship

Member in the Chandler Lake B-2 quadrangle has produced *Otapiria* cf. *O. marshalli* (Trechmann) in association with an *Inoceramus* cf. *I. lucifer* indicative of Middle Jurassic age. That unit has also yielded *Otapiria tailleuri* Imlay, *Meleagrinella* sp., *Inoceramus* prisms, and abundant radiolarian in the Chandler Lake B-4 quadrangle (Imlay 1967). Near the northern boundary of the park and preserve in the Chandler Lake B-1 and B-2 quadrangle, gray-black argillaceous, bituminous limestones previously considered to belong to the Shublik Formation have yielded *Halobia* of *H. ornatissima* group and *Monotis*. *Monotis ochotica* of late Norian (Late Triassic) age has been found in the Philip Smith Mountains B-5 quadrangle. Finally, Ichthyosaur remains have been found in this unit in the Howad Pass quadrangle to the northeast of GAAR (Tailleur et al. 1973).

Shublik Formation (Middle–Upper Triassic)

The Shublik Formation is the North Slope subterrane is correlative with much of the Otuk Formation. It is comprised of a mixture of richly fossiliferous shale, mudstone, carbonate rocks, siltstone and sandstone (Moore et al. 1994). Detterman et al. (1975) identified ammonites, *Halobia*, and *Monotis* indicative of Middle and Late Triassic age in this unit. In GAAR, it is present only in the Doonerak fenster of the Wiseman D-2 quadrangle, where it has produced *Halobia* and *Daonella* cf. *frami*.

Okpikruak Formation (Early Cretaceous)

The Okpikruak Formation forms the youngest rocks in the Endicott Mountains subterrane. It primarily consists on gray deep marine mudstone with minor amounts of thin-bedded sandstone and conglomerate that were shed northward from the Brooks Range prior to deformation of the subterrane (allochthon). This unit contains Early Cretaceous *Buchia* bivalves. Earliest Cretaceous *Buchia okensis* (Pavlow) has been found in this unit in the Chandler Lake B-2 Quadrangle. The Chandler Lake B-4 quadrangle has yielded Berriasian and Valanginain *Buchia subokensis* (Pavlow), *Buchia crassicollis solida* (Lahusen), *Buchia sublaevis* (Keyserling), and unidentified ammonites and crinoids. *Buchia crassicollis* (Keyserling) has been reported from the Chandler Lake C-5 quadrangle.

Coquinoid limestone (Lower Cretaceous)

A very thin but distinctive unit known as the coquinoid limestone has been recognized at a series of localities along the entire northern from of the central Brooks Range. This limestone rests on the Otuk Formation and consists entirely of a spectacular fossil hash comprised almost entirely of the bivalve *Buchia sublaevis* Keyserling. This unit is reported from the GAAR preserve in the Chandler Lake B-2 quadrangle and from a klippe in the Chandler Lake A-4 and A-5 quadrangles and likely is present elsewhere in the park and preserve, particularly along the northern front of the Brooks Range. The unit is Valanginian (Early Cretaceous) in age.

Fortress Mountain Formation (Lower Cretaceous)

The Fortress Mountain area of GAAR in the Chandler Lake C-5 quadrangle is the type area for the Fortress Mountain Formation. The Fortress Mountain Formation consists of shale, sandstone, and conglomerate and represents fan-delta deposits shed into a deep basin. It contains Albian (Early Cretaceous) age bivalves including *Aucellina dowlingi* McLearn, and *Inoceramus* cf. *I. altifluminis* McLearn (Imlay 1961). Rocks of this unit near the northern boundary of the park in the Chandler Lake B-4 quadrangle have also yielded *Inoceramus anglicus* Woods, *Arctica?* sp., *Thracia* cf. *T. kissoumi* McLearn, *Astarte ignikensis* Imlay, *Dicranodonta dowlingi* McLearn, and *Tancredia stelcki* McLearn.

Miscellaneous Pleistocene to Holocene units

Unnamed Quaternary units in GAAR have produced several collections and there is a good possibility that much more material is present in deposits of this age. These deposits are prevalent along the banks of rivers and streams and as well as the gravel bars in them. In the Killik River A-2 quadrangle, a caribou pelvis identified as *Rangifer tarandus* (Linnaeus) and a sample of wood were collected from overbank deposits of the Killik River.

Rasic and Matheus (2007) discussed Holocene moose material found near the Lakeside archeological site located in a deflating dune field on the east side of the Killik River within GAAR. They stated that isolated bone specimens such as this are not uncommon in the dry lake beds and dune blowouts found in the Killik River valley.

Park Collections

Forty-eight specimens are cataloged as paleontological resources in the GAAR museum collection. A number of specimens were collected from the Lisburne Group (Mississippian and Pennsylvanian) by Jim Fritts of the Alaska Geological and Geophysical Survey. Stratigraphic information and provenance is not provided in the online web-catalog for many of the fossil specimens. Cataloged specimens include foraminifera (GAAR 6535), coral (GAAR 6534, 6537, 6538), bryozoan (GAAR 6535), gastropod (GAAR 6821), crinoids (GAAR 6691), conodonts (GAAR 6717, 6797, 6810, 6825), graptolites (GAAR 6811), radiolaria (GAAR 6783, 6817) and a number of composite specimens (GAAR 6539, 6540, 6785, 6786, 6788, 6789, 6793).

There are several specimens of Pleistocene/Holocene mammals in the GAAR collection. These include remains identified as *Bison priscus* (GAAR 5904) collected in 1989. A complete mammoth tusk from *Mammuthus primigenius* (GAAR 15082) is curated into the collection. The remains of *Alces alces* (moose)(GAAR 10355, 11208), *Ovis dalli* (Dall Sheep)(GAAR 10354), and *Rangifer tarandus* (woodland caribou)(GAAR 10351, 10352, 15301-15306, 15323, 15327, 15328, 15331-15335) are frequently discovered along the gravel bars of the Alatna River. Additionally, there are a few unidentified mammal bones curated in the park collections (GAAR 10353, 15324-15326, 15329, 15330).

Paleontological Resource Management, Preliminary Recommendations

- Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held for GAAR on May 8-10, 2007. These meetings and the corresponding scoping summary includes recommendations related to the paleontological resources for GAAR and other ARCN parks.
- Park staff should continue to be made aware of the potential for discovery of fossil material during other field work, particularly along river bluffs, caves, sink holes, road cuts, streams, creeks, gullies, and erosional features. In particular, bedrock units such as the Kayak Shale, Lisburne Group carbonates, limestone member of the Otuk Formation, and the coquinoid limestone should be considered as having high potential for fossil discovery. Overlying Pleistocene and Holocene units along river bluffs, road cuts, streams, in creeks, caves, sink holes and gullies should also be considered as having potential for vertebrate discoveries.
- Park staff should be encouraged to observe exposed cliffs, other erosional bedrock, and streams for fossil material while conducting their usual duties. Staff should photodocument and potentially monitor any occurrences of paleontological resources.
- The park should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils. The park may consider a formal site documentation and condition assessment for significant fossil localities.
- 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.
- 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. Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist.
- Paleontological field inventories may indicate the need for long-term monitoring of in situ fossil resources. The NPS has developed a strategy for paleontological resource monitoring and has

been published by the Geological Society of America in a special publication on Geological Monitoring (Santucci et al. 2009). Site specific paleontological resource monitoring prescriptions should be considered for significant fossil localities.

- GAAR should seek technical assistance from the NPS Geologic Resources Division regarding issues related to paleontological resource management, protection and/or interpretation.

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Kobuk Valley National Park

Kobuk Valley National Park (KOVA) was established in 1980 and covers 708,480 ha (1,750,700 acres). It lies south of Noatak National Preserve and spans the Kobuk River Valley. The park was established to "maintain the environmental integrity of the natural features of the Kobuk River Valley, including the Kobuk, Salmon, and other rivers, the boreal forest, and the Great Kobuk Sand Dunes, in an undeveloped state; to protect and interpret, in cooperation with Native Alaskans, archeological sites associated with Native cultures; to protect migration routes for the Arctic caribou herd; to protect habitat for, and populations of, fish and wildlife including but not limited to caribou, moose, black and grizzly bears, wolves, and waterfowl; and to protect the viability of subsistence resources."

Three general landscape types exist within Kobuk Valley National Park: the Baird Mountains, the Waring Mountains, and the Kobuk Valley (floodplains and terraces). The Baird Mountains, north and east of the river, are the western extension of the Brooks Range and separate the Kobuk and Noatak rivers. They range in height from 762 to 1,450 m (2,500 to 4,760 ft). On the south side of the Kobuk River lie the Waring Mountains, which are broadly folded, northeast-trending mountains that are generally less than 610 m (2,000 ft). The Kobuk River runs through the lowland between these two sets of mountains. This area is largely covered by glacial drift and alluvial deposits, including clayey till, outwash gravel, sand, and silt.

Geologic Background

Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, have been held (need date). A formal paleontological resource survey has not been conducted, but there has been over a half century of geologic investigation in the park area, primarily by U.S. Geological Survey scientists, but also by Alaska Division of Geological and Geophysical Surveys, and university and industry scientists. These investigations indicate that some of the rock units found in the park contain paleontological resources, and there is potential for continued discovery.

The Alaska Paleontological Database web site (http://www.alaskafossil.org/) contains a recent compilation of paleontological information based primarily on extensive U.S. Geological Survey paleontological reports, but also includes many other sources and helpful links to sites with geologic maps and other information. This resource, coupled with some additional literature sources, provides the basis of this report and is the source of the information for the fossils listed below unless otherwise indicated. Moore et al. (1994, 1997) provide a very helpful overview of the complex geology of northern Alaska that can be used to place the paleontologic information in context and was used extensively for the framework geology used in the report. Other important bodies of work with information relevant to the framework geology and paleontology of GAAR include Tailleur and Weimer (1987), Gryc (1988) and Mull and Adams (1989).

The geology of KOVA has been divided onto several geologic provinces and tectonostratigraphic terranes, as well as stratigraphic units. These will be discussed briefly below.

Geologic Provinces

Four east-west trending geologic provinces are found within the boundaries of KOVA. These are defined by structural character, degree of metamorphism, and stratigraphy. The geologic provinces primarily reflect the deformational history related to the formation of the Brooks Range and generally increase in metamorphic grade to the south. The northern boundary of KOVA at most places lies in the central belt province, which forms the geographic core of the Brooks Range. This province is composed of ductilely deformed Paleozoic slate, phyllite, schist, carbonate rocks and gneiss. The metasedimentary rocks of this belt commonly retain their primary sedimentary textures. Southward are thin bands of the phyllite belt with metasedimentary phyllites, and the greenstone belt with resistant metamorphosed basalt and chert. The southern part of KOVA lies within the Cretaceous sediments of the Kobuk-Koyokuk basin, which are

thought to have been shed off of the Brooks Range while it was forming in the Early Cretaceous. Because of the increase in metamorphic grade southward within the Brooks Range provinces, the best potential for well preserved fossils, other than in the southernmost Cretaceous sediments, is in the central belt province.

Terranes

Terranes are fault bounded geologic bodies of rock that have been moved and deformed by tectonic forces. A terrane has an internally similar sequence of sedimentary units (stratigraphy) and deformational history that differs significantly from neighboring terranes. Subterranes are fault bounded blocks whose stratigraphies can be linked to other nearby terranes, but that are different enough to indicate significant amounts of tectonic displacement between the subterranes.

Alaska was divided into a number of tectonostratigraphic terranes by Jones et al. (1987). Using additional information for northern Alaska, Moore et al. (1994, 1997) modified this terrane scheme to create a terrane and subterrane and/or allochthon scheme. The rocks of KOVA can be assigned to two tectonostratigraphic terranes: the Arctic Alaska terrane and the Angayucham terrane.

Two regions in the central and eastern part of KOVA lie in the Angayucham terrane part of which outcrops along the southern margin of the Brooks Range (Moore et al. 1994). Rocks of this terrane are primarily composed of slightly metamorphosed mafic volcanic rocks, diabase, gabbro, and ultramafic rocks. Dolomitic mudrock and chert in the Ambler River B-5 quadrangle containing widely scattered tabulate corals and abundant brachiopods (pentameroids?) and conodonts of Middle Devonian age may lie in this terrane, and possibly Late Silurian-Early Devonian conodonts from a locality from the same quadrangle.

The rest of KOVA, except the southernmost part, is underlain by subterranes of the Arctic Alaska terrane that are named from north to south Hammond, Coldfoot and Slate Creek subterranes, which increase in metamorphic grade, respectively. Because of this metamorphism, most fossils in the park come from the Hammond terrane and some possibly from the Coldfoot, but no fossils are known from the Slate Creek terrane in the park area. The bedrock of the southernmost part of KOVA is composed of Cretaceous sediments of the Kobuk-Koyukuk Basin representing continental Alaska. Fossils are sparse in this basin, but numerous fossil leaves are reported to have been recovered along the Koyukuk River (T. Moore, USGS, pers. comm., 2009).

Sources of Paleontological Resources

Fossils have been documented from the following geologic formations as well as the museum collections within KOVA. These fossils present opportunities for resource management (including field surveys, inventory, and monitoring), education, interpretation, and continued or future scientific research in the park.

Baird Group (Cambrian–Upper Devonian)

Rocks of the Baird Group apparently represent remnants of a once widespread Cambrian to Devonian carbonate platform or platforms (Dumoulin and Harris 1994). In the Hammond subterrane of KOVA, this group contains the Skajit Limestone and other unnamed carbonate units. Included in this stratigraphic interval are a number of fossil localities that chiefly contain conodonts from unknown rock units that fall in the age range of the Baird Group.

Fossils from undifferentiated strata of the Baird Group in KOVA include a locality in the Baird Mountains C-1 quadrangle containing poorly preserved, Early to Middle Ordovician conodonts, including *Microzarkodina* and *Periodon* elements; and a Middle Ordovician to Middle Devonian locality in the Baird Mountains D-2 quadrangle containing conodonts and possibly corals. The Ambler River B-5 quadrangle also has several fossil localities assigned to the Baird Group, including a limestone-dolomite unit of Devonian age mapped along the south edge of the Brooks Range, particularly in the Cosmos Hills

and Jade Mountains areas (Patton et al. 1968; Fritts 1970). These rocks are mostly of Early and Middle Devonian age as indicated by the corals *Emmonsia*, *Diplochone*, *Pseudotryplasma*, and *Taimyrophyllum* in various collections (Oliver et al. 1975). Middle Devonian conodonts and fish bone are also known from this unit in this quadrangle. Till et al. (2008) provided a comprehensive list of conodont localities in the southern Brooks Range, including parts of KOVA.

Baird Group: Skajit Limestone (Ordovician–Devonian)

The name Skajit Limestone is applied to thick, massive, middle Paleozoic carbonate units in the Hammond subterrane (Moore at al. 1994). Fossils are not common in this unit, but they have been found in some areas. Rocks assigned to this unit in KOVA have only produced conodonts of Middle Ordovician to Middle Devonian age, although some of the units are composed of fossil hash. Localities are known from the Baird Mountains C-2 and D-2 quadrangles. The locality in the Baird Mountains D-2 quadrangle contains a very shallow-water species association characteristic of warm, shallow-water biofacies of the North American mid-continent.

"Twilight zone" between Baird Group and Schist Belt (Middle Ordovician–Lower Mississippian)

This informal name applies to strata adjacent to the Baird Group located at the southern boundary of the Hammond terrane, where it abuts the Coldfoot terrane. Conodont fossils are known from marble lenses and beds in these strata from both the Baird Mountains B-3 and C-3 quadrangles; they indicate an age range for these rocks from Middle Ordovician to Early Mississippian. At one location a bedded limestone facies also contains possible skeletal fragments.

Lisburne Group (Middle Devonian–Mississippian)

One fossil locality in KOVA has been assigned to the Lisburne Group in the Ambler River B-5 quadrangle. It contains Middle Devonian to Mississippian conodonts including *Ozarkodina*.

Unnamed sedimentary rocks (Lower and Upper Cretaceous)

A sequence of unnamed Lower and Upper Cretaceous sedimentary rocks were deposited in the Kobuk-Koyokuk basin at the southern edge of KOVA, adjacent to and south of the Kobuk River and exposed in the Waring Mountains. These rocks at one time were assigned to the Shaktolik Group, but Patton (1973) abandoned this nomenclature. These rocks have produced Early Cretaceous (Albian) age fossils from several localities near the southern boundary of the park. In the Baird Mountains A-2 quadrangle, Albian conifer and dicotyledon plants have been found in a sequence of quartz conglomerate, quartz-carbonate sandstone, coal, rhyolitic crystal tuffs, and calcareous micaceous mudstone on the west side Kobuk River. The collection contains the conifer *Cephalotaxopsis microphylla laxa* Holl and the dicotyledon *Pseudoprotophyllum dentatum* Holl. A second collection found in sandstone near or just south of the park boundary in the Selawick D-2 quadrangle contains an assemblage of bivalve indicative of a Middle Albian age, including *Yaadia* cf. *Y. whiteavesi* Packard (Elder and Miller 1991).

Pleistocene deposits

Pleistocene fossils have been found at several localities along the Kobuk River in the Ambler River A-5 quadrangle in bedded eolian and fluvial sand of the last glaciation. These collections include a *Mammuthus primigenius* (Blumbach) lower molar and mammoth bone, and a horse cervical from *Equus* sp. cf. *E.* (*Asinus*) *lambei* Hay.

Hamilton et al. (1984, 1993) discussed Late Pleistocene vertebrates and other fossils found at Epiguruk Bluff on the Kobuk River. They list the remains of large mammals recovered in situ from Epiguruk Bluff as *Mammuthus primigenius* (wooly mammoth), *Mammuthus* sp., and *Equus* sp., cf. *E.* (*Asinus*) *lambei*, *Bison* sp., *Rangifer* (*Caribou*), and Canidae. The few small mammal remains recovered were all of modern aspect. They include *Lemmus sibircus* and *Dicrostonyx* sp., (lemming), *Spermophilus* (*Spermophilus*) *parryi* (ground squirrel), and *Microtus* sp. (vole). Wood and freshwater mollusks (*Lymnaea* spp., *Pisidium* spp.) were also found at the site which has been dated between 37,000 and 14,000 years ago. There is probably good potential for the discovery of more Pleistocene material along river banks.

Park Collections

The KOVA collections contain four paleontological specimens including a fragment of a mammoth tooth identified as *Mammuthus primigenius* (KOVA 21) and three collections of bone fragments, tentatively identified as elk (KOVA 768, 769, 770) (E. Devinney, Western Arctic National Parklands, pers. comm. November 2009).

Paleontological Resource Management, Preliminary Recommendations

- Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held for KOVA on May 8-10, 2007. These meetings and the corresponding scoping summary includes recommendations related to the paleontological resources for KOVA and other ARCN parks.
- Park staff should continue to be made aware of the potential for discovery of fossil material during other field work, particularly along river bluffs, caves, sink holes, road cuts, streams, creeks, gullies, and erosional 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 photodocument and potentially monitor any occurrences of paleontological resources.
- The park should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils. The park may consider a formal site documentation and condition assessment for significant fossil localities.
- 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.
- 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. Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist.
- Paleontological field inventories may indicate the need for long-term monitoring of in situ fossil resources. The NPS has developed a strategy for paleontological resource monitoring and has been published by the Geological Society of America in a special publication on Geological Monitoring (Santucci et al. 2009). Site specific paleontological resource monitoring prescriptions should be considered for significant fossil localities.
- KOVA should seek technical assistance from the NPS Geologic Resources Division regarding issues related to paleontological resource management, protection and/or interpretation.

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Data Sets

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~1960s–present. (USGS museum specimens; associated specimen notes; collection records; maps; etc.). Originated by USGS staff and other researchers; status: Active.

Noatak National Preserve

Noatak National Preserve (NOAT) was established in 1980 from land originally designated as the Noatak National Monument (established 1978). It covers 2,660,598 ha (6,574,481 acres), lies north of the Arctic Circle and is bordered on the east by Gates of the Arctic National Park and Preserve, on the south by Kobuk Valley National Park and on the north by the National Petroleum Reserve. The preserve was established to "maintain the environmental integrity of the Noatak River and adjacent uplands," to protect wildlife habitat and populations, and protect archaeological resources in order to provide opportunities for scientific research. The park lies in a mountainous region adjacent to the Noatak River. The Noatak River originates in Gates of the Arctic National Park and Preserve to the east, and flows westward through the central portion of the preserve, before exiting at its western border and turning south to empty into Kotzebue Sound. Sandstone, shale, chert, and limestone make up the bedrock geology in the De Long Mountains to the north of the Noatak River, and the Baird Mountains to the south of the river in the preserve. Large isolated klippen of displaced gabbroic and granitic rocks, ultramafic rocks and metavolcanic rocks are also present. The lowland areas of the Noatak drainage are made up of sedimentary materials, including siltstones, sandstones and limestones. Unconsolidated deposits of gravel, clay, silt and sand are concentrated in the lower areas of the Noatak drainage.

Geologic Background

Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, have been held (need date). A formal paleontological resource survey has not been conducted, but over a half century of geologic investigation in the park area primarily by U.S. Geological Survey scientists, but also by Alaska Division of Geological and Geophysical Surveys, and university and industry scientists have indicated that many of the sedimentary rock units found in the park contain considerable paleontological resources, and that there is potential for continued discovery.

The Alaska Paleontological Database web site (http://www.alaskafossil.org/) contains a recent compilation of paleontological information based primarily on extensive U.S. Geological Survey paleontological reports, but also contains many other sources and helpful links to sites with geologic maps and other information. This resource, coupled with some additional literature sources, provides the basis of this report and is the source of the information for the fossils listed below unless otherwise indicated. Moore et al. (1994, 1997) provide a very helpful overview of the complex geology of northern Alaska that can be used to place the paleontologic information in context and was used extensively for the framework geology used in the report. Other important bodies of work with information relevant to the framework geology and paleontology of GAAR include Gryc (1988), Mull and Adams (1989), Cole et al. (1997), Toro et al. (1997), Moore et al. (2004, 2008), Dumoulin et al. (2004), and DeVera et al. (2004).

The geology of NOAT has been divided onto several geologic provinces and tectonostratigraphic terranes, as well as formations. Each of these will be discussed briefly below.

Geologic Provinces

Four east-west trending geologic provinces are found within the boundaries of NOAT. These are defined by structural character, degree of metamorphism, and stratigraphy. They primarily reflect the deformational history related to the formation of the Brooks Range. In general, the park is bounded to the north and south by relatively undeformed Cretaceous sedimentary rocks of the Colville and Koyokuk basins, respectively. In between are the geologic provinces of the Brooks Range, which generally increase in metamorphic grade to the south. The northern boundary of NOAT at most places lies near the northern boundary of the disturbed belt province, slightly south of its boundary with the Colville basin. The disturbed belt consists of complexly deformed and imbricated Mesozoic and Paleozoic rocks; much of the northern part of the park lies in the disturbed belt which is the axial part of the western Brooks Range. The crestal belt forms the core of NOAT, and consists of folded and thrusted Mesozoic and Paleozoic rocks. Much of the southern part of NOAT lies in the central belt, which forms the geographic

core of the Brooks Range. This province is composed of ductilely deformed Paleozoic slate, phyllite, schist, carbonate rocks and gneiss. The metasedimentary rocks commonly retain their primary sedimentary textures. Southernmost extension of NOAT preserve crosses into the schist belt, which is mostly composed of schistose metasedimentary and metavolcanic rocks. Because of the increase in metamorphic grade southward within the Brooks Range, the best potential for well preserved fossils is in the northern part of the park.

Terranes

Terranes are fault bounded geologic bodies of rock that have been moved and deformed by tectonic forces. A terrane has an internally similar sequence of sedimentary units (stratigraphy) and deformational history that differs significantly from neighboring terranes. Subterranes are fault bounded blocks whose stratigraphies can be linked to other nearby terranes, but that are different enough to indicate significant amounts of tectonic displacement between the subterranes.

Alaska was divided into a number of tectonostratigraphic terranes by Jones et al. (1987). Using additional information for northern Alaska, Moore et al. (1994, 1997) modified this terrane scheme to create a terrane and subterrane and/or allochthon scheme. The rocks of NOAT can be assigned to two tectonostratigraphic terranes: the Arctic Alaska terrane and the Angayucham terrane.

A number of isolated regions in the northern and western part of NOAT compose part of the Angayucham terrane. They are exposed in klippen that form the structurally highest rocks in the Brooks Range—known as the Copter Peak and Misheguk Mountain allochthons (Moore et al. 1994). Rocks of this terrane are primarily composed of slightly to completely metamorphosed mafic volcanic rocks, diabase, gabbro, and ultramafic rocks. In the Copter Peak allochthon, some inter-pillow chert and bedded chert, as well as limestone have yielded fossils. Limestones have produced Late Devonian macrofossils and conodonts (Nelson and Nelson 1982) and radiolarian fossils mainly of Triassic age, but also are known from the Mississippian and Pennsylvanian ages (Ellerseick et al. 1984; Moore et al. 1994).

The rest of NOAT is underlain by subterranes of the Arctic Alaska terrane that are named from north to south, the De Long Mountains, Endicott Mountains, Hammond, and Coldfoot subterranes. The bulk of the park is underlain by the Endicott Mountain and Hammond subterranes. Most of these subterranes share common stratigraphy which will be discussed in the sections to follow. The Noatak Preserve may slightly extend into the Coldfoot subterrane at the southernmost tip. This terrane is more metamorphosed and deformed than the others.

The Endicott and De Long Mountains terranes share a similar Devonian through Lower Cretaceous stratigraphy. The Devonian to Pennsylvanian rocks are mostly marine carbonates that are overlain by siliceous sediments and underlain by Upper Devonian and/or Lower Mississippian clastic deposits. The carbonate rocks may contain both macro- and microfossils, whereas the siliceous rocks tend to contain mostly microfossils as will be discussed in detail in the Formations section below. The stratigraphy of the Hammond subterrane is poorly understood, but has a lower Paleozoic carbonate section. Finally, the tiny bit of Coldfoot terrane in the southernmost part of NOAT is mainly comprised of lower Paleozoic schistose metasedimentary and metavolcanic rocks that have yielded rare megafossils and conodonts (Hitzman et al. 1986; Moore et al. 1994). A Carboniferous carbonate section that is overlain by clastic strata thought to be Permian in age is present near the boundary of the Hammond and Coldfoot subterranes. Although assigned to the Hammond terrane by Moore et al. (1994), regional considerations suggest that it may instead rest on Coldfoot subterrane rocks (Moore et al. 1997).

Sources of Paleontological Resources

Fossils have been documented from the following geologic formations as well as the museum collections within NOAT. These fossils present opportunities for resource management (including field surveys, inventory, and monitoring), education, interpretation, and continued or future scientific research in the park.

Baird Group (Cambrian to Upper Devonian)

Rocks of the Baird Group apparently represent remnants of a once widespread Cambrian to Devonian carbonate platform or platforms (Dumoulin and Harris 1994). In the Hammond subterrane of NOAT, this group contains unnamed lower Paleozoic carbonate rocks. In the De Long Mountains subterrane, the Baird Group is represented by the Eli Limestone and the Kugururok Formation.

Fossils from undifferentiated rocks of the Baird Group in NOAT include Middle Ordovician to Silurian conodonts from the Baird Mountain D-1 quadrangle. Dumoulin and Harris (1987) described this rock sequence as their northeastern carbonate sequence and said that the basal Ordovician carbonate rocks contain mollusks, acrotretid brachiopods, and agnostid trilobites as well as conodonts, and were deposited in shallow water conditions. These rocks are overlain by Ordovician graptolite and conodont-bearing phyllite deposited in a mid-shelf to basinal setting (Carter and Tallieur 1984). These rocks are then overlain by Silurian shallow water dolostone containing graptolites. The Baird Mountain C-5 quadrangle contains Baird Group rocks of Dumoulin and Harris' (1987) west-central carbonate sequence. Rocks of this both shallow and deepwater sequence contain Early Ordovician conodonts and Cambrian to Ordovician brachiopods.

Baird Group: Unnamed Lower Paleozoic carbonate rocks (Silurian to Devonian)

These rocks consist of thick, massive, middle Paleozoic carbonate units in the Hammond subterrane that are correlative with the Skajit Limestone to the east (Moore at al. 1994). Fossils are not common in these units, but some have been found locally. In NOAT, these rocks have produced Late Devonian tabulate and rugose corals, brachiopods, and stromatoporoids in the Baird Mountains D-6 and C-5 quadrangles. This unit has also yielded Late Devonian samples of the same fossil groups, except stromatoporoids, from the Noatak C-1 quadrangle. A gray millimeter-laminated dolomite with locally abundant algae and worm burrows representing this unit has yielded Silurian to Middle Devonian conodonts in the Baird Mountains D-1 quadrangle. Till et al. (2008) provided for a comprehensive list of conodont localities in the southern Brooks Range, including parts of NOAT.

Baird Group: Eli Limestone (Middle to Upper Devonian)

The Eli Limestone is found in the Kelly River allochthon of the De Long Mountains subterrane. It is composed of shallow marine carbonate rocks that are locally argillaceous and that were probably deposited in a shallow shelf or platform setting receiving clay-rich clastic detritus (Moore et al. 1994). In the Misheguk Mountain A-5 quadrangle, this unit has produced Late Devonian conodonts, foraminifers, stromatoporoids, bryozoans, rugose corals, brachiopods. The Eli has yielded conodonts and foraminifers of similar age in the Misheguk Mountain B-5 quadrangle.

Fossils collected from the presumable type area of the Eli Formation in the Baird Mountains C-6 quadrangle include Late Devonian, brachiopods, echinoderms, and gastropods. All the specimens from this locality are molds and casts and are badly distorted and no original shell material is preserved. Collections contain *Cyrtospirifer* and two of the collections contain a large rhynchonelloid brachiopod that is probably *Gastrodetoechia*. In addition, all the collections contain indeterminate echinodermal debris and rounded objects that may be unidentifiable bivalve shells. Finally, the Eli Limestone in the Baird Mountains D-6 quadrangle has produced Middle Devonian conodonts, stromatoporoids, and tabulate and rugose corals, including *Tabulophyllum* cf. *T. mcconnelli* (Whiteaves).

Baird Group: Kugururok Formation (Middle to Upper Devonian)

The Baird Group is represented by the Kugururok Formation in the Nuka Ridge allochthon of the De Long Mountains subterrane. This unit is composed of a lower interval of calcareous shale and conglomeritic limestone overlain by massive to thin-bedded limestone and dolomite, and then cross-bedded limestone. It was probably deposited on a shallow marine carbonate shelf or platform receiving clastic detritus (Moore at al. 1994). The Kugururok has produced Late Devonian conodonts and brachiopods in the Baird Mountains D-6 quadrangle. In the Misheguk Mountain A-4 quadrangle, this unit has yielded Middle to Late Devonian rugose corals. Middle to Late Devonian rugose corals, brachiopods, trilobites [*Dechenella* (*Dechenella?*)], and ostracode fragments are known from the

Kugururok Formation in the Misheguk Mountain B-4 quadrangle. Finally, this unit has produced Devonian stromatoporoids, and tabulate and rugose corals from the De Long Mountains A-1/B-1 quadrangle border (Oliver at al. 1975).

Endicott Group (Upper Devonian–Lower Permian)

The Endicott Group is composed of time-transgressive units that represent a transgressive-regressive sequence across northern Alaska. The lowest unit consists of marine prodelta deposits of the Hunt Fork Shale. Above this lie the regressive marginal marine deposits of the Noatak Sandstone, overlain by delta plain and fluvial deposits of the Kanayut Conglomerate. The overlying marginal marine to shelf deposits of the Kayak Shale represent the next transgressive period. Fossils are known from all of these units except, possibly, the Kanayut Conglomerate in NOAT (see Noatak Sandstone below).

Endicott Group: Hunt Fork Shale (Upper Devonian–Mississippian)

The Hunt Fork Shale is mapped in both the Endicott Mountains subterrane and the Hammond subterrane. Fossils are only known from the former subterrane (Moore et al. 1994). The unit consists mostly of thin-bedded dark gray shale with lesser amounts, increasing upwards, of siltstone and quartzose sandstone, which are the product of mud-rich turbidites in a prodelta setting. In the Endicott Mountain subterrane shallow marine fossils are likely derived from shelfal sandstones of a deltaic sequence. The Hunt Fork has produced Devonian brachiopods, echinoderms, and bivalves in the Howard Pass B-4 quadrangle of NOAT. Late Devonian conodonts, brachiopods, echinoderms, and bivalves are also known from the Hunt Fork in the Baird Mountains C-5 quadrangle, and brachiopods are present in this unit in the Baird Mountains C-6 quadrangle. Late Devonian fossils from the Hunt Fork in the Misheguk Mountain A-3 quadrangle include echinoderms, bivalves, rhynchonelloid and *Cyrtospirifer* brachiopods, bellerophontacean gastropods, and an orthoceroid cephalopod.

Endicott Group: Noatak Sandstone (Upper Devonian–Lower Mississippian)

The Noatak Sandstone of the Endicott Mountains subterrane is a succession of sandstone with minor shale and conglomerate beds that represent marginal marine deposits that were developed between the marine Hunt Fork Shale and the terrestrial Kanayut Conglomerate. The Noatak is known to contain Late Devonian conodonts in the Baird Mountains C-5 and D-4 quadrangles. A unit assigned to either the Noatak Sandstone or the Kanayut Conglomerate in the Misheguk Mountain B-2 quadrangle produced Late Devonian to Early Mississippian brachiopods (Mayfield et al. 1984). In the De Long Mountains A-1 quadrangle, brachiopods of the genus *Cyrtospirifer*, grammysiid bivalves, and ostracodes indicate a Late Devonian marine phase of the Noatak there.

Endicott Group: Kayak Shale (Early Mississippian)

The Kayak Shale is a highly fossiliferous unit present in both the Endicott Mountains and Hammond subterranes. In its type area, in the Endicott Mountains subterrane near Shainin Lake, adjacent to GAAR, the Kayak Shale has been divided five members including a basal sandstone member and two black shale members with intervening bioclastic carbonate members. The Kayak records the northwestward transgression of the sea across the Kanayut delta deposits (Moore et al. 1994). The black shales represent shallow to deep marine sedimentation with massive fossiliferous debris flows forming limestone beds (Nilsen 1981). In the Misheguk Mountain A-1 quadrangle, the Kayak has yielded Mississippian productoid, spiriferoid, and rhynchonelloid brachiopods, tabulate corals, echinoderm debris, and bryozoans. Mississippian conodonts have been found in the Kayak Shale in the Misheguk Mountain A-3, and Baird Mountains D-6 quadrangles. In the Howard Pass B-5 and B-4 quadrangles, this unit has produced diverse assemblages of Mississippian gastropods, brachiopods, crinoids, conodonts, ichthyoliths, sponges, and corals (Dover et al. 2004).

Lisburne Group (Lower Mississippian–Lower Permian)

The Lisburne Group occurs in the Endicott Mountains and De Long Mountains subterranes in NOAT and consists primarily of carbonate units of Mississippian and Pennsylvanian age. To the east in the Chandler Lake quadrangle of the central Brooks Range, Bowsher and Dutro (1957) subdivided the Lisburne into the Wachsmuth and Alapah limestones. These shallow water carbonate platform deposits

grade westward into a thinner sequence of shale, limestone and chert of the more basinal facies of the Kuna Formation. In the De Long Mountains subterrane in NOAT, the Lisburne Group is represented by carbonate units of the Utukok and Kogruk formations (Moore et al. 1994). These formations represent progressive onlap of a slowly subsiding shallow platform. Lisburne rocks tend to be highly fossiliferous.

Fossils have been found at numerous localities in NOAT in strata assigned only to the Lisburne Group with no formational assignment. These include Mississippian rugose corals from the Baird Mountains D-6 quadrangle, conodonts from the De Long Mountains B-1 quadrangle, and rugose and tabulate corals, foraminifera, gastropods, and ammonites from the Noatak C-1 and A-1/A-2 quadrangles (Gordon 1957; Yochelson and Dutro 1960).

In the Misheguk Mountain quadrangle, numerous fossil localities have been assigned only to the Lisburne Group, including localities containing Early Mississippian pleurotomariacean gastropods from the A-1 quadrangle; and Early Mississippian gastropods including euomphalaceans, pleurotomariaceans, *Anematina rockymontanum* (Shimer), *Naticopsis* (Naticopsis) *suturicompta* (new species), and indeterminate neritaceans in the A-1 quadrangle (Yochelson and Dutro 1960). Mississippian conodonts are known from the Lisburne Group in the A-3 quadrangle. In the B-1 and B-2 quadrangles, numerous brachiopod taxa are known including *Camarotoechia* aff. *C. metallica* (White) and *Imbrexia* aff. *I. forbesi* (Norwood and Pratten). In the B-4 quadrangle, lowest of the three unnamed stratigraphic divisions of the Lisburne Group has produced Mississippian coral, crinoid columnals, trilobites, nautiloids, gastropods, and brachiopods including *Chonetes* (new species) and *Leptaena* cf. *L. analoga* (Phillips) (Gordon 1957). Finally, Late Mississippian brachiopods are known from the Lisburne in the Misheguk Mountain B-5 quadrangle.

Lisburne Group: Utukok Formation (Lower Mississippian)

The Utukok Formation was defined by Sable and Dutro (1961) in the Misheguk Mountain quadrangle and is composed of fine-grained quartzose sandstone that grades upward into sandy limestone and calcareous shale. The unit is 1,000 m (3,300 ft) thick in the type area, but thins to 10 m (33 ft) to the south in the Baird Mountains quadrangle. It was deposited in a shallow marine shelf or platform setting and is known to contain mostly brachiopods and conodonts (Moore et al. 1994).

In the Misheguk Mountain quadrangle, Mayfield et al. (1984) reported Early Mississippian fossils including conodonts in the Utukok of the A-5 quadrangle; conodonts, ichthyoliths, and brachiopods in the B-2 quadrangle; brachiopods in the B-3 quadrangle; and brachiopods, rugose coral and conodonts in the B-5 quadrangle. In addition, the Utukok has produced Early Mississippian conodonts and ichthyoliths from the Baird Mountains D-6 quadrangle and conodonts from the De Long Mountains A-1 quadrangle.

Lisburne Group: Kogruk Formation (Mississippian)

The Kogruk Formation was also defined by Sable and Dutro (1961) in the Misheguk Mountain quadrangle and is composed of cliff-forming limestone with abundant nodular chert and silicified zones. The limestone is comprised of bryozoan-echinoderm packstone and wackestone. The lower part of the unit was deposited in a shallow water shoal and tidal channel environment and the upper part reflects more open marine conditions (Armstrong 1970).

In the Misheguk Mountain quadrangle, the Kogruk Formation has yielded Early Mississippian conodonts in the B-3 and D-6 quadrangles, Late Mississippian foraminifera in the B-4 quadrangle (Curtis et al. 1984) and Late Mississippian foraminifera, brachiopods, and corals from a siliceous-bryozoan-echinoderm grainstone and arenaceous-brachiopod wackestone in the B-5 quadrangle. The Kogruk has produced Late Mississippian rugose corals, diverse brachiopods, and echinoderms in the De Long Mountains B-1 quadrangle.

Lisburne Group: Wachsmuth Limestone (Lower Mississippian)
At its type locality in the Chandler Lake quadrangle to the east of NOAT, the Wachsmuth Limestone lies conformable on the Kayak Shale and consists of shaly limestone, crinoidal limestone, dolomite, and banded chert-limestone (Moore et al. 1994). The Wachsmuth has limited distribution in the eastern part of NOAT. This unit has produced Early Mississippian euomphalacean gastropods in the Howard Pass A-2 quadrangle.

Lisburne Group: Kuna Formation (Lower Mississippian–Lower Pennsylvanian)
The Kuna Formation is a deep water unit composed of phosphatic black shale and dolomite with lesser amounts of black radiolarian- and spiculite-bearing chert (Mull et al. 1982). Only Mississippian conodonts are known from the Kuna in NOAT. Conodonts have been found in the Howard Pass B-3 and B-4 quadrangles, the Misheguk Mountain B-5 quadrangle, and the Baird Mountains D-65 quadrangle.

Nuka Formation (Mississippian–Permian)
The Nuka Formation occupies the position of the Lisburne Limestone in highly allochthonous parts of the De Long Mountains subterrane near the northern edge of NOAT. It consists of limestone, arkosic limestone, arkose, and quartz sandstone and appears to represent both marine and non-marine deposits (Moore et al. 1994). Fossils are locally abundant in the Nuka. In the Misheguk Mountain B-4 quadrangle, the Nuka contains Permian echinoderms, bivalves, rugose corals, foraminifera, and a large brachiopod assemblage containing *Derbyia?*, *Septacamera?*, *Meekella?*, *Neospirifer*, *Cancrinella?*, and dictyoclostids (Curtis et al. 1984). The Nuka in the Misheguk Mountain C-1 quadrangle, just north of the park boundary, has produced Late Mississippian rugose coral, bryozoans, brachiopods, goniatitid ammonoids, trilobites, pectenoid and schizodid bivalves, and the gastropod *Mourlonia* cf. *M. reloba* Yochelson and Dutro.

Etivluk Group (Permian–Jurassic)
In the NOAT area, the Etivluk Group is present in the northern part of the park in the Endicott Mountains and De Long Mountains subterranes. It consists predominantly of siliceous shale and siltstone, and is divided into the Siksikpuk and Otuk formations. Rocks of the undivided Etivluk Group in NOAT have produced Triassic radiolarians in the Misheguk Mountain A-3, A-4, B-1, B-2, B-3, B-4, and B-5 quadrangles. Conodonts also have been found in the Misheguk Mountain B-5 quadrangle (Ellerseick et al. 1984; Curtis et al. 1984; Mayfield et al. 1984).

Etivluk Group: Siksikpuk Formation (Permian)
The Siksikpuk Formation is mostly composed of shale and siltstone that can be cherty, calcareous, or ferruginous. In NOAT, Pennsylvanian to Early Permian radiolarians have been found in the Siksikpuk Formation in the Misheguk Mountain B-1, B-2, B-4, B-5, C-1, and C-3 quadrangles.

Etivluk Group: Otuk Formation (Upper Triassic–Middle Jurassic)
The Otuk Formation is characterized by thinly bedded chert, shale, silicified mudstone, and silicified limestone. The upper part of the Otuk is the Blanckenship Member, which consists of organic-rich black shale. The Otuk is largely composed of black fine-grained deposits reflecting low oxygen conditions though much of the time of deposition. The limestone member of the Otuk typically is quite fossiliferous and contains a pectinid-dominated fossil assemblage. This pectinid assemblage is represented by Late Triassic (Norian) *Monotis* bivalves in the De Long Mountains B-1 quadrangle. Triassic radiolarians are known from the Otuk in NOAT in the Howard Pass B-4 and Misheguk Mountain B-2 and C-1 quadrangles.

Unnamed gray chert unit (Triassic–Lower Jurassic)
A sheared, amygdaloidal pillow basalt with radiolarian chert in fault contact with vesicular basalt and limestone in the Howard Pass B-4 quadrangle contains Triassic to Early Jurassic radiolaria.

Okpikruak Formation (Lower Cretaceous)

The Okpikruak Formation forms the youngest rocks in the Endicott Mountains subterrane. It primarily consists of gray, deep marine mudstone with minor amounts of thin-bedded sandstone and conglomerate. This unit contains Early Cretaceous *Buchia* bivalves. In NOAT, the Okpikruak contains Berriasian and Valanginian (Early Cretaceous) *Buchia crassicollis* (Keyserling), *B. okensis* (Pavlow), and *B. subokensis* (Pavlow) in the Misheguk Mountain B-2, B-4 and B-5 quadrangles.

Pleistocene deposits

Although few are known from NOAT, there is a good potential for invertebrate and vertebrate fossils to be found in Pleistocene as well as Holocene deposits in the park. A Pleistocene unit on a cut bank on the north side of Noatak River in the Misheguk Mountain A-1 quadrangle exposes a bedrock terrace overlain by gravel, silt, and peat deposits that contain ostracodes, gastropod, bivalves, and thecamoebians. In addition, one mammoth tusk resides in park collections from NOAT.

Park Collections

The NOAT museum collections contains one paleontological specimen (NOAT 4) which is a poorly preserved mammoth tusk identified as Mammuthus primigenius (E. Devinney, Western Arctic National Parklands, pers. comm. November 2009).

Paleontological Resource Management, Preliminary Recommendations

- Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held for NOAT on May 8-10, 2007. These meetings and the corresponding scoping summary includes recommendations related to the paleontological resources for NOAT and other ARCN parks.
- Park staff should continue to be made aware of the potential for discovery of fossil material during other field work, particularly along river bluffs, caves, sink holes, road cuts, streams, creeks, gullies, and erosional 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 photodocument and potentially monitor any occurrences of paleontological resources. In particular, bedrock units such as the Kayak Shale, Lisburne Group carbonates, and limestone member of the Otuk Formation should be considered as having high potential for fossil discovery. Overlying Pleistocene and Holocene units along river bluffs, road cuts, streams, creeks, in caves, sink holes and gullies should also be considered as having potential for vertebrate discoveries
- The park should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils. The park may consider a formal site documentation and condition assessment for significant fossil localities.
- 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.
- 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. Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist.
- Paleontological field inventories may indicate the need for long-term monitoring of in situ fossil resources. The NPS has developed a strategy for paleontological resource monitoring and has been published by the Geological Society of America in a special publication on Geological Monitoring (Santucci et al. 2009). Site specific paleontological resource monitoring prescriptions should be considered for significant fossil localities.

- NOAT should seek technical assistance from the NPS Geologic Resources Division regarding issues related to paleontological resource management, protection and/or interpretation.

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Data Sets

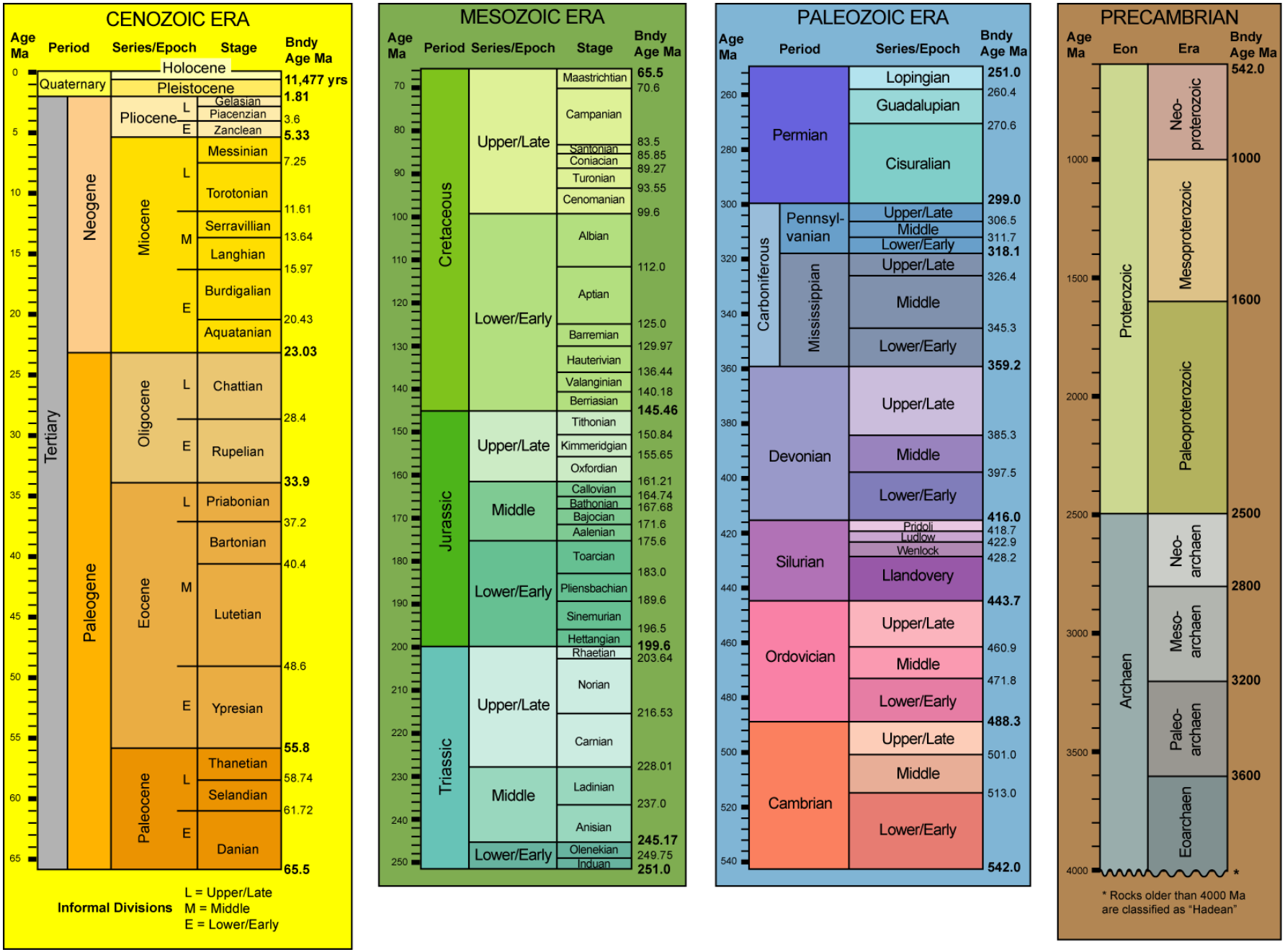
Noatak National Preserve Paleontological Archives.
1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Noatak National Preserve Museum Collections.
1899–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by NOCA staff; status: Active.

Alaska Paleontological Database.
1990s–present. (electronic paleontological resource data: locality information, specimen lists, maps, etc.). Originated by MDIRA staff; status: Active. Online: www.alaskafossil.org.

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

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

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