



Brooks Range National Parklands: Cape Krusenstern National Monument, Gates of the Arctic National Park and Preserve, Kobuk Valley National Park, and Noatak National Preserve

Geologic and Soil Resources Inventory Summary



Photograph of the DeLong Mountains west of Copter Peak, in the northern part of Noatak National Preserve. The DeLong Mountains are a subrange of the Brooks Range, a mountain range that stretches across northern Alaska. The Brooks Range began forming in the Jurassic Period (201.3–145.0 million years ago), when oceanic rocks collided with rocks of northern Alaska. NPS photograph by Emily Mesner.

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Geologic and Soil Resources Inventory

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Abstract

This document summarizes the status of National Park Service (NPS) Geologic Resources Inventory (GRI) and Soil Resources Inventory (SRI) deliverables for the Brooks Range national parklands (Cape Krusenstern National Monument, Gates of the Arctic National Park and Preserve, Kobuk Valley National Park, and Noatak National Preserve). It also provides information about the parklands' geologic setting and history, geologic heritage, and geologic resource management. This document is intended to assist park staff with prioritizing technical assistance or new inventory and assessment funding requests in the near term (roughly 1–5 years).

GRI hosted a baseline scoping meeting for the Brooks Range national parklands in 2007 and a follow-up meeting occurred in 2025. Baseline bedrock and surficial geologic maps were delivered to the parklands in 2023 and 2024. SRI delivered a legacy soil database and map to the parklands in 2009. The most up-to-date soils data is available via Web Soil Survey, which is maintained by the USDA Natural Resources Conservation Service (NRCS).

The “Geologic Setting and History” section summarizes the geologic setting of northern Alaska, the terranes that make up Alaska’s bedrock, and the geologic history of northern Alaska. This geologic history stretches back almost 1 billion years to the Neoproterozoic Era and primarily involves the formation and interactions of the Arctic Alaska and Angayucham terranes. Notable geologic events include the formation of the Brooks Range mountains, opening of the Canada Basin of the Arctic Ocean, and glacial/interglacial cycles of the Quaternary Period.

The “Geologic Heritage” section highlights connections between the parklands’ geology, history, and cultural identity. Geologic heritage resources of particular interest include the Brooks Range mountains, wild rivers and lakes, beach ridges, sand dunes, paleontological resources, hot springs, and stratotypes.

The “Geologic Resource Management” section provides information about geologic hazards, geologic resource protection, and potential geologic inventory and assessment needs. Geologic hazards include coastal change, earthquakes, ice jams, landslides, permafrost thaw, river erosion, rusting rivers, and tsunamis. Geologic inventory ideas include projects related to abandoned mineral lands, caves and karst, erosion and flooding, geologic resources inventory reports, hot springs, the Kobuk Sand Dunes, paleontological resources, rusting rivers, permafrost thaw features, surficial geologic mapping, and stratotypes.

Guidance for park staff regarding proposal processes and timeframes for the new Inventories and Assessment (I&A) Program is available on the [GSRI](#) and [I&A](#) SharePoint sites.

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Background of the GSRI

The Geologic and Soil Resources Inventory (GSRI) aids in the collection of new data and derives new information from existing data regarding the presence, absence, abundance, distribution, and significance of geologic or soil features or processes to inform park management decisions and planning. The GSRI also includes the legacy Geologic Resources Inventory (GRI) and Soil Resources Inventory (SRI) programs.

In the late 1990s, the GRI and SRI programs were established as two of the 12 original baseline inventories in the Inventory and Monitoring (I&M) program. These baseline inventories compiled existing information, acquired new information, and helped establish a minimum level of data across the more than 270 parks that are part of the [I&M networks](#). For both GRI and SRI, the primary deliverable was a digital (GIS) map. Between the 1990s and early 2020s, in addition to a digital map, GRI scoping summaries, geologic map posters, and GRI reports were produced for most of the 270 parks. GRI and SRI baseline inventory products are available through the [NPS DataStore](#). These products are designed to enhance stewardship of park resources by providing valuable information about soils, geologic formations, hazards, and connections between geology, history, and other natural resources.

The GRI and SRI are now unified as one inventory, the GSRI, under the Inventories & Assessment (I&A) Program. The I&A Program, and henceforth the GSRI, operates under a park-proposed inventory strategy in which parks submit natural resource inventory and assessment project proposals to the Project Management Information System (PMIS) during the Service-wide Comprehensive Call (SCC). Park staff should refer to the [GSRI SharePoint](#) and [I&A Program SharePoint](#) for instructions on how to submit a project proposal including basic eligibility requirements, evaluation criteria, and the approval and implementation process.

As of 2025, the GSRI is in the process of completing baseline inventories for I&M parks and transitioning to the I&A model of accepting park-proposed projects from all NPS units. During this transition period, 13 “priority” parks, including the Brooks Range national parklands (Cape Krusenstern National Monument [CAKR], Gates of the Arctic National Park and Preserve [GAAR], Kobuk Valley National Park [KOVA], and Noatak National Preserve [NOAT]), were identified as missing a baseline GRI report. This GSRI summary serves as a substitute for a baseline GRI report and is intended to support the parks’ participation in the I&A Program. As such, it summarizes the status of GRI and SRI deliverables for the Brooks Range national parklands and provides information on current geology and soils resource management concerns with a focus on potential inventory needs. Information in this summary was compiled from existing reports, meetings with park staff, and the best professional judgment from GSRI and WASO Geologic Resources Division (GRD) geoscientists.

Baseline GSRI Products

Geology

The following baseline GSRI products are available for the Brooks Range national parklands: (1) a scoping summary, (2) geologic map data in a geographic information system (GIS) format, (3) posters displaying the GRI GIS data; and (4) a GSRI summary (this document). These products are available via the “Geologic Resources Inventory Project for Cape Krusenstern National Monument, Gates of the Arctic National Park, Kobuk Valley National Park, and Noatak National Preserve” on the NPS DataStore at: <https://irma.nps.gov/DataStore/Reference/Profile/2244109>.

Geologic maps provide information on the distribution of bedrock units, surficial units, and geologic structures such as faults and folds. These maps are invaluable for understanding potential hazards (e.g., landslides, earthquakes), guiding resource management, and evaluating the suitability of areas for infrastructure, trails, and visitor use. Information provided in baseline GSRI products is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based upon the information provided in these products. Minor inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features in the GRI GIS data or on the posters.

Scoping Meeting

On 8–10 May 2007, the NPS held a scoping meeting for the Arctic Inventory & Monitoring Network parks at the NPS Fairbanks Administrative Office in Fairbanks, Alaska. The Arctic Inventory & Monitoring Network includes five park units: Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Gates of the Arctic National Park and Preserve, Kobuk Valley National Park, and Noatak National Preserve. The scoping meeting brought together NPS staff and geologic experts who reviewed and assessed available geologic maps, developed a geologic mapping plan, and discussed geologic features, processes, and resource management issues. A scoping summary (Thornberry-Ehrlich 2008) summarizes the findings of that meeting. The scoping summary is available on the NPS Datastore at: <https://irma.nps.gov/DataStore/Reference/Profile/2250178>.

GRI GIS Data

Four geospatial GRI GIS datasets are available for the Brooks Range national parklands: a bedrock geologic map that covers all the parks, sensitive geologic data (e.g., mine point features) that covers all the parks, a surficial geologic map that covers Noatak National Preserve, and a surficial geologic map that covers Gates of the Arctic National Park and Preserve. The GRI GIS data can be downloaded from the NPS DataStore using the following links:

- Bedrock geology: <https://irma.nps.gov/DataStore/Reference/Profile/2307190>
- Sensitive geologic data (NPS access only):
<https://irma.nps.gov/DataStore/Reference/Profile/2297346>
- NOAT surficial geology: <https://irma.nps.gov/DataStore/Reference/Profile/2300427>
- GAAR surficial geology: <https://irma.nps.gov/DataStore/Reference/Profile/2300184>

The GRI GIS data was compiled by the GRI team in 2023 and 2024 and may be updated if new, more accurate geologic maps become available or if software advances require an update to the digital format. These data are the principal deliverables of the GRI. The GRI team did not conduct original geologic mapping but compiled existing geologic information (i.e., paper maps and/or digital data) into the GRI GIS data. Scoping participants and the GRI team identified the best available source maps based on coverage (area mapped), map scale, date of mapping, and compatibility of the mapping to the current geologic interpretation of an area.

More information about the GRI GIS data can be found in the files accompanying the data. The “GIS readme file” explains the available file formats for the GRI GIS data, how to use the different file formats, and where to find more information about the GIS data model. The “ancillary map information document” shows the coverage of the data, lists the geologic maps or GIS data used to produce the GRI GIS data, the map units and map unit descriptions (including descriptions from all source maps), and additional information about the source maps.

The source maps below were used to produce the GRI GIS data for the parks:

- Wilson, F. H., C. P. Hults, C. G. Mull, and S. M. Karl. 2015. Geologic Map of Alaska (scale 1:1,584,000). Scientific Investigations Map SIM-3340. U.S. Geological Survey, Reston, Virginia. <https://pubs.usgs.gov/publication/sim3340>
- Hamilton, T. D. 2011. Surficial geologic map of the Noatak National Preserve, Alaska (scale 1:250,000). Scientific Investigations Map SIM-3036. U.S. Geological Survey, Reston, Virginia. <https://pubs.usgs.gov/publication/sim3036>
- Hamilton, T. D., and K. A. Labay. 2011. Surficial geologic map of the Gates of the Arctic National Park and Preserve, Alaska (scale 1:300,000). Scientific Investigations Map SIM-3125. U.S. Geological Survey, Reston, Virginia. <https://pubs.usgs.gov/publication/sim3125>

GRI Posters

Posters of each of the Brooks Range national parklands with the GRI GIS bedrock geologic data draped over a shaded relief image of the park and surrounding area were created by the GSRI team (Harrington 2026). Posters were not made for the surficial geologic data, but posters of those data are available in the source map publications (Hamilton 2011; Hamilton and Labay 2011). The GRI posters are not a substitute for the GIS data but are supplied as a helpful tool for office and field use and for users without access to ArcGIS. Not all GIS feature classes are included on the posters, and geographic information and selected park features have been added. GIS features classes left off the posters include mine point features, geologic sample localities, glacial features lines, geologic line features, and alteration and metamorphic areas. Digital elevation data and added geographic information are not included in the GRI GIS data but are available online from a variety of sources. The GRI posters are available on the NPS Datastore at: <https://irma.nps.gov/DataStore/Reference/Profile/2318175>.

GSRI Summary

This summary presents information about the Brooks Range national parklands' geologic setting and history, geologic heritage, and geologic resource management. It synthesizes information from the 2007 scoping meeting, 2015 follow-up meeting, park planning documents, and additional geologic research. The GSRI summary is available on the NPS Datastore at:

<https://irma.nps.gov/DataStore/Reference/Profile/2318172>.

Soils

Soil maps provide information on soil types, including a variety of different characteristics and management considerations such as linear extensibility (“shrink-swell”) potential, erosion potential, soil stability, suitability for site development, suitability for recreation development (e.g., trails), and many other topics. Perrone (2023) provided an overview of the use of soil data at the NPS WASO level and lists soil data currently available in the US Department of Agriculture Natural Resources Conservation Service (NRCS) [Web Soil Survey](#) along with NPS-specific uses for the data. The NRCS plans to complete all soil survey areas in the US by 2026 (Thompson et al. 2020).

The SRI completed a soil map for the Arctic Network parks in 2009 (SRI 2009). The SRI map is available on the NPS DataStore at: <https://irma.nps.gov/DataStore/Reference/Profile/2171607>. This map is a static dataset that will not be updated in the future as revisions or new data become available. Additional soils data is available in the ecological land survey and landcover map of the Arctic Network parks (Jorgenson et al. 2009).

The most up-to-date soils data for Brooks Range national parklands is available via [Web Soil Survey](#), which is updated and maintained regularly by the NRCS. Management-focused maps for the parklands or potential project areas can be developed on-demand on the website. The Web Soil Survey homepage gives instructions for how to view and download soil data.

The Web Soil Survey data are broken down into soil survey areas that are each assigned a code and a name. The Web Soil Survey area “Cape Krusenstern National Monument and Bordering Area, Alaska” (area code AK755) covers Cape Krusenstern National Monument (Table 1). The Web Soil Survey area “Brooks Range – Gates of the Arctic National Park and Preserve Area, Alaska” (area code AK752) covers Gates of the Arctic National Park and Preserve (Table 1). The Web Soil Survey area “Brooks Range – Kobuk Valley National Park and Noatak Preserve Area, Alaska” (area code AK753) covers Kobuk Valley National Park (KOVA) and Noatak National Preserve (Table 1). To view the soil data for the parks on Web Soil Survey, use the navigation pane on the left side of the main webpage to select a soil survey area and set it as the “area of interest” using the “AOI” icon along the top of the map. Use the “Soil Map” tab at the top to view the soil map and the “Soil Data Explorer” tab to view additional soil data including linear extensibility and suitability for development. See additional Web Soil Survey [guidance](#) and [FAQs](#) or contact the [NRCS state soil scientist](#) for technical assistance.

Table 1. Web Soil Survey areas for the Brooks Range national parklands.

Web Soil Survey Area Code	Web Soil Survey Area Name	Park(s)	Status
AK755	Cape Krusenstern National Monument and Bordering Area, Alaska	CAKR	Complete
AK752	Brooks Range – Gates of the Arctic National Park and Preserve Area, Alaska	GAAR	Complete
AK753	Brooks Range – Kobuk Valley National Park and Noatak Preserve Area, Alaska	KOVA and NOAT	Complete

Park Establishment and Setting

The Brooks Range national parklands include four NPS units located above the Arctic Circle in northern Alaska: 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 four NPS units are grouped together in this report because their bedrock geology is continuous and they share one GRI bedrock geology map. The Brooks Range national parklands, like most of the NPS units in Alaska, were established by the 1980 Alaska National Interest Lands Conservation Act (ANILCA). This landmark piece of conservation legislation set aside 54 million acres of national parklands in Alaska and laid out the purposes of each new NPS unit (ANILCA 1980). The following are the “purpose statements” for each of the Brooks Range national parklands from their Foundation Statement, which is a document that formally describes a park unit’s mission.

- “The purpose of Cape Krusenstern National Monument is to preserve, study, and interpret a sequential archaeological record of human migration and adaptation, and to protect arctic ecosystems and subsistence resources” (NPS 2010a).
- “The purpose of Gates of the Arctic National Park and Preserve is to preserve the vast, wild, undeveloped character and environmental integrity of Alaska’s central Brooks Range and to provide opportunities for wilderness recreation and traditional subsistence uses” (NPS 2009a).
- “The purpose of Kobuk Valley National Park is to maintain the environmental integrity of boreal forest, montane, and riverine ecosystems. The park protects and interprets diverse resources including arctic sand dunes, archaeological sites, and subsistence resources” (NPS 2010b).
- “The purpose of Noatak National Preserve is to protect an intact 6.7-million-acre, mountain-ringed river basin ecosystem for outstanding scientific research and wilderness opportunities within an arctic-subarctic environment” (NPS 2009b).

The Brooks Range national parklands protect over 17 million acres of land in northern Alaska, stretching almost continuously from the Chukchi Sea in the west to the Dalton Highway in the east. These parklands encompass the western and central portions of the Brooks Range, a vast mountain range that extends across northern Alaska and into Canada’s Yukon Territory. The Brooks Range national parklands are some of the premiere Wilderness park units in the NPS system, collectively containing over 13 million acres of designated wilderness. CAKR is the farthest west of the Brooks Range national parklands and the only unit that is not continuous with the other three (NOAT shares its southern border with KOVA and eastern border with GAAR). CAKR is located along the coast of Kotzebue Sound and the Chukchi Sea. It protects approximately 560,000 acres of diverse Arctic coastal and upland ecosystems, including the Cape Krusenstern beach ridges. NOAT is located just east of CAKR and protects 6.7 million acres of the mountain-ringed Noatak River basin. KOVA is located immediately south of NOAT and contains over 1.75 million acres of land, including the Kobuk River valley and Great Kobuk Sand Dunes. GAAR is to the east of NOAT and encompasses almost 8.5 million acres of rugged peaks and valleys in the central Brooks Range.

The Brooks Range national parklands are very remote and inaccessible by road. Visitors access these park units by aircraft, boat, foot, or, in the wintertime, snowmachine. CAKR, KOVA, and NOAT are managed together as the Western Arctic National Parklands, while GAAR is managed together with Yukon-Charley Rivers National Preserve. The Western Arctic National Parklands headquarters and information center are located in Kotzebue, a city on the Baldwin Peninsula approximately 15 miles south of CAKR and NOAT. Park headquarters for GAAR is located approximately 200 miles southeast of the park, in Alaska's second largest city, Fairbanks. Visitor centers for GAAR include the Alaska Public Lands Information Center in Fairbanks, a ranger station and visitor center situated just outside the park in Bettles, Alaska, the Arctic Interagency Visitor Center just outside the park on the Dalton Highway in Coldfoot, Alaska, and a seasonal ranger station in Anaktuvuk Pass, the only community within the boundaries of GAAR or any of the Brooks Range national parklands. In 2024, the Brooks Range national parklands received an estimated 65,187 recreational visitors (CAKR: 17,736; GAAR: 11,907; KOVA: 17,233; NOAT: 18,311; Ziesler and Horn 2025). Popular visitor activities include hiking, backpacking, rafting, hunting, fishing, and wildlife viewing.

Geologic Setting and History

Tectonic setting

The Earth's crust is broken into tectonic plates that slowly shift position relative to each other over time. Alaska is part of the North American tectonic plate, which encompasses North America, Greenland, northeast Russia, the Bering Sea, and parts of the Atlantic and Arctic oceans. Tectonic plates interact with each other at their edges. These interactions can be convergent (pushing together), divergent (moving apart), or transform (sliding past). The boundary between the North American plate and the adjacent Pacific plate is along the southern margin of Alaska. This boundary is convergent in southwest and southcentral Alaska, and transitions to transform in southeast Alaska. The denser oceanic crust of the Pacific plate is moving northwestward, sliding past and subducting (descending) beneath the less dense continental crust of the North American plate at a rate of 5–8 cm/year (2–3 in/year; Haeussler and Plafker 2003). The collision and subduction of the Pacific plate with southern Alaska is causing significant deformation of the overriding North American plate, creating many of Alaska's modern landscape features such as mountains, basins, and volcanoes.

In contrast to the tectonically active coastline of southern Alaska, northern Alaska is a passive continental margin that transitions from the Alaskan coastal plain to the Canada Basin of the Arctic Ocean without an active tectonic boundary. As a result, northern Alaska lacks the modern earthquake, volcanic, and mountain-building activity seen in southern Alaska. Passive margins typically develop where divergent plate boundaries (e.g., mid-ocean spreading ridge) develop and rift continental crust apart, forming new oceanic crust between the rifted areas. The northern continental margin of Alaska transitions from the continental North Slope coastal plain to the Alaska-Beaufort shelf and then slopes down into the oceanic Canada Basin abyssal plain. The Arctic Ocean is a complex region made up of multiple basins separated by elevated ridges (Petrov et al. 2021). The Canada Basin is one of the largest basins within the Arctic Ocean.

Terranes

Although Alaska is now part of the North American plate, most of the bedrock that makes up Alaska did not form in its current location relative to the ancient geologic core of the North America plate. Just as the Earth's tectonic plates are slowly moving today, they have been shifting relative to each other over the billions of years of Earth's history (see Table 2 for a geologic time scale). Because of this continuous (albeit slow, ~5 to 15 cm/yr) movement, Earth's tectonic plates have been in different configurations at various points in geologic time (e.g., the supercontinent Pangea being one such configuration). In addition to changing location, tectonic plates can also change in size through processes of: (1) plate growth—magma from the mantle can move upward and solidify to create new crust; (2) plate accretion—crust from one plate can be transferred to another through collision; or (3) plate dismantle—crust can be lost when a plate subducts into the mantle.

Table 2. Geologic time scale.

The geologic time scale puts the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. Boundary ages are in millions of years ago (MYA) and follow the International Commission on Stratigraphy (2023). Where no geologic time subdivision exists, “n/a” indicates not applicable.

Eon	Era(s)	Period(s)	Epoch(s)	MYA
Phanerozoic	Cenozoic	Quaternary	Holocene	0.0117–today
Phanerozoic	Cenozoic	Quaternary	Pleistocene	2.6–0.0117
Phanerozoic	Cenozoic	Neogene	Pliocene	5.3–2.6
Phanerozoic	Cenozoic	Neogene	Miocene	23.0–5.3
Phanerozoic	Cenozoic	Paleogene	Oligocene	33.9–23.0
Phanerozoic	Cenozoic	Paleogene	Eocene	56.0–33.9
Phanerozoic	Cenozoic	Paleogene	Paleocene	66.0–56.0
Phanerozoic	Mesozoic	Cretaceous	Upper, Lower	145.0–66.0
Phanerozoic	Mesozoic	Jurassic	Upper, Middle, Lower	201.3–145.0
Phanerozoic	Mesozoic	Triassic	Upper, Middle, Lower	251.9–201.3
Phanerozoic	Paleozoic	Permian	Lopingian, Guadalupian, Cisuralian	298.9–251.9
Phanerozoic	Paleozoic	Pennsylvanian	Upper, Middle, Lower	323.2–298.9
Phanerozoic	Paleozoic	Mississippian	Upper, Middle, Lower	358.9–323.2
Phanerozoic	Paleozoic	Devonian	Upper, Middle, Lower	419.2–358.9
Phanerozoic	Paleozoic	Silurian	Pridoli, Ludlow, Wenlock, Llandovery	443.8–419.2
Phanerozoic	Paleozoic	Ordovician	Upper, Middle, Lower	485.4–443.8
Phanerozoic	Paleozoic	Cambrian	Furongian, Miaolingian, Series 2, Terreneuvian	538.8–485.4
Proterozoic	Neoproterozoic	Ediacaran, Cryogenian, Tonian	n/a	1,000–538.8
Proterozoic	Mesoproterozoic	Stenian, Ectasian, Calymmian	n/a	1,600–1,000
Proterozoic	Paleoproterozoic	Statherian, Orosirian, Rhyacian, Siderian	n/a	2,500–1,600
Archean	Neo-, Meso-, Paleo-, Eo-archean	n/a	n/a	4,000–2,500
Hadean	n/a	n/a	n/a	~4,600–4,000

The western margin of the North American plate has received significant additions of crust since the Mesozoic Era (~145 million years ago) through the process of accretion. This zone of accreted crust encompasses almost all of Alaska. Millions of years ago, subduction of oceanic crust beneath the western edge of the North American plate brought fragments of crust, known as “terrane,” to the edge of North America. As subduction continued, the terranes collided with the North American margin and accreted to the North American plate. The process of terrane accretion added significant amounts of crust to the west side of North America and caused deformation of the North American plate. The most prominent deformational feature is a series of mountain ranges along the western side of North and South America, collectively referred to as the American Cordillera. The North American portion of the Cordillera includes most of the mountains in the western United States and

Canada, including the Sierra Nevada, Rocky Mountains, and Alaska Range. The Brooks Range, in northern Alaska, is the northernmost extension of the North American Cordillera.

The bedrock of Alaska is composed of a variety of crustal fragments called terranes (Coney et al. 1980; Nokleberg et al. 1994; Yukon Geological Survey 2020). A terrane is a fault-bounded fragment of crust that has a different geologic history when compared to adjacent rocks (Jones et al. 1983). Rocks that formed during or after terrane accretion are called overlap assemblages. Overlap assemblages are sedimentary or igneous rocks deposited on or intruded into two or more adjacent terranes (Nokleberg et al. 1994). The bedrock that underlies the Brooks Range national parklands belong to two terranes: the Arctic Alaska terrane and the Angayucham terrane (Yukon Geological Survey 2020; Figure 1). Additionally, the Brooks Range national parklands contain geologic units that are part of the Coville and Koyukuk basins, both of which are overlap assemblages that developed during and after terrane accretion.

The Arctic Alaska terrane is widespread in northern Alaska, encompassing the Brooks Range, North Slope, and Seward Peninsula (Moore and Box 2016). Almost all the bedrock in the Brooks Range national parklands belongs to the Arctic Alaska terrane. The Arctic Alaska terrane is a composite terrane; this means that a portion of the terrane has an early geologic history that differs from other parts of the terrane, but at some time all the rocks came together and evolved as one unit. Rocks of the Arctic Alaska terrane range in age from the Neoproterozoic Era to the Cretaceous Period and can be split into two broad groups: (1) Neoproterozoic and early Paleozoic rocks that display at least two distinct paleogeographic signatures; and (2) mid-Paleozoic to Jurassic rocks that all formed as part of a shared continental margin along the North American plate (see Table 2 for an explanation of the geologic time divisions used throughout this report). The Angayucham terrane is smaller and represents the remains of an ocean that closed during the formation of the Brooks Range.

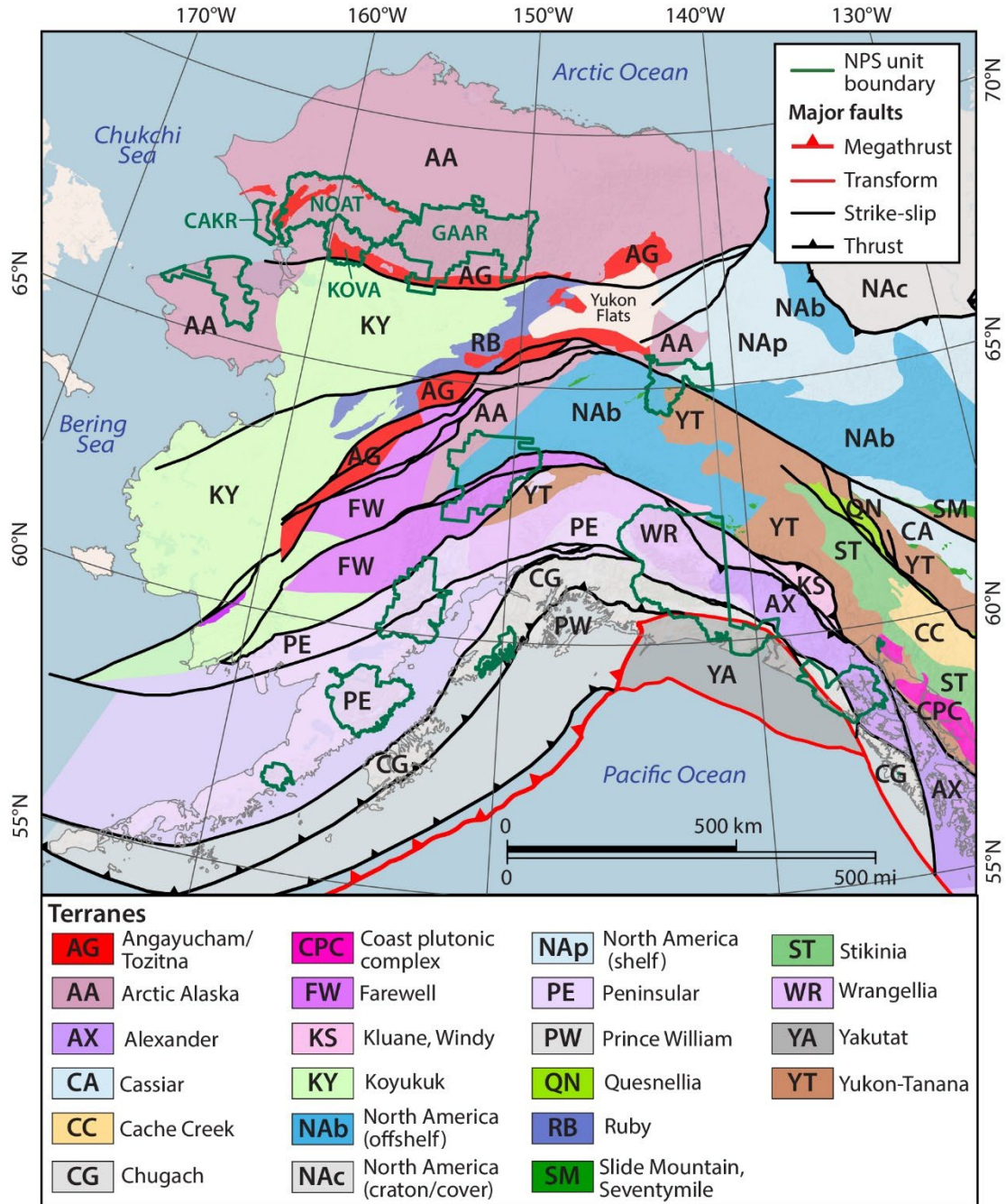


Figure 1. Terrane map of Alaska. Alaska is composed of displaced terranes separated by major fault systems. A terrane is a fault-bounded package of rocks that has a distinct geologic history when compared to adjacent rocks. Alaskan terranes have been transported by plate tectonics (i.e., translated) from where they originally formed and accreted together to the edge of the North American plate. Bedrock of the Brooks Range national parklands belong to the Arctic Alaska and Angayucham terranes. Figure modified from content originally published by Yukon Geological Survey (2020)/Amanda Lanik (University of Alaska Museum of the North).

Geologic History

Proterozoic–mid-Paleozoic

The Arctic Alaska terrane is composed of at least two crustal blocks that evolved independently until the mid-Paleozoic Era. Neoproterozoic- and early Paleozoic-aged rocks are widespread within the Arctic Alaska terrane; they occur at depth beneath the North Slope, in the eastern Brooks Range, on the Seward Peninsula, and within the Brooks Range national parklands along the southern Brooks Range and around Mount Doonerak; see the GRI GIS bedrock data and posters). Many of the Proterozoic and early Paleozoic rocks are metasedimentary (metamorphosed sedimentary) rocks (e.g., marble, quartzite, and schist) that formed in shallow to deep ocean environments. The northeastern extent of these rocks (North Slope and eastern Brooks Range) contain evidence, such as fossils and detrital zircons, that indicate they formed as part of the North American continent (Dutro et al. 1972; Strauss et al. 2013, 2017; Cox et al. 2015; Lane et al. 2016). In contrast, the western portion of the Arctic Alaska terrane (central and western Brooks Range and the Seward Peninsula) contains early Paleozoic rocks that differ from North American rocks in terms of fossil paleogeographic affinity (Blodgett et al. 2002; Dumoulin et al. 2002, 2014) and geochronological signatures (Amato et al. 2009; Miller et al. 2011; Hoiland et al. 2018). These data suggest that the eastern Arctic Alaska terrane evolved as part of, or close to, the North American continent during the early Paleozoic Era, while the western Arctic Alaska terrane has exotic origins with respect to North America. These disparate portions accreted together and were joined to North America by the Devonian Period (Strauss et al. 2013; Hoiland et al. 2018). The accretion event may be recorded by the widespread evidence for pre-Mississippian deformation in eastern Arctic Alaska strata, referred to as the Romanzof and Ellesmerian orogenies (Moore et al. 1994; Lane 2007).

Mid-Paleozoic–Jurassic

Following the amalgamation of the eastern and western portions of Arctic Alaska terrane, the Angayucham ocean opened adjacent to the Arctic Alaska terrane (Moore et al. 1994). The opening of the Angayucham ocean likely began in the Devonian Period, as rifting adjacent to the Arctic Alaska terrane caused new oceanic crust to form. The remains of this oceanic crust are found today as the Angayucham terrane in the southern foothills of the Brooks Range and to the north in thrust sheets in the western and eastern Brooks Range. These rocks include Devonian–Jurassic metamorphosed volcanic rocks such as basalt, as well as mafic and ultramafic intrusive igneous rocks such as gabbro (see the GRI GIS bedrock map).

With the opening of the Angayucham ocean, a south-facing passive margin (present-day orientation) developed across the Arctic Alaska terrane (Moore et al. 1994). Passive margin sedimentation persisted across the Arctic Alaska terrane from the Devonian to the Jurassic Periods; these marine sedimentary rocks are widespread within the Brooks Range national parklands today. Sedimentary rocks that were deposited along the Arctic Alaska passive margin include the late Devonian carbonates of the Baird Group, late Devonian and early Mississippian clastic sedimentary rocks of the Endicott Group, the Late Mississippian and Pennsylvanian carbonates of the Lisburne Group, and the Permian to Triassic sedimentary rocks of the Sadlerochit and Etivluk Groups (see the GRI GIS bedrock data and posters).

Jurassic–Cretaceous

Starting in the Jurassic Period, the boundary between the Arctic Alaska terrane and adjacent Angayucham ocean transitioned from a passive tectonic setting to an active setting with the formation of the Brooks Range mountains. In the late Jurassic, a subduction zone formed within the Angayucham ocean and caused convergence of rocks of the Angayucham terrane with those of the Arctic Alaska terrane (Moore et al. 1994). This tectonic convergence, known as the Brookian orogeny (mountain-building event), continued into the Cretaceous Period and formed the Brooks Range mountains through a complex combination of thrusting, crustal thickening, and uplift. The early stages of the Brookian orogeny involved rocks of the Angayucham terrane thrusting on top of the Arctic Alaska terrane. As the orogeny continued, deformation progressively propagated farther into the Arctic Alaska terrane, with rocks that formed the edge of the Arctic Alaska terrane thrusting on top of more interior rocks of the Arctic Alaska terrane. As a result, the Brooks Range is composed of seven sheets of rock (called allochthons) that were thrust atop each other and bounded by major thrust faults (Moore et al. 1994). The structurally highest allochthons contain oceanic rocks of the Angayucham terrane, while the structurally lower allochthons are composed of rocks of the Arctic Alaska terrane.

Another major tectonic event that happened in northern Alaska during the late Jurassic and early Cretaceous periods was the opening of the Canada Basin (Till 2016). Prior to this rifting event, the Arctic Alaska terrane was situated northeast of where it is today, next to the Canadian Arctic Islands. Multiple models have been put forward to explain the opening of the Canada Basin (see Lawver and Scotese 1990 for a review), but the most widely proposed theory involves counterclockwise rotation of the Arctic Alaska terrane from the Canadian Arctic Islands (e.g., Lawver et al. 2002; Mickey et al. 2002; Gottlieb et al. 2014; Till 2016). According to this model, rifting initiated between the Arctic Alaska terrane and Canadian Arctic Islands in the late Jurassic to early Cretaceous periods. This rifting formed new oceanic crust that underlies the Canada Basin and rotated the Arctic Alaska terrane to its current location in northern Alaska.

Cretaceous-present

The uplifted Brooks Range became a source of sediment for sedimentary basins that developed to the north and south of the mountains (Moore et al. 1994). The Colville Basin located north of the Brooks Range is filled with sedimentary rocks that began forming in the Cretaceous Period and are continuing to form today. Most of the rocks in the Colville Basin are located north of the Brooks Range national parklands, underlying the North Slope coastal plain and Beaufort and Chukchi Seas; however, some of the oldest rocks (e.g. Fortress Mountain and Okpikruak Formations) are found in the northern parts of NOAT and GAAR (see the GRI GIS bedrock data and posters). The Koyukuk Basin is located south of the Brooks Range and the Cretaceous-aged sedimentary rocks of this basin can be found in the southernmost part of KOVA (see the GRI GIS bedrock data and posters).

Geologic processes (e.g., erosion and deposition) that operated millions of years ago to create the bedrock of the Brooks Range national parklands have continued in the more recent times to form unconsolidated or weakly consolidated surficial geologic deposits. Surficial deposits blanket the bedrock in all but the steepest terrain and can range from a thin veneer of sediments only centimeters

(inches) deep to thick deposits many meters (yards) deep. Most of the surficial deposits mapped within the Brooks Range national parklands formed during the Quaternary Period. GRI surficial geologic maps are available for GAAR (Hamilton and Labay 2011) and NOAT (Hamilton 2011). The GRI Brooks Range bedrock geologic map contains generalized surficial units for CAKR and KOVA. However, bedrock geologic maps often omit surficial deposits to show underlying bedrock units, so the surficial geologic information available in the GRI bedrock map is not as detailed or comprehensive as a dedicated surficial map would provide. More detailed surficial mapping may be available for portions of CAKR and KOVA through the U.S. Geological Survey's National Geologic Map Database (https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html).

During the Quaternary Period, earth's climate oscillated between colder glacial periods characterized by large continental ice sheets and warmer interglacial periods. Glacial periods in northern Alaska were cold and dry, resulting in the formation of widespread permafrost (perennially frozen ground), glacier expansion in the Brooks Range, and the development of steppe-tundra, sand dune, and glacial-dammed lakes in lowland areas (Péwé 1975). Sea level was significantly lower during glacial periods, which caused the shelf beneath the Bering and Chukchi seas to be subaerially exposed and connect Alaska and Siberia via the Bering Land Bridge (Hopkins 1967). The Bering Land Bridge formed the center of a larger landmass called "Beringia" that stretched from the Lena River in Russia, across northern Alaska, and to the Mackenzie River in Yukon Territory (Hultén 1937). Although Beringia contained mountain glaciers in higher elevation areas like the Brooks Range, it was not entirely covered by ice sheets like southern Alaska and the rest of Canada. During the last glacial period (approximately 115,000 to 11,700 years ago), Beringia supported a diverse assortment of Pleistocene megafauna, such as mammoths, bison, muskoxen, lions, bears, and humans (Hopkins et al. 1982).

At least five major glacial intervals left behind surficial deposits in the Brooks Range national parklands: (1) the Pliocene- and possibly Miocene-aged Gunsight Mountain glacial interval; (2) the early Pleistocene Anaktukuk River glaciation; (3) the middle Pleistocene Sagavanirktok River glaciation; (4) the late Pleistocene Ikillik glaciation; and (5) neoglacial deposits formed by recent and modern glaciers (Hamilton 2011; Hamilton and Labay 2011). These deposits are primarily glacial drift that includes poorly sorted clay- to boulder-sized sediments left behind when the glaciers retreated. Sometime these sediments are found in landforms such as moraines that mark former glacial extent. More details on the history of these glacial intervals can be found in Hamilton (2011) and Hamilton and Labay (2011).

In addition to glacial deposits, widespread lake and eolian (wind-blown) surficial deposits formed within the Brooks Range national parklands during glacial periods. In NOAT, the expansion of glaciers from the De Long and Baird Mountains periodically dammed the flow of the Noatak River, forming a succession of lakes collectively termed Glacial Lake Noatak (Hamilton and Van Etten 1984; Hamilton 2001). Glacial Lake Noatak developed and drained multiple times throughout the Quaternary Period, with the size of the lake fluctuating but reaching a maximum surface area of at least 4,400 km² (1,700 mi²; Hamilton 2001). Glaciolacustrine (glacial lake) surficial geologic deposits that record this history occur widely within the Noatak River drainage basin and are exposed

in bluffs along the river (Hamilton 2008; Hamilton 2011). Hamilton (2008) provides a guide to the Noatak River-bluff deposits. The cold, dry environment of glacial periods, combined with an ample supply of fine-grained sediments from glacial erosion, led to the development of widespread eolian (wind-blown) deposits (e.g., sand dunes and loess; Hopkins et al. 1982). In the Brooks Range national parklands, eolian deposits that formed during glacial periods are most widespread in the Kobuk River valley. The still-active Great and Little Kobuk Sand Dunes in KOVA are modern remains of dune fields that were much larger during glacial periods.

About 12,000 years ago, the last glacial period ended and the earth shifted into a warmer, interglacial period called the Holocene. Warming led to many landscape-scale changes in northern Alaska that are continuing today. Glaciers in the Brooks Range retreated from their last glacial maximum extent and are continuing to retreat and shrink today (Loso et al. 2014). Sea level rose as a response to global glacier melt, flooding the Bering Land Bridge and establishing Alaska's modern coastline. Sea level stabilized in the Chukchi Sea approximately 5,000 years ago and coastal processes since then have formed the beach ridges at Cape Krusenstern (Mason and Jordan 1993). Active erosional and depositional processes (e.g., landslides, glaciers, rivers, and wind) continue to shape the modern landscape of the Brooks Range national parklands.

Geologic Heritage

Geologic heritage (also called “geoheritage”) evokes the idea that the geology of a place is an integral part of its history and cultural identity. It is the nexus of geology and human experience, encompassing the geologic features, processes, and stories characteristic of our nation, which are preserved for the full range of values that society places on them. In 2015, in cooperation with the American Geosciences Institute, the NPS Geologic Resources Division published *America’s Geologic Heritage: An Invitation to Leadership* (NPS and AGI 2015). The booklet introduced the American experience of geologic heritage and outlined key principles and concepts, including five big ideas:

- America’s geologic landscape is an integral part of its history and cultural identity, and Americans have a proud tradition of exploring and preserving geologic heritage.
- America’s geologic heritage, as shaped by geologic processes over billions of years, is diverse and extensive.
- America’s geologic heritage holds abundant values—aesthetic, artistic, cultural, ecological, economic, educational, recreational, and scientific—for all Americans.
- America’s geologic heritage benefits from established conservation methods developed within the United States and around the world.
- America’s geologic heritage engages many communities, and involvement by individuals will ensure its conservation for future generations.

Geoheritage sites are conserved so that their lessons and beauty will remain as a legacy for future generations. Such areas generally have great potential for scientific studies, use as outdoor classrooms, and enhancing public understanding and enjoyment. Geoheritage sites are fundamental to understanding dynamic Earth systems, the succession and diversity of life, climatic change over time, the evolution of landforms, and the origin of mineral deposits. Currently, the United States does not have a comprehensive national registry of geoheritage sites. Although park units are not specifically established for geoheritage values, any geologic component included in a park unit’s enabling legislation, its planning and management documents, and other conservation programs can be regarded as a part of America’s geoheritage.

The Brooks Range national parklands contain significant geologic features, processes, and landscapes that compose a rich geoheritage that is, in part, the reason these park units were created (ANILCA 1980). The parks’ foundation statements identify the fundamental resources and values that compose the core mission of each park (NPS 2009a; NPS 2009b; NPS 2010a; NPS 2010b). Resources and values identified in these documents with a geologic nexus include coastal processes and beach ridges in CAKR; the central Brooks Range, unique geologic features, and wild rivers in GAAR; arctic sand dunes, the Kobuk River valley, wild rivers, and fossils in KOVA; and the mountain-ringed Noatak River basin NOAT.

The Brooks Range national parklands encompass the western and central portions of the Brooks Range, a vast mountain range that stretches about 950 km (600 mi) across all northern Alaska and into Canada. The Brooks Range was named in 1925 for the U.S. Geological Survey chief Alaskan geologist Alfred Hulse Brooks. The Brooks Range contains many sub-ranges, including (from west to east) the De Long Mountains, the Baird Mountains, the Waring Mountains, the Schwatka Mountains, and the Endicott Mountains. The orientation of passes in the Brooks Range, such as Howard Pass and Anaktuvuk Pass, constrain caribou migration routes and affect where people in the region hunt and live. Peaks within the Brooks Range reach elevations of about 1,200–2,700 m (4,000–9,000 ft) and are significant landmarks within the parklands. The “Gates of the Arctic,” for which GAAR is named, refers to two adjacent peaks (Frigid Crags and Boreal Mountain) that flank the North Fork of the Koyukuk River (Figure 2). The Arrigetch Peaks are a longstanding landmark within GAAR, meaning “fingers of the hand extended,” that are a designated National Natural Landmark (Figure 3). Tectonic events during the Jurassic Period (201.3–145 million years ago) initially formed the Brooks Range, and continued geologic processes such as uplift, lake formation, glacier erosion, and river erosion have shaped these mountains into the rugged peaks and valleys that typify the Brooks Range national parklands today (see the “Geologic History” section of this report for more details).



Figure 2. Photograph of the Gates of the Arctic. The Gates of the Arctic, for which GAAR is named, are a pair of peaks (Frigid Crags and Boreal Mountain) that flank the North Fork of the Koyukuk River. This iconic passage was named by Robert Marshall, a US Forest Service forester who was an early advocate for GAAR. His books “Arctic Village,” published in 1933, and “Alaska Wilderness,” published in 1956, were inspiration for later wilderness enthusiasts who advocated for the preservation of a large section of the central Brooks Range as GAAR. NPS photograph.



Figure 3. Photograph of the Arrigetch Peaks. The Arrigetch Peaks are a significant landmark within GAAR designated as a Natural National Landmark in 1968. The Arrigetch, meaning “fingers of the hand extended,” contains notably steep and jagged peaks that rise 900 to 1,200 m (3,000 to 4,000 ft) above the adjacent valley bottoms. These peaks are composed of resistant granitic rock that was carved by repeated alpine glaciations, producing classic glacial features such as U-shaped valleys and paternoster lakes (seen in the central part of this photograph). NPS Photograph by Ronald Karpilo.

The rivers and lakes within the Brooks Range national parklands are another important aspect of their geoheritage. Both KOVA and NOAT are named for rivers that bisect these parks (the Kobuk River and Noatak River, respectively). Additionally, the Brooks Range national parklands contain seven wild rivers designated under the Wild and Scenic River System: the Noatak River, Salmon River, Kobuk River, Alatna River, John River, Tinyaguk River, and the North Fork of the Koyukuk River (Figure 4). All the designated rivers within the Brooks Range national parklands are “wild,” meaning they are free of impoundments, inaccessible by road, and have essentially primitive watersheds. The goal of the Wild and Scenic River System is to protect and enhance the outstanding values of the rivers and preserve them in their free-flowing condition. Walker Lake within GAAR is a designated National Natural Landmark (Figure 5). Walker Lake is a scenic, moraine-dammed lake that is an example of the geologic and biological relationships of a mountain lake at the northern limit of forest growth.



Figure 4. Photograph of the Noatak River. The Noatak River, for which NOAT is named, is a designated Wild River that flows from its headwaters in GAAR, through NOAT, and empties into Kotzebue Sound between NOAT and CAKR. It is the largest mountain-ringed river basin and longest free-flowing river in the United States. During glacial periods of the Pleistocene Epoch, glaciers in the eastern Brooks Range impounded the Noatak River, producing Glacial Lake Noatak and associated lake deposits that are now exposed along the banks of the river (see the “Geologic Historic” section of this report for more information). NPS photograph by Annie Carlson.



Figure 5. Photograph of Walker Lake. Walker Lake, located on the south slope of the Brooks Range in GAAR, is a designated National Natural Landmark. The lake is nearly 23 kilometers (14 miles) long and averages more than 1.6 kilometers (1 mile) in width. It is a striking example of the many glacial lakes formed by glacial erosion or behind moraine deposits along both flanks of the Brooks Range. A 2018 repeat photography study of Walker Lake provides photographs that highlight changes in the landscape between the early 1900s and 2018 (Karpilo et al. 2018). NPS photograph by Ron Karpilo.

Other geoheritage features identified in Brooks Range national parklands foundation statement reports include beach ridges, sand dunes, and paleontological resources (fossils). Cape Krusenstern (the namesake of CAKR) is a cape composed of over 1,000 beach ridges that built-up over the last 5,000 years (Figure 6). The beach ridges contain archaeological resources that trace human use of the coast as it evolved over this period. KOVA contains the Great Kobuk Sand Dunes and Little Kobuk Sand Dunes, which are eolian (wind-blown) features that are a remnant of much larger dune fields that existed in northern Alaska during the last ice age (Figure 7). Fossils are noted in the KOVA foundation statement as contributing to the understanding of climatic cycles, past environmental conditions, and the spread of life forms within the arctic-interior (NPS 2010b). The Brooks Range national parklands contain a rich paleontological record ranging from marine creatures that were alive millions of years ago, to ice-aged mammals that lived 12 thousand years ago. These geoheritage features are described in more detail in dedicated sections below.



Figure 6. Photograph of the Cape Krusenstern beach ridges. Cape Krusenstern, for which CAKR is named, is composed of over 1,000 beach ridges that were built by continued coastal sedimentation over the last 5,000 years. The coast of CAKR was inhabited by humans during this timeframe, which can be traced by archaeological sites found on various beach ridges. NPS photograph by Shelby Anderson.



Figure 7. Photograph of the Greak Kobuk Sand Dunes. The Greak Kobuk Sand Dunes are the largest active Arctic dune field in the United States and provide habitat for several rare and endemic species. They are a remnant from the ice ages of the Pleistocene Epoch, when cold and dry conditions produced widespread aeolian (wind-blown) deposits across northern Alaska. The Great Kobuk Sand Dunes are identified in KOVA's enabling legislation as one of the core natural resources the park was created to protect and interpret. NPS photograph.

Beach Ridges

CAKR is named after Cape Krusenstern, a cape along the monument's coast that is composed of over 100 beach ridges that formed over the last 5,000 years (NPS 2010a; see Figure 6; Figure 8). Cape Krusenstern makes up the southwest corner of the monument and is situated where the monument's north-south oriented coastline on the Chukchi Sea abruptly transitions to an east-west oriented coastline on Kotzebue Sound. Krusenstern Lagoon sits behind the cape's beach ridge complex and is connected to the sea through the Tukrok River. Archaeological resources have been found in the beach ridges, tracing human use of the coast for almost 5,000 years (Giddings and Anderson 1986; Anderson and Freeburg 2013; Anderson and Freeburg 2014). The beach ridges and archaeological record contained within them are essential park resources that the monument was created to study, interpret, and protect (ANILCA 1980; NPS 2010a). Additionally, CAKR and adjacent lands to the north and west were designated as the Cape Krusenstern Archaeological District National Historic Landmark in 1973.

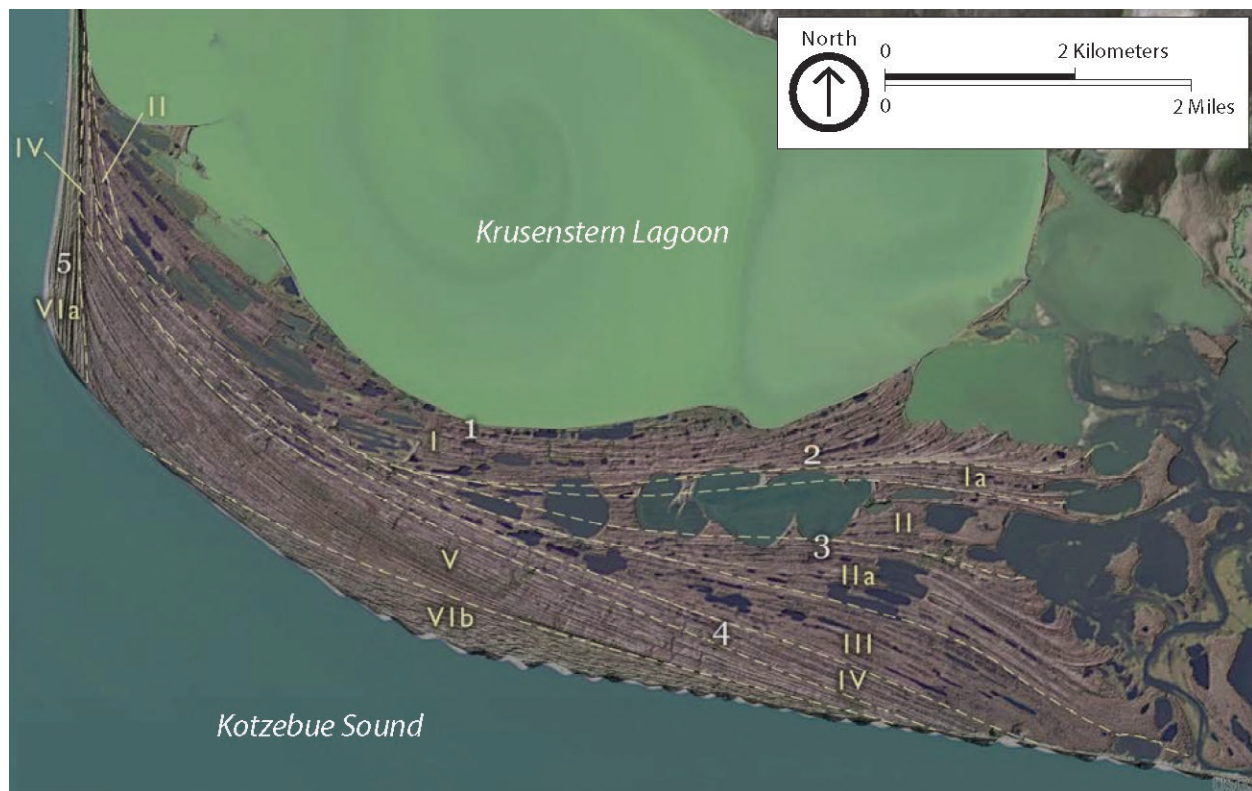


Figure 8. Map of the Cape Krusenstern beach ridge complex. The Cape Krusenstern beach ridges were deposited in the last 5,000 years by sediment transported southward along NOAT's Chukchi Sea coast. Researchers have divided the beach ridges into six distinct sets (roman numeral labels) that are distinguished by erosional truncations, and changes in ridge orientation and elevation (Anderson et al. 2020). Arabic numerals indicate photo locations from Anderson et al. (2020). Figure modified from a map originally made by Adam K. Freeburg and published in Anderson et al. (2020).

The Cape Krusenstern beach ridge complex is a depositional geologic feature that built up after sea level stabilized in the Chukchi Sea approximately 5,000 years ago (Mason and Jordan 1993; Mason and Jordan 2002; Anderson et al. 2020). During the last glacial period of the Pleistocene Epoch, sea level was much lower than today and the shallow continental shelf between Alaska and Siberia was subaerially exposed to form the Bering Land Bridge (Hopkins 1959). At the end of the Pleistocene Epoch, glacial melt caused sea level to rise globally and the Bering Land Bridge to be flooded. Approximately 5,000 years ago, sea level reached modern levels (+/- about 2 m) and depositional features, including the Cape Krusenstern beach ridges, began to form along the coast of northwest Alaska (Mason and Jordan 1993; Mason and Jordan 2002). Beach ridges form in areas where sediment is being deposited. In the case of Cape Krusenstern, sediment is transported southward down the Chukchi Sea coast and deposited in sand and gravel spits where the coast bends sharply east. Over time, continued deposition has built a complex of beach ridges where the oldest ridges are more inland and younger ridges are closer to the ocean (Moore 1960).

Scientists have divided the Cape Krusenstern beach ridges into six distinct sets or units (Anderson et al. 2020, and references therein; Figure 8). The units are distinguished based on differences in overall

ridge orientation, minor differences in ridge elevation, and erosional truncations (Anderson et al. 2020). Unit 1 and 2 are the oldest units; radiometric dating of geologic features indicates they formed between 5,000 and 3,400 cal BP (calibrated years before present) and between 2,800 and 2,400 cal BP, respectively (Anderson et al. 2020). Unit 1 is located farthest from the modern coast, bordering Krusenstern Lagoon, and Unit 2 is located just outboard of Unit 1, primarily on the eastern side of the complex (Anderson et al. 2020). Both units contain slightly lower beach ridges (compared to younger units) that are interspersed with lakes and are truncated by an erosional unconformity that formed prior to the deposition of Unit 3 (Anderson et al. 2020). Dating of geologic features within Unit 3 indicate it formed between 3,000 and 2,100 cal BP, after a period of erosion that reoriented the coastline (Anderson et al. 2020). Dating of Unit 4 indicates it formed between about 2,700 and 2,300 cal BP, after another erosional event and reorientation of the coastline (Anderson et al. 2020). The beach ridges of Unit 4 are somewhat higher, well-drained, and closely spaced compared to those of Units 1, 2, and 3 (Anderson et al. 2020). Unit 5 marks a significant shift in beach ridge morphology due to an increase in sediment supply and deposition rate (Anderson et al. 2020). As a result, the beach ridges of Unit 5 and 6 are higher elevation, more closely spaced, and well drained (Anderson et al. 2020). Dating of Unit 5 indicates it formed between about 2,000 and 1,700 cal BP, while Unit 6 formed over the past 1,300 years. Beach ridges are currently being added to the western side of Unit 6 (Anderson et al. 2020). The main distinction between Unit 5 and 6 is a slight reorientation of the coastline (Anderson et al. 2020).

The physical differences seen in the beach ridge morphology in the different units (e.g, beach ridge height, spacing, and orientation) are the product of past shifts in coastal deposition dynamics. The deposition dynamics of Cape Krusenstern can shift in response to a variety of factors such as changes in sea level, sediment supply, sea ice extent, wind and wave fluctuations, and storm frequency and intensity. Mason and Jordan (1993) suggested that erosional unconformities, such as those seen between Units 3 and 4, are evidence of past periods of increased storm activity in the Chukchi Sea. However, more recent research by Anderson et al. (2020) argued that such changes may instead be the result of more minor, temporally limited events. Anderson et al. (2020) suggested further research at higher temporal and spatial resolution is needed to resolve questions of how regional climate patterns have affected the coastal depositional and erosional processes at Cape Krusenstern.

Coastal change in CAKR is monitored by the NPS Arctic Inventory and Monitoring Network (Manley and Lestak 2012). Monitoring of shoreline change between 2003 and 2014 found that the Cape Krusenstern beach ridge complex is accreting (adding sediment) to the west-facing portion of the complex, as well as in areas along the south-facing shoreline (Swanson 2020). Erosion (loss of sediment) is primarily occurring at the southwest-facing corner of the beach ridge complex, as well as in smaller areas along the south-facing shoreline (Swanson 2020). See Swanson (2020) for maps showing erosion and accretion along the CAKR coastline.

Kobuk Sand Dunes

KOVA contains two large active dune fields, the Great Kobuk Sand Dunes and the Little Kobuk Sand Dunes, as well as the smaller Hunt River Sand Dunes along the Kobuk River (Figure 9). The Great Kobuk Sand Dunes cover an area of approximately 62 km² (24 mi²) between the Kobuk River

and Waring Mountains in the southcentral part of the park, while the Little Kobuk Sand Dunes cover approximately 8 km² (3 mi²) in the southeastern part of the park (Dijkmans and Koster 1990). The Great Kobuk Sand Dunes are the largest active Arctic dune field in North America, and provide habitat for several rare species, some of which are endemic to the dunes (NPS 2017). Protecting and interpreting the Kobuk Sand Dunes was identified in KOVA's enabling legislation as one of the purposes of the park (ANILCA 1980; NPS 2010b).

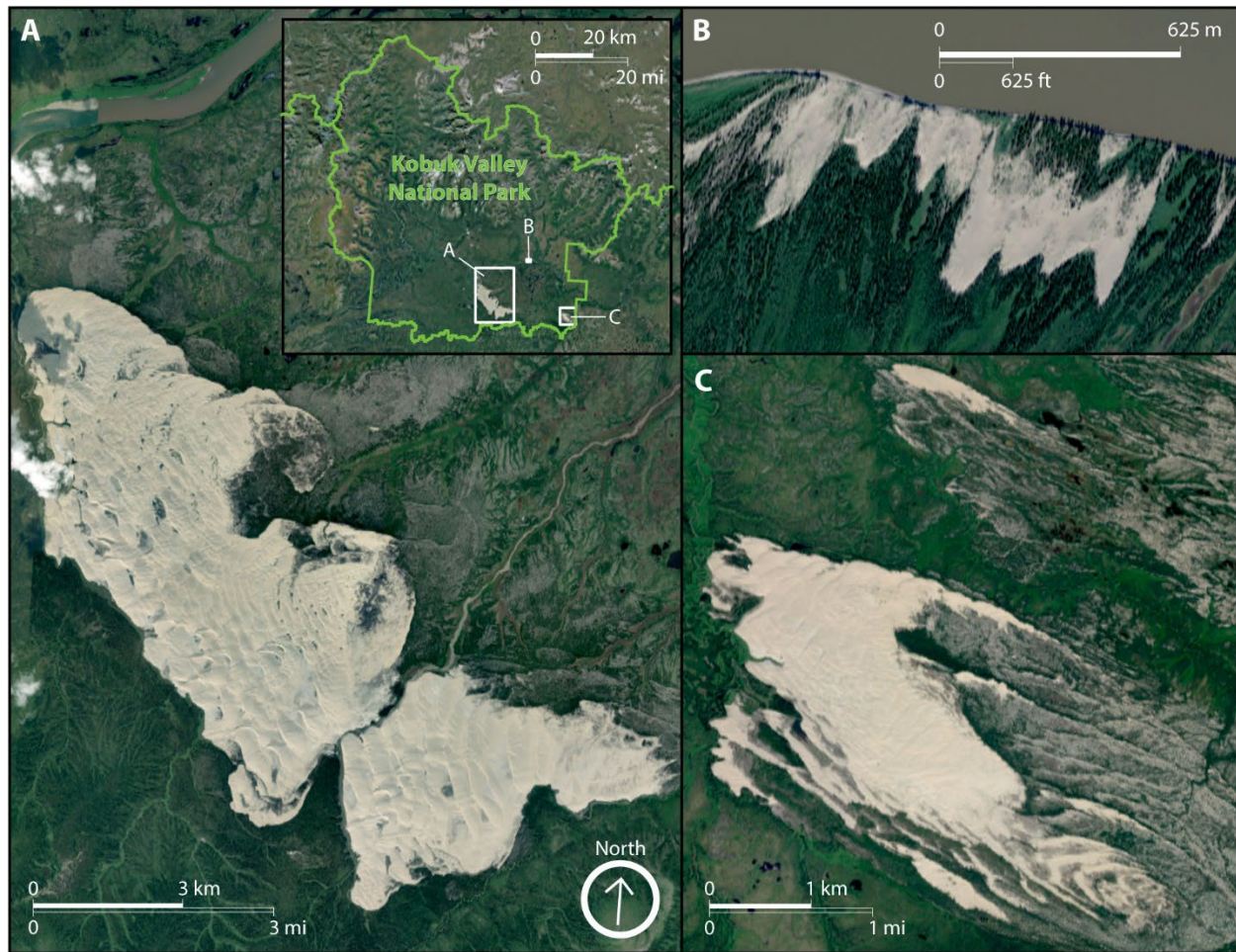


Figure 9. Maps of the three active sand dune fields in KOVA. (A) The Great Kobuk Sand Dunes are the park's largest dune field. (B) The Hunt River Sand Dunes are a small patch of active sand dunes along the Kobuk River, near the mouth of the Hunt River. (C) The Little Kobuk Sand Dunes occur to the east of the Great Kobuk Sand Dunes, near the park's southeast corner. Inset map shows the location of each of the dune fields within the park. Map created by Amanda Lanik using 0.5 m resolution WorldView satellite imagery.

During the height of the last glacial period, eolian (wind-blown) sediments such as sand sheets and dunes were much more widespread in central and northern Alaska than today, covering over 30,000 km² (10,000 mi²; Hopkins et al. 1982). Most of these sand deposits have been stabilized and revegetated since the end of the last glacial period, however, several active dune deposits still exist, including those found in KOVA. The Great Kobuk Sand Dunes in KOVA and the Nogahabara Sand

Dunes in the Koyukuk National Wildlife Refuge are the largest of these still-active dunes. The overall trend of the Great Kobuk Sand Dune since the end of the last glacial period has been fluctuating shrinkage, with periods of increased sand deposition during four intervals (4800–4200, 3300–2600, 1300–700, and 300–100 calendar years ago; Mann et al. 2002). The Great Kobuk Sand Dunes have shrunk over the last 80 to 100 years (Mann et al. 2002). The dune's past fluctuations have been the result of climatic changes, particularly changes in aridity and vegetation, and future fluctuations will also likely be dictated by these factors. The NPS monitors expansion or contraction of the Great Kobuk Sand Dunes periodically using vegetation plots, photographs, and satellite images (NPS 2017).

The Kobuk Sand Dunes contain a variety of dune forms that are the result of strong winds that blow to the west and northwest during the winter (Dijkmans and Koster 1990; Figure 10). The Great Kobuk Sand Dunes consists mainly of N–S to NW–SE oriented transverse dune ridges that are perpendicular to the prevailing wind (Dijkmans and Koster 1990). In some areas the ridges have developed into barchan-like dunes, which are crescent-shaped dunes with tails pointing to the northwest (Dijkmans and Koster 1990). The Little Kobuk Sand Dunes also contains NW–SE transverse dune ridges, and in the southeastern portion the dunes are U-shaped and parabolic, with tails pointing to the southeast (Dijkmans and Koster 1990). In the winter, strong winds blow from the east to the west, and these winds are primarily responsible for sand transport and dune formation (Dijkmans and Koster 1990). The dunes migrate within the dune fields over time, moving in the direction of the prevailing wind. A 2009 study used satellite imagery to determine the rate of dune migration within the Great Kobuk Sand Dunes, finding the dunes migrated about 2 m/yr (6.5 ft/yr) over a five-year period (Necsoiu et al. 2009). This study suggested that improved dune migration rate estimates could be made with a detailed digital elevation model of the sand dunes (Necsoiu et al. 2009), which could be derived using LiDAR (Light Detection and Ranging) or SfM (Structure from Motion) techniques.

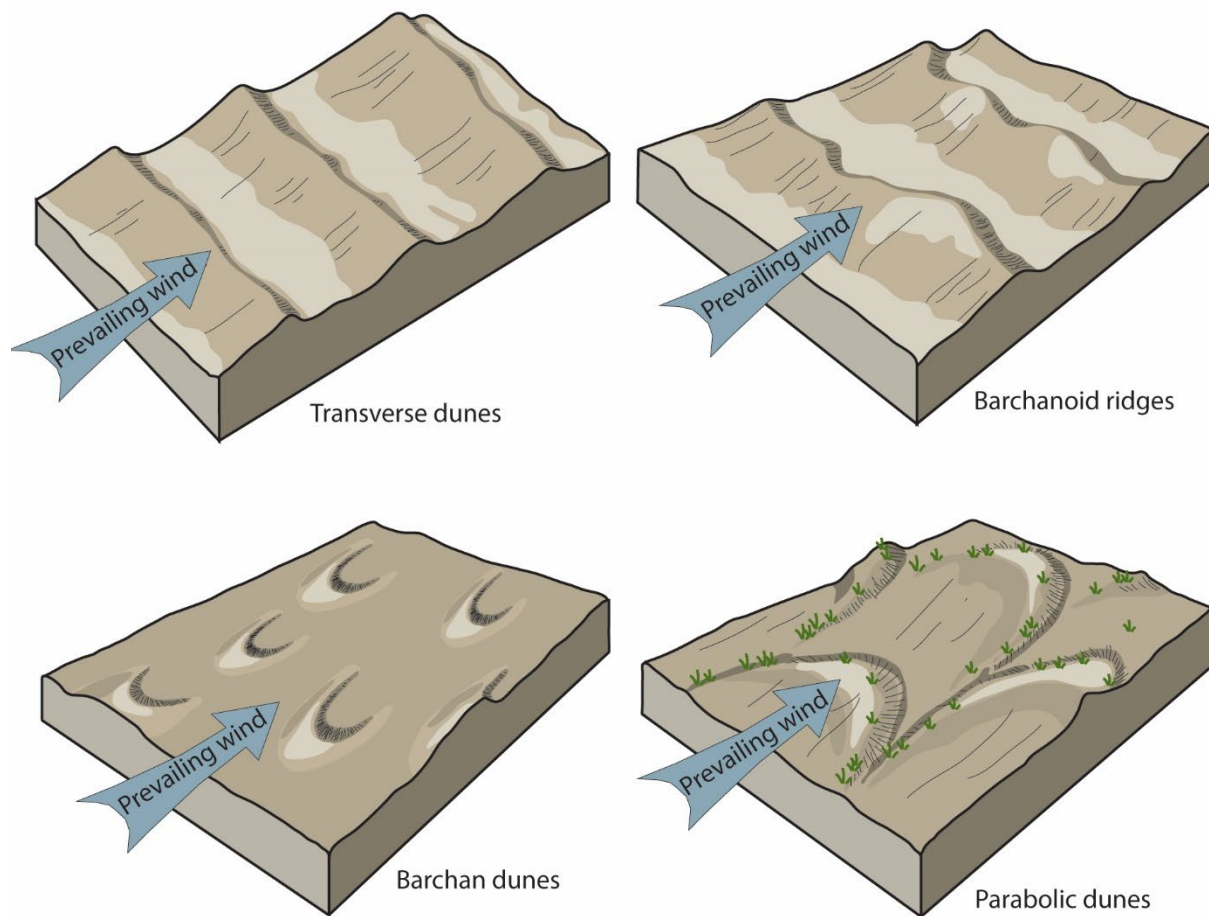


Figure 10. Diagrams of sand dune types found in KOVA. Transverse dunes, which are ridges that form perpendicular to the prevailing wind direction, are widely found in both the Great and Little Kobuk Sand Dunes (see Figure 7 for a photograph of a transverse dune ridge in KOVA). In some parts of the Great Kobuk Sand Dunes, the transverse dunes have taken on a barchanoidal morphology, and in some areas barchan dunes with tails pointing downwind occur as well. Parabolic dunes, with tails pointing into the prevailing wind, occur within the Little Kobuk Sand Dunes. NPS graphic by Trista Thornberry-Ehrlich (Colorado State University).

Paleontological Resources

The paleontological resources, or fossils, in the Brooks Range national parklands record a long history of life that spans over 500 million years. Fossils are any evidence of life that has been preserved in a geologic context. Globally, this encompasses 3.7-billion-year-old microscopic cyanobacteria, 15,000-year-old woolly mammoths, and everything in between. Life has changed many times over the billions of years of Earth’s history, and this evolution is recorded by fossils found in rocks worldwide. The current geologic eon, known as the “Phanerozoic,” is divided into three eras based on the types of organisms that dominated each timeframe (see Table 2 for a geologic time scale). The eras are separated by mass extinction events. The Brooks Range national parklands contain fossils from all three eras, which are the Paleozoic Era (“old life” in Greek; 541–252 million

years ago), Mesozoic Era (“middle life” in Greek; 252–66 million years ago), and Cenozoic Era (“new life” in Greek; 66 million years ago–today).

The following description of paleontological resources is summarized from the Arctic Inventory & Monitoring Network Paleontological Resource Inventory report (Elder et al. 2009) and Paleontological Resource Condition Assessment report (Lanik et al. 2020). More detailed information about fossils in the Brooks Range national parklands can be found in these reports. Additionally, the NPS Alaska Paleontological Resource Database contains fossil information in a format that can be easily sorted and viewed spatially (contact the [Alaska Regional Natural Resources team](#) for access).

The Brooks Range national parklands contain abundant fossils found in sedimentary and metasedimentary rocks that were deposited during the Paleozoic Era (538.8–251.9 million years ago; Figure 11). These include rocks of the pre-Mississippian sequence (Doonerak fenster and Baird Group) and the lower part of the Ellesmerian Sequence (Endicott and Lisburne Groups). The beginning of the Paleozoic Era is marked by the “Cambrian explosion,” which is an evolution event characterized by a sudden abundance of complex life forms (including animal life) that left behind fossils that are very different from older forms of life. Most of the Paleozoic-aged fossils found in the parks are the remains of marine organisms that thrived in Paleozoic seas; however, some plant fossils have been found in rocks of the Endicott Group. The marine fossils include mollusks such as bivalves, cephalopods, and gastropods; shelled animals such as brachiopods and hyoliths; echinoderms such as crinoids (sea-lilies); reef-builders such as corals, sponges, and stromatoporoids; colonial animals such as bryozoans and graptolites; arthropods such as trilobites; and microscopic fossils such as conodonts, foraminifera, ostracods, and radiolarians.



Figure 11. Photograph of fossils found in NOAT. This cobble, found along a creek in NOAT, contains fossil shell impressions including brachiopods, a gastropod, and a crinoid ossicle. These fossils are typical of the types of organisms that lived in Paleozoic seas. Similar fossils can be found in many of the Paleozoic sedimentary rocks in the Brooks Range national parklands. NPS photograph.

Fossils of organisms that lived during the Mesozoic Era (251.9–66.0 million years ago) also occur within the Brooks Range national parklands. Mesozoic-aged fossils have been found within rocks of the upper Ellesmerian Sequence (Shublik Formation and Otuk Formation) and lower Brookian Sequence (Okpikruak Formation and clastic rocks of the Koyukuk Basin). The transition from the Paleozoic Era to Mesozoic Era was marked by the largest mass extinction in Earth’s history, during which many of the organisms that characterized the Paleozoic Era went extinct. The parks’ Mesozoic rocks contain marine fossils, including mollusks such as bivalves and ammonites, and microfossils such as conodonts, foraminifera, and radiolarians. The Mesozoic rocks also contain plant fossils, including palynomorphs (pollen) and macrofossils (leaves and wood). An ichthyosaur skeleton was found in the Otuk Formation just outside the NOAT boundary and the potential exists for similar fossils to exist within the parks.

The Brooks Range national parklands also contain fossils from organisms that lived during the Cenozoic Era (66 million years ago–present). Except for probable Eocene-aged (56–33.9 million

years ago) plants found in GAAR (Hollick 1936), Cenozoic fossils in the Brooks Range national parklands are primarily preserved within surficial deposits. A mass extinction occurred at the end of the Mesozoic Era, which killed off all non-avian dinosaurs, as well as marine creatures such as ichthyosaurs and ammonites. The extinction of these groups left space for mammals to radiate and diversify during the Cenozoic Era. CAKR contains some marine mollusks along the coast, but otherwise the Cenozoic fossils in the parklands are primarily pollen fossils and mammal bones. Pollen has been collected from lake cores across the parklands and reflects changing climatic conditions over time. The mammal fossils are mostly from animals that lived during the Pleistocene Epoch (2.6 million–12,000 years ago) and include now-extinct ice age megafauna such as mammoths and steppe bison.

Hot Springs

Three thermal springs have been documented within GAAR: the Reed River Hot Springs, Alatna River Hot Springs, and Kugrak River Hot Springs (Strecker 2016; Arndt 2024). The Reed River Hot Springs is noted in the Geothermal Steam Act of 1970 (amended in 1988) as a significant geothermal feature within the National Park System. The Geothermal Steam Act of 1970 prohibits geothermal leasing in NPS units and authorizes the Secretary of the Interior to mitigate or not issue geothermal leases that would have a significant adverse impact on notable thermal features within an NPS unit. The act also requires science-informed inventory and monitoring of significant geothermal features within an NPS unit (such as the Reed River Hot Springs).

The Reed River Hot Springs have been described by several older reports (Stoney 1900; Waring 1917; Pessel 1975), with more recent surveys including a one-day reconnaissance by NPS scientists in 1982 (NPS 1982) and a more in-depth vegetation-focused survey by NPS scientists in 2016 (Strecker 2016; Figure 12). The 1982 survey mapped four hot springs clusters at Reed River Hot Springs, however, the 2016 survey was only able to relocate two of the hot spring clusters (Strecker 2016). The 2016 survey of the Reed River Hot Springs identified multiple pools with water temperatures ranging from about 20 to 50 degrees Celsius (70 to 120 degrees Fahrenheit). The 2016 report also described the vegetation around the hot springs, which included unique species that are otherwise not part of the known flora of GAAR (Strecker 2016). Non-native and invasive plants were not found during 2016 survey, and it is essential to minimize potential future anthropogenic disturbance and non-local plant introductions to protect the area's unique vegetation. Strecker (2016) recommended future inventories of animals, microorganisms, non-vascular plants, lichens, and fungi at the Reed River Hots Springs.



Figure 12. Photograph of two hot water outlets in Reed River Hot Springs. Reed River Hot Springs, located in GAAR, is a significant geothermal feature noted in the Geothermal Steam Act of 1970. It is composed of multiple hot spring clusters that, due to the geothermal influence, support a range of azonal and rare plants. NPS photograph by Lisa Strecker from Strecker et al. (2016).

The Alatna River and Kugrak River Hot Springs are not listed in the Geothermal Steam Act of 1970 and little information is currently available for these thermal features. The omission of these springs from the Geothermal Steam Act of 1970 could be due to a lack of information about the springs in the 1980s when the act was amended (Arndt 2024). Approximate coordinates of the Alatna River and Kugrak River Hot Springs are available in a 2016 NPS report (Strecker 2016), but further descriptions of the hot springs' physical characteristics are limited (see Arndt 2024 for a summary). Both Strecker (2016) and Arndt (2024) recommended future studies to better document the Alatna River and Kugrak River Hot Springs.

Stratotypes

GAAR and NOAT contain 28 stratotypes, which are important geologic reference exposures that help identify, define, and correlate geologic units (Henderson et al. 2022). Geologic units, such as those displayed in the GRI GIS data, form the framework through which the geology of an area is studied and understood. When geologists describe a new geologic unit, a stratotype is assigned to exposures containing all (or most) of the unique diagnostic criteria that define that unit. Stratotypes have significant scientific value and are often world-class locations to study outcrops of rock. Typically, formalized geologic units are named after geographic locations that coincide with the original stratotype designation; notable examples from the Brooks Range national parklands include the Noatak Sandstone, named after the Noatak basin in NOAT, and the Fortress Mountain Formation, named after Fortress Mountain in GAAR. Table 3 provides a summary of the stratotypes within the

Brooks Range national parklands and more detailed information (including maps showing stratotype locations) can be found in the Arctic Inventory & Monitoring Network Geologic Type Section Inventory report (Henderson et al. 2022).

Several variations of stratotypes exist, including type sections, type areas, type localities, reference sections, and Global Boundary Stratotype Sections and Points (GSSPs). Of the 28 stratotypes within GAAR and NOAT, eleven are type sections, seven are type localities, two are type areas, and eight are reference sections (Table 3; Henderson et al. 2022). A type section (used for a stratified unit) or type area (used for a non-stratified unit) serves as the standard for recognition and definition of a geologic unit (North American Commission on Stratigraphic Nomenclature 2021). A type locality is the geographic territory encompassing a formally recognized type section or area (North American Commission on Stratigraphic Nomenclature 2021). A reference section is another exposure that supplements the type section in some way. The designation of a reference section may be necessary for well-established geologic units that were never assigned a formal type section; when a type section has been destroyed, covered, or is otherwise inaccessible; or when multiple exposures are needed to illustrate heterogeneity or a key feature not found in the type section (North American Commission on Stratigraphic Nomenclature 2021).

Table 3. Stratotypes in the Brooks Range national parklands.

Maps showing the distribution of these stratotypes can be found in Henderson et al. (2022).

Age	Park(s)	Unit Name (GRI map symbol)	Stratotype Description	Reference(s)
Early Cretaceous (Albian)	GAAR	Fortress Mountain Formation (Kfm)	Type section (composite): partial sections along Kiruktagiak River and on Castle Mountain, Chandler Lake Quadrangle.	Patton 1956
Early Triassic (Olenekian)–Middle Jurassic (Bajocian)	GAAR, NOAT	Otuk Formation, Etivluk Group (JTRcs)	Principal reference section: Monotis Creek, Chandler Lake Quadrangle. Reference section: exposures along a tributary of Kelly River, DeLong Mountains Quadrangle.	Mull et al. 1982
Pennsylvanian–Triassic	GAAR	Imnaitchiak Chert, Etivluk Group (TRPNic)	Reference section: on the south side of a hill along lower Akmalik Creek, Killik River Quadrangle.	Mull et al. 1986
Late Mississippian–Middle Pennsylvanian	GAAR, NOAT	Kuna Formation, Lisburne Group (Mlku)	Principal reference section: upper Otuk Creek, Killik River Quadrangle. Reference sections: (1) tributary of Wrench Creek, DeLong Mountains Quadrangle; (2) Pupik Hills, Howard Pass Quadrangle; and (3) exposures along Ekokpuk Creek, Chandler Lake Quadrangle.	Mull et al. 1982
Middle–Late Mississippian	GAAR	Alapah Limestone, Lisburne Group (PNMI)	Type section (composite): along the ridge top of Sugarloaf Hill, on the west slope of Mount Wachsmuth; and at the west end of North Ridge, Mount Wachsmuth, Chandler Lake Quadrangle. Type locality: on the northern part of Mount Wachsmuth, Shainin Lake area, Chandler Lake Quadrangle.	Bowsher and Dutro 1957

Age	Park(s)	Unit Name (GRI map symbol)	Stratotype Description	Reference(s)
Early–Late Mississippian	GAAR	Wachsmuth Formation, Lisburne Group (Mlw)	Type section (composite): on the south face of Mount Wachsmuth; along the west slope of Mount Wachsmuth; and up the south face of Sugarloaf Hill, Chandler Lake Quadrangle Type locality: Mount Wachsmuth, Chandler Lake Quadrangle.	Bowsher and Dutro 1957
Early–Late Mississippian (middle Osagean–probably late Meramecian)	GAAR	Akmalik Chert, Lisburne Group (PMlc)	Type locality: canyon of Akmalik Creek about 3 km (2 mi) southwest of Kikiktat Mountain, Killik River Quadrangle.	Mull et al. 1986
Early Mississippian (Visean)	GAAR	Kayak Shale, Endicott Group (Mk)	Type section: in the saddle on the south side of Mount Wachsmuth, about 2.9 km (1.8 mi) east of Shainin Lake camp, Chandler Lake Quadrangle. Type locality: near the foot of the south slope of Mount Wachsmuth, Chandler Lake Quadrangle.	Bowsher and Dutro 1957
Early Mississippian	GAAR	Kurupa Sandstone, Endicott Group (Mks)	Reference section: exposures in a canyon of Akmalik Creek, 3 km (2 mi) southwest of Kikiktat Mountain, Killik River Quadrangle.	Mull et al. 1986
Late Devonian (Frasnian)–Early Mississippian (Tournaisian)	GAAR	Kanayut Conglomerate, Endicott Group (MDky)	Type section (composite): section along the east side of Alapah Creek about 11.4 km (7.1 mi) southeast of the camp on Shainin Lake; section on the south side of Block Mountain about 244 m (800 ft) above the valley floor of Alapah Creek, 10.6 km (6.6 mi) south-southeast of the camp on Shainin Lake; and ridge section about 2.9 km (1.8 mi) miles east of the camp on Shainin Lake, Chandler Lake Quadrangle. Type locality: exposures on the ridge east of Alapah Creek, south of Mount Wachsmuth, Shainin Lake area, Chandler Lake Quadrangle.	Bowsher and Dutro 1957
Late Devonian–Early(?) Mississippian	GAAR	Stuver Member, Kanayut Conglomerate, Endicott Group (MDkys)	Type section: located about 1 km (0.6 mi) south-southeast of Mount Wachsmuth, on a ridge about 2.9 km (1.8 mi) east of the camp on Shainin Lake, Chandler Lake Quadrangle. Type locality: on the ridge 1.1 km (0.7 mi) south of Mount Wachsmuth, Chandler Lake Quadrangle.	Bowsher and Dutro 1957; Nilsen and Moore 1984
Late Devonian–Early Mississippian	NOAT	Noatak Sandstone, Endicott Group (Dnu)	Type section: exposures on the mountain side 7.2 km (4.5 mi) northwest of the junction of the Nimiuktuk and Noatak rivers, Misheguk Mountain Quadrangle. Type area: mountains immediately west of Nimiuktuk River (Kingasivik Mountains) and south of DeLong Mountains, Misheguk Mountain Quadrangle.	Smith and Mertie 1930; Dutro 1952

Age	Park(s)	Unit Name (GRI map symbol)	Stratotype Description	Reference(s)
Late Devonian	GAAR	Shainin Lake Member, Kanayut Conglomerate, Endicott Group (Dkym)	Type section: prominent cliff directly south of the confluence of Kayak and Alapah Creeks, about 8 km (5 mi) south-southeast of Shainin Lake, Chandler Lake Quadrangle.	Nilsen and Moore 1984
Late Devonian	GAAR	Ear Peak Member, Kanayut Conglomerate, Endicott Group (Dkyl)	Type section: along the ridge 1.8 km (1.1 mi) southeast of Ear Peak, Chandler Lake Quadrangle.	Nilsen and Moore 1984
Late Devonian (Frasnian–Famennian)	GAAR	Hunt Fork Shale, Endicott Group (Dhf)	Type locality: exposures 40 km (25 mi) east of Killik River, along Fire Creek, an east-flowing tributary of Okokmilaga River, Killik River Quadrangle	Chapman et al. 1964
Middle (Givetian)–Late Devonian	NOAT	Kugururok Formation, Baird Group (Dbk)	Type section: on the north side of Mont Bastille, central DeLong Mountains, Misheguk Mountains Quadrangle.	Sable and Dutro 1961
Middle–Late Devonian	NOAT	Eli Limestone, Baird Group (Dbe)	Type section: east of the north branch of Eli River, Baird Mountains Quadrangle.	Tailleux et al. 1967
Late Devonian–early Permian	GAAR	Endicott Group (MDe)	Type area: exposures in Endicott Mountains, Survey Pass Quadrangle.	Tailleux et al. 1967

Geologic Resource Management

This section briefly summarizes geologic hazards, geologic resource protection, and potential geologic resources inventory and assessment needs for the Brooks Range national parklands. Geologic hazards refer to notable hazards stemming from geologic features or processes that may require active management. Geologic resource protection provides resources to aid in management of geologic resources or processes. Geologic inventory and assessment needs include project ideas that were identified by discussions with NPS staff, in NPS planning documents, or through literature review. Refer to the [Guidance for Resource Management SharePoint](#) for more information regarding geologic resource management.

Geologic Hazards

The dynamic landscapes of the Brooks Range national parklands present a variety of natural hazards that may threaten NPS facilities, staff, visitors, or resources. Many of these natural hazards are geologic hazards (e.g., volcanoes, earthquakes, and landslides), or “geohazards”. Geohazards are active geologic processes that have the potential to cause damage to NPS resources, structures, facilities, or loss of life. Geohazards with the potential to impact all or some of the Brooks Range national parklands include coastal change, earthquakes, ice jams, landslides, permafrost thaw, river erosion, rusting rivers, and tsunamis. See Table 4 for a summary of these geohazards and references for further information.

Preserving naturally occurring geologic processes, including geohazards, is part of the mission of the NPS; however, the NPS also has a responsibility to minimize geohazard risk within park units. The NPS policy states that the NPS will “devise effective geologic hazard identification and management strategies;” “strive to understand future hazards;” and “minimize their potential impact on visitors, staff, and developed areas” (NPS 2006). Some geohazards, such as volcanic eruptions, earthquakes, and tsunamis, are natural processes that are impossible to stop. In these cases, management objectives should be to understand the risk presented by the geohazard and take action to minimize exposure of people and resources to that risk. Other geohazards, such as river erosion or rockfall, are natural processes that may be able to be slowed or halted by management action. However, such actions interfere with the mission of maintaining natural processes in an unimpaired state and can often have cascading and perhaps unintended consequences for a park unit’s natural systems. The NPS management policy states “before interfering with natural processes that are potentially hazardous, superintendents will consider other alternatives” (NPS 2006). See Hults et al. (2019) for further information about managing geohazards in Alaska’s National Parks.

Resources are available to aid NPS staff with managing geohazards in park units. The 2018 volume of “Alaska Park Science” focuses on geohazards in Alaska national parks and includes articles about a variety of geohazards, including landslides, ice jams, coastal erosion, and earthquakes (Hults and Chambers 2019). The “Addressing Climate Change and Natural Hazards Handbook” (NPS 2025a), grounded in NPS Policy Memorandum 15-01 (Jarvis 2015), provides information to help identify, avoid, and mitigate risks associated with changing environmental conditions, natural hazards, and effects on proposed and planned facility investments. Park managers can get assistance with

geohazards issues by submitting a technical assistance request (TAR) to the Alaska Regional Natural Resources Team or Geologic Resources Division (<https://irma.nps.gov/STAR/>; NPS access only). Geohazard-focused projects can be submitted for funding through the service-wide comprehensive call (SCC). For example, an inventory of landslide and tsunami hazard along the coasts of Kenai Fjords National Park and Wrangell-St. Elias National Park and Preserve has been funded through the Inventory and Assessment Program for fiscal year 2026. Finally, a variety of other federal and state agencies provide geohazards information and support in Alaska, including the U.S. Geological Survey, the Alaska Earthquake Center, and Alaska Volcano Observatory.

Table 4. Potential geohazards in the Brooks Range national parklands, including brief descriptions of each hazard and pertinent references.

Geohazard	Park(s)	Description	Reference(s)
Coastal Change	CAKR	Coastal change, including erosion (sediment loss) and accretion (sediment gain), is monitored in CAKR by the NPS Arctic Inventory & Monitoring Network. Maps showing coastal change in CAKR between 1980, 2003, and 2013/2014 are available in Swanson (2020). Over this timeframe, parts of the CAKR coast eroded and other parts accreted; the detailed maps can be used to assess change in any specific area of interest. Reductions in sea ice extent and permafrost will likely impact future coastal dynamics in CAKR and could increase coastal erosion (Farquharson et al. 2019).	Farquharson et al. (2019); Swanson (2020)
Earthquakes	CAKR GAAR KOVA NOAT	Most of GAAR has a low (5–25%) chance of experiencing a damaging earthquake within 100 years, and most of CAKR, KOVA, and NOAT has a moderate (25–75%) chance of experiencing a damaging earthquake within 100 years. Some areas in eastern NOAT have a high (75–95%) chance of a damaging earthquake within 100 years (Petersen et al. 2024). See Petersen et al. (2024) for seismic hazard maps of the United States and West et al. (2019) for information about addressing earthquake hazards in Alaska’s national parks.	Petersen et al. (2024); West et al. (2019)
Ice Jams	CAKR GAAR KOVA NOAT	Many of the rivers in the Brooks Range national parklands freeze each winter and the breakup of river ice in the spring can be accompanied by hazards such as flooding and ice scouring along the riverbanks. The River Watch program, a collaboration between the State of Alaska and the National Weather Service, monitors river ice breakup and assists communities in the event of breakup related flooding. General information about ice jam flooding and the River Watch program can be found in Lindsey (2019). The Cold Regions Research and Engineering Laboratory (CRREL) maintains a database of ice jam flood events in the United States that can be searched by river and water year.	Lindsey 2019; CRREL Ice Jam Database: Home ; River Watch Program website: River Watch Program
Landslides	CAKR GAAR KOVA NOAT	Most of GAAR and areas of KOVA, and NOAT have steep slopes that are susceptible to landslides, while CAKR has more gentle topography and fewer steep landslide-prone slopes. See the US Geological Survey Landslide Inventory and Susceptibility map for details. Here, the term “landslide” is used as an all-inclusive term that includes various types of slope movement (e.g., rockfalls, debris flows, ridge spreading, etc.). While many areas within the Brooks Range national parklands have landslide hazards, the lack of infrastructure and low visitation rates limit landslide risk in the parks.	US Geological Survey Landslide Inventory and Susceptibility map: U.S. Landslide Inventory and Susceptibility

Geohazard	Park(s)	Description	Reference(s)
Permafrost Thaw	CAKR GAAR KOVA NOAT	The Brooks Range national parklands are within the continuous permafrost zone, meaning that permafrost (perennially frozen ground) underlies over 90% of the parks. Warming due to climate change is projected to thaw the permafrost underlying much of the southern half of the Brooks Range national parklands by the 2090s; see Panda et al. (2016) for details. Thawing permafrost can result in landscape changes, such as changes to hydrology, slumping, and release of greenhouse gasses. Permafrost is monitored by the NPS Arctic Inventory & Monitoring Network (Swanson 2017).	Panda et al. (2016); Swanson (2017); Swanson (2021)
River Erosion	CAKR GAAR KOVA NOAT	Riverbank erosion is a natural process that is essential for maintaining geomorphic stability and sustaining riverine ecosystems. In some cases, bank erosion may threaten park facilities, infrastructure, or resources. Bank erosion may be accelerated by events or factors such as flooding, ice jams, thawing permafrost, or forest fires; additionally, human activities such as placer mining can impair natural river function. Mitigation measures to address erosion issues should be assessed on a case-by-case basis. See Field et al. (2025) for information regarding best practices for managing bank erosion within NPS units.	Field et al. (2025)
Rusting Rivers	GAAR KOVA NOAT	Over the last 10 years, at least 75 streams in the Brooks Range (including in GAAR, KOVA, and NOAT) have turned orange because of hydrological and geochemical changes that are likely related to permafrost thaw. Discolored streams in KOVA and NOAT have lower pH, higher turbidity, decreased biodiversity, and elevated sulfate, iron, and trace metal concentrations compared to clear streams. Rusting rivers have the potential to negatively impact drinking water supplies, aquatic food webs, subsistence fishing, and visitor experience in parks. Stream communities and ecosystems are monitored by the NPS Arctic Inventory & Monitoring Network (O'Donnell and Miller 2018).	O'Donnell and Miller (2018), O'Donnell et al. (2024)
Tsunamis	CAKR	Tsunami hazard along the coast of northwest Alaska is much lower compared to southern Alaska because northern Alaska has fewer tsunami-triggering events, such as large earthquakes or landslides that enter the ocean. Additionally, tsunamis generated farther afield in the Pacific Ocean are typically attenuated before reaching the Chukchi Sea by the Aleutian Islands and Bering Strait. Modeling of tsunamis triggered by large earthquakes in the North Pacific Ocean found that even powerful events such as the 1960 magnitude 9.5 Chilean earthquake would produce a tsunami wave of only a few centimeters in the Chukchi Sea (Medvedeva et al. 2023).	Medvedeva et al. (2023)

Geologic Resource Protection

The mission of the NPS is to preserve natural and cultural resources for present and future generations, including geologic resources. To accomplish this mission, various laws, regulations, and policies have been enacted that specifically apply to geologic and soil resources or processes. The NPS GRD developed an article series, “[Geology & Minerals—Resource Laws, Regulations, and Policies](#)” to summarize these protection measures. The “Geologic Resource Management” section of the NPS Management Policies (NPS 2006, section 4.8) contains guidance regarding the protection of geologic processes (4.8.1) and the management of geologic features (4.8.2). The Brooks Range national parklands contain geologic features and processes that are addressed in each of the subsections, including shorelines, caves and karst, geologic hazards, paleontological resources, geothermal resources, and soil resources.

Geologic Inventory and Assessment Needs

Moving forward, the GSRI program will fund inventory and assessment projects that collect new data, or derive new information from existing data, regarding the presence, absence, abundance, distribution, and significance of geologic or soil features or processes to inform park management decisions and planning. The following table (Table 5) presents geologic resource inventory and assessment project ideas that were identified during discussion with park staff, in NPS planning documents, or through literature review. Some geologic resource inventories are not eligible for GSRI funding because they are covered by other fund sources; these include abandoned mineral lands, orphaned oil and gas wells, coastal processes, coastal storm response, sea-level change projections or mitigation, coastal engineering structures, or shoreline sediment movement. For more information about the GSRI and guidance for submitting a project proposal, refer to the [GSRI SharePoint](#) (NPS access only).

Table 5. Geologic and soil inventory and assessment needs for the Brooks Range national parklands.

Subject	Park(s)	Inventory and Assessment Need(s)	Reference(s)
Abandoned mineral lands	CAKR GAAR KOVA NOAT	Abandoned mineral lands (AML) sites in the Brooks Range national parklands are inventoried in the NPS AML database. Most of the sites are gold placer mines that need to be revisited to assess their current state. A project is currently in development to re-inventory AML sites in KOVA. More information about AML sites is available in the AML database: https://irma.nps.gov/AML/ (NPS access only).	Sarah Venator, NPS Alaska Region AML Coordinator, written communication, 3 February 2026
Caves and Karst	CAKR GAAR KOVA NOAT	The Brooks Range national parklands do not have any currently documented cave or karst resources, but limestone bedrock that could host undiscovered karst features is widespread across the parklands (particularly in GAAR) and caves are rumored to exist. The Federal Cave Resources Protection Act of 1988 requires the NPS to identify “significant caves” in NPS areas. An inventory of karst potential across the parklands and focused field surveys would help address the current lack of information regarding caves and karst.	Paul Burger, NPS Alaska Region Hydrologist, written communication, 28 January 2026; Federal Cave Resources Protection Act 1988
Erosion and Flooding	CAKR KOVA NOAT	Recent and unusual flooding events have occurred on the Noatak River and in other areas within the parklands. An inventory of flood events on these rivers would aid in understanding and measuring current erosional and flooding changes park staff are seeing. Additionally, WEAR staff have expressed interest in more data regarding erosion and flooding along the parks’ coast and rivers.	Annie Carlson, WEAR Integrated Resources Program Manager, written communication 3 April 2026
Geologic Resources Inventory Reports	CAKR GAAR KOVA NOAT	Baseline inventory of geologic resources is identified in the resource stewardship strategy summaries for all the Brooks Range national parklands (NPS 2020; NPS 2025b; NPS 2025c; NPS 2025d). This GSRI summary provides baseline information about the parklands geologic setting and history, geoheritage features, and management and inventory needs; however, if more detailed information is desired, park staff could request full GRI reports that would provide more comprehensive information about the geologic resources within the parklands.	NPS 2020; NPS 2025b; NPS 2025c; NPS 2025d

Subject	Park(s)	Inventory and Assessment Need(s)	Reference(s)
Hot Springs	GAAR	GAAR contains three thermal springs, one of which (Reed River Hot Springs) is noted as a significant feature in the Geothermal Steam Act of 1970. The Geothermal Steam Act of 1970 requires science-informed inventory and monitoring of significant geothermal features within an NPS unit. A recent survey of the Reed River Hot Springs recommended future species inventories (Strecker 2016). Additionally, Strecker (2016) and a summary of geothermal features across the NPS (Arndt 2024) recommended better characterization of the two other hot springs within GAAR, the Alatna River and Kugruk River Hot Springs.	Strecker 2016; Arndt 2024; Geothermal Steam Act 1970
Kobuk Sand Dunes	KOVA	Necsoiu et al. (2009) noted that the migration rates of the Kobuk Sand Dunes could be more accurately calculated if higher resolution digital elevation models (DEMs) were available for the dune fields. High resolution DEMs could be created using lidar or structure from motion techniques.	Necsoiu et al. 2009
Paleontological Resources	CAKR GAAR KOVA NOAT	Several sources provide literature-based information about the paleontological resources in the Brooks Range national parklands: (1) the Arctic Network paleontological resource inventory report (Elder et al. 2009); (2) the Arctic Network natural resource condition assessment (Lanik et al. 2020; and (3) the Alaska Region Paleontological Resource database. The Paleontological Resources Preservation Act of 2009 requires science-informed inventory, monitoring, protection, and interpretation of fossils on NPS lands. The resource stewardship strategy summaries for all the Brooks Range national parklands identify documentation of paleontological resources as a need. Additionally, Elder et al (2009) provided a variety of management recommendations, including field inventories to document in situ fossil occurrences. Field inventories could focus on known significant fossil localities or potential new finds. For example, an ichthyosaur skeleton with preserved gut contents was discovered in the Otuk Formation just outside NOAT, and there is the potential for NOAT or GAAR to contain similar fossils that have not yet been discovered.	Elder et al. 2009; Lanik et al. 2020; NPS 2020; NPS 2025b; NPS 2025c; NPS 2025d; Paleontological Resources Preservation Act 2009
Rusting Rivers	GAAR KOVA NOAT	An inventory of the spatial extent and strata depth of sulfide deposits and sulfide-bearing geologic units in the Brooks Range national parklands would help understand rusting rivers and predict where they may develop in the future. More detailed mapping of ice-rich permafrost would also be useful to address the rusting rivers issue.	Jon O'Donnell, NPS Arctic Network Aquatic Ecologist, written communication, 19 February 2026
Permafrost Thaw Features	CAKR KOVA NOAT	Permafrost thaw features such as thaw slumps are developing within the parklands, which can affect nearby hydrologic regimes and fish habitat. An inventory of thaw slumps would help managers identify areas that may be adversely impacted by the development of permafrost thaw features. For example, a recent study was conducted in the Selawik National Wildlife Refuge to assess the effects that permafrost thaw slump on the Selawik River had on the river's fish populations (Hander et al. 2026).	Hander et al. 2026; Annie Carlson, WEAR Integrated Resources Program Manager, written communication 3 April 2026

Subject	Park(s)	Inventory and Assessment Need(s)	Reference(s)
Surficial Geologic Mapping	CAKR KOVA	Park-wide surficial geologic maps are available for GAAR and NOAT through the GRI program, however, these products are not currently available for CAKR and KOVA. Surficial geologic maps may be available for portions of CAKR and KOVA through the U.S. Geological Survey's National Geologic Map Database (https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html), but these maps may not be recent or cover needed areas. Park-wide mapping of the surficial geology of CAKR and KOVA would address this information gap.	n/a
Stratotypes	GAAR NOAT	The Arctic Network type section inventory provided a variety of management recommendations for type sections in the Brooks Range national parklands (see Henderson et al. 2022 for the full list). Recommendations that align with the GSRI fund source include a field inventory of type sections to obtain good photographs and representative geologic samples.	Henderson et al. 2022

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