National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

National Park Service Geologic Type Section Inventory

Arctic Inventory & Monitoring Network

Natural Resource Report NPS/ARCN/NRR—2022/2832

ON THE COVER

Freestanding spires of jointed granite called “tors” composed of the Late Cretaceous Oonatut Granite Complex in the type locality surrounding Serpentine Hot Springs in Bering Land Bridge National Preserve. NPS photo.

National Park Service Geologic Type Section Inventory

Arctic Inventory & Monitoring Network

Natural Resource Report NPS/ARCN/NRR—2022/2832

Tim C. Henderson[1], Vincent L. Santucci[1], Tim Connors[2], and Justin S. Tweet[3]

[1]National Park Service
Geologic Resources Division
1849 "C" Street, NW
Washington, D.C. 20240

[2]National Park Service
Geologic Resources Division
Post Office Box 25287
Denver, Colorado 80225

[3]National Park Service
9149 79th Street S.
Cottage Grove, Minnesota 55016

May 2022

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

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

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible and technically accurate.

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

This report is available in digital format from the Arctic Inventory and Monitoring Network and Natural Resource Publications Management websites. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Henderson, T. C., V. L. Santucci, T. Connors, and J. S. Tweet. 2022. National Park Service geologic type section inventory: Arctic Inventory & Monitoring Network. Natural Resource Report NPS/ARCN/NRR—2022/2832. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/nrr-2293381.

NPS 953/180400, May 2022

Contents

Contents (continued)

Contents (continued)

Page

Figures

Figures (continued)

Figures (continued)

Tables

Photographs

Executive Summary

A fundamental responsibility of the National Park Service (NPS) is to ensure that park resources are preserved, protected, and managed in consideration of the resources themselves and for the benefit and enjoyment by the public. Through the inventory, monitoring, and study of park resources, we gain a greater understanding of the scope, significance, distribution, and management issues associated with these resources and their use. This baseline of natural resource information is available to inform park managers, scientists, stakeholders, and the public about the conditions of these resources and the factors or activities which may threaten or influence their stability and preservation.

There are several different categories of geologic or stratigraphic units (supergroup, group, formation, member, bed) that form a hierarchical system of classification. The mapping of stratigraphic units involves the evaluation of lithologies (rock types), bedding properties, thickness, geographic distribution, and other factors. Mappable geologic units may be described and named through a rigorously defined process that is standardized and codified by the professional geologic community (North American Commission on Stratigraphic Nomenclature 2021). In most instances when a new geologic unit such as a formation is described and named in the scientific literature, a specific and well-exposed section or exposure area of the unit is designated as the stratotype (see "Definitions" below). The type section is an important reference exposure for a named geologic unit that presents a relatively complete and representative example for this unit. Geologic stratotypes are important both historically and scientifically, and should be available for other researchers to evaluate in the future.

The inventory of all geologic stratotypes throughout the 423 units of the NPS is an important effort in documenting these locations in order that NPS staff recognize and protect these areas for future studies. The focus adopted for completing the baseline inventories throughout the NPS is centered on the 32 inventory and monitoring networks (I&M) established during the late 1990s. The I&M networks are clusters of parks within a defined geographic area based on the ecoregions of North America (Fenneman 1946; Bailey 1976; Omernik 1987). These networks share similar physical resources (geology, hydrology, climate), biological resources (flora, fauna), and ecological characteristics. Specialists familiar with the resources and ecological parameters of the network, and associated parks, work with park staff to support network level activities (inventory, monitoring, research, data management).

Adopting a network-based approach to inventories worked well when the NPS undertook paleontological resource inventories for the 32 I&M networks. The planning team from the NPS Geologic Resources Division who proposed and designed this inventory selected the Greater Yellowstone Inventory and Monitoring Network (GRYN) as the pilot network for initiating this project (Henderson et al. 2020). Through the research undertaken to identify the geologic stratotypes within the parks of the GRYN methodologies for data mining and reporting on these resources were established. Methodologies and reporting adopted for the GRYN have been used in the development of this report for the Arctic Inventory & Monitoring Network (ARCN).

The goal of this project is to consolidate information pertaining to geologic type sections that occur within NPS-administered areas, in order that this information is available throughout the NPS to inform park managers and to promote the preservation and protection of these important geologic landmarks and geologic heritage resources. The review of stratotype occurrences for the ARCN shows there are currently no designated stratotypes for Cape Krusenstern National Monument (CAKR) and Kobuk Valley National Park (KOVA). Bering Land Bridge National Preserve (BELA) contains four type localities; Gates of the Arctic National Park and Preserve (GAAR) has eight type sections, seven type localities, one type area, and four reference sections; and Noatak National Preserve (NOAT) contains three type sections, one type area, and four reference sections (Table 1).

This report concludes with a recommendation section that addresses outstanding issues and future steps regarding park unit stratotypes. These recommendations will hopefully guide decision-making and help ensure that these geoheritage resources are properly protected and that proposed park activities or development will not adversely impact the stability and condition of these geologic exposures.

Table 1. List of ARCN stratotype units sorted by park unit and geologic age, with associated reference publications and locations. See Appendix B for a geologic time scale. Units without GRI map symbols are not currently included on a GRI map.

Park	Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
BELA	Lost Jim Basalt (Qlj)	Hopkins 1963	Type locality: Lost Jim Cone near Imuruk Lake, Seward Peninsula, AK.	Holocene
BELA	Camille Basalt	Hopkins 1963	Type locality: Camille Cone, in the Imuruk Lake area, Seward peninsula, AK.	Pleistocene(?)
BELA	Imuruk Volcanics	Hopkins 1963	Type locality: Canyon of Kugruk River, 5 km (3 mi) below Imuruk Lake [Bendeleben C-2 Quadrangle], Seward Peninsula, AK.	Neogene–middle Pleistocene
BELA	Oonatut Granite Complex (Ktg)	Hudson 1979	Type locality: designated as Serpentine Hot Springs area in headwater region of Serpentine River [Bendeleben D-6 and D-5 Quadrangles], north-central Seward Peninsula, AK.	Late Cretaceous
GAAR	Fortress Mountain Formation (Kfm)	Patton 1956	Type section (composite): partial sections along Kiruktagiak River and on Castle Mountain, Chandler Lake Quadrangle, northern AK.	Early Cretaceous (Albian)
GAAR	Otuk Formation, Etivluk Group (JTRrcs)	Mull et al. 1982	Principal reference section: Monotis Creek [in NE/4 sec. 29, T. 12 S., R. 4 W., western Chandler Lake Quadrangle], Endicott Mountains, AK.	Early Triassic (Olenekian)–Middle Jurassic (Bajocian)
GAAR	Imnaitchiak Chert, Etivluk Group (TRPNic)	Mull et al. 1986	Reference section: on south side of hill along lower Akmalik Creek [in NE/4 sec. 27, T. 12 S., R. 10 W., Umiat Meridian], AK.	Pennsylvanian–Triassic
GAAR	Kuna Formation, Lisburne Group (Mlku)	Mull et al. 1982	Reference section: exposures along Ekokpuk Creek [in SW/4 sec. 11, T. 16 S., R. 4 W., Umiat Meridian, Chandler Lake Quadrangle], eastern Endicott Mountains, AK.	Late Mississippian–Middle Pennsylvanian
GAAR	Alapah Limestone, Lisburne Group (PNMl)	Bowsher and Dutro 1957	Type section (composite): 1) along ridge top of Sugarloaf Hill, west slope of Mount Wachsmuth; and 2) at west end of North Ridge, Mount Wachsmuth, central Brooks Range, AK. Type locality: on northern part of Mount Wachsmuth, Shainin Lake area, central Brooks Range, AK.	Middle–Late Mississippian
GAAR	Wachsmuth Formation, Lisburne Group (Mlw)	Bowsher and Dutro 1957	Type section (composite): 1) south face of Mount Wachsmuth, 2) along west slope of Mount Wachsmuth and up the south face of Sugarloaf Hill, central Brooks Range, northern AK. Type locality: Mount Wachsmuth, AK.	Early–Late Mississippian

Table 1 (continued). List of ARCN stratotype units sorted by park unit and geologic age, with associated reference publications and locations. See Appendix B for a geologic time scale. Units without GRI map symbols are not currently included on a GRI map.

Park	Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
GAAR	Akmalik Chert, Lisburne Group (PMlc)	Mull et al. 1986	Type locality: canyon of Akmalik Creek about 3 km (2 mi) southwest of Kikiktat Mountain [in sec. 30, T. 12 S., R. 10 W., Umiat Meridian, Killik River Quadrangle], central Brooks Range, northern AK.	Early–Late Mississippian (middle Osagean–probably late Meramecian)
GAAR	Kayak Shale, Endicott Group (Mk)	Bowsher and Dutro 1957	Type section: in saddle on south side of Mount Wachsmuth, about 2.9 km (1.8 mi) east of Shainin Lake camp at latitude 68°19′19″ N., longitude 150°54′29″ W. (approximate), AK. Type locality: near the foot of the south slope of Mount Wachsmuth, AK.	Early Mississippian (Visean)
GAAR	Kurupa Sandstone, Endicott Group (Mks)	Mull et al. 1986	Reference section: exposures in canyon of Akmalik Creek, 3 km (2 mi) southwest of Kikiktat Mountain [in sec. 30, T. 12 S., R. 10 W., Umiat Meridian, Killik River Quadrangle], north-central AK.	Early Mississippian
GAAR	Stuver Member, Kanayut Conglomerate, Endicott Group (MDkys)	Bowsher and Dutro 1957; Nilsen and Moore 1984	Type section: located about 1 km (0.6 mi) south-southeast of Mount Wachsmuth [sec. 16, T. 13 S., R. 5 E.] on a ridge about 2.9 km (1.8 mi) east of the camp on Shainin Lake, central Brooks Range, northern AK. Type locality: on the ridge 1.1 km (0.7 mi) south of Mount Wachsmuth, AK.	Late Devonian–Early(?) Mississippian
GAAR	Shainin Lake Member, Kanayut Conglomerate, Endicott Group (Dkym)	Nilsen and Moore 1984	Type section: prominent cliff directly south of confluence of Kayak and Alapah Creeks, about 8 km (5 mi) south-southeast of Shainin Lake [in sec. 4, T. 14 S., R. 5 E., Umiat Meridian, Chandler Lake Quadrangle], northern AK.	Late Devonian
GAAR	Ear Peak Member, Kanayut Conglomerate, Endicott Group (Dkyl)	Nilsen and Moore 1984	Type section: along ridge 1.8 km (1.1 mi) southeast of Ear Peak [in secs. 13 and 24, T. 13 S., R. 5 E., and in sec. 18, T. 13 S., R. 6 E., Umiat Meridian, Chandler Lake Quadrangle], northern AK.	Late Devonian

Table 1 (continued). List of ARCN stratotype units sorted by park unit and geologic age, with associated reference publications and locations. See Appendix B for a geologic time scale. Units without GRI map symbols are not currently included on a GRI map.

Park	Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
GAAR	Kanayut Conglomerate, Endicott Group (MDky)	Bowsher and Dutro 1957	Type section (composite): 1) section along the east side of Alapah Creek about 11.4 km (7.1 mi) S. 30° E. of the camp on Shainin Lake; 2) 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 3) ridge section about 2.9 km (1.8 mi) miles east of the camp on Shainin Lake. Type locality: exposures on ridge east of Alapah Creek, south of Mount Wachsmuth, Shainin Lake area, central Brooks Range, AK	Late Devonian (Frasnian)–Early Mississippian (Tournaisian)
GAAR	Hunt Fork Shale, Endicott Group (Dhf)	Chapman et al. 1964	Type locality: exposures 40 km (25 mi) east of Killik River, along Fire Creek, east-flowing tributary of Okokmilaga River, central Brooks Range, AK.	Late Devonian (Frasnian–Famennian)
GAAR	Endicott Group (MDe)	Tailleur et al. 1967	Type area: exposures in Endicott Mountains, central Brooks Range, northern AK.	Late Devonian–early Permian
NOAT	Otuk Formation (JTRrcs)	Mull et al. 1982	Reference section: exposures along tributary of Kelly River [in SW/4 sec. 16, T. 12 S., R. 45 W. western DeLong Mountains Quadrangle], AK.	Early Triassic (Olenekian)–Middle Jurassic (Bajocian)
NOAT	Kuna Formation, Lisburne Group (Mlku)	Mull et al. 1982	Principal reference section: upper Otuk Creek [in SE/4 sec. 19, T. 34 N., R. 4 E., Kateel River Meridian, Killik River Quadrangle], central Endicott Mountains, AK. Reference sections: 1) tributary of Wrench Creek [in NW/4 sec. 26, T. 32 N., R. 17 W., Kateel River Meridian, eastern DeLong Mountains Quadrangle], AK; and 2) Pupik Hills [in SW/4, sec. 35, T. 33 N., R. 5 E., Kateel River Meridian, Howard Pass Quadrangle], western Endicott Mountains, AK.	Late Mississippian–Middle Pennsylvanian
NOAT	Noatak Sandstone, Endicott Group (Dnu)	Smith and Mertie 1930; Dutro 1952	Type section: exposures on mountain side 7.2 km (4.5 mi) N. 15° W. of junction of Nimiuktuk and Noatak rivers, Misheguk Mountain Quadrangle, Brooks Range, AK. Type area: mountains immediately west of Nimiuktuk River (Kingasivik Mountains) and south of DeLong Mountains [in Misheguk Mountain Quadrangle], western Brooks Range, AK.	Late Devonian–Early Mississippian

Table 1 (continued). List of ARCN stratotype units sorted by park unit and geologic age, with associated reference publications and locations. See Appendix B for a geologic time scale. Units without GRI map symbols are not currently included on a GRI map.

Park	Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
NOAT	Kugururok Formation, Baird Group (Dbk)	Sable and Dutro 1961	Type section: on north side of Mont Bastille, central DeLong Mountains, northern AK.	Middle (Givetian)–Late Devonian
NOAT	Eli Limestone, Baird Group (Dbe)	Tailleur et al. 1967	Type section: east of north branch of Eli River (east of Ahaliknak River, at latitude 67°47′30″ N., longitude 161°51′00″ W.) western Baird Mountains, northern AK.	Middle–Late Devonian

Acknowledgments

Many individuals were consulted in the preparation of this report on the geologic stratotypes of the national parks of the Arctic Inventory & Monitoring Network (ARCN). We first want to extend our sincere appreciation to Randy Orndorff, David Soller, and Nancy Stamm (U.S. Geological Survey) for their assistance with this inventory report and other important National Park Service (NPS) projects. Randy, Dave, and Nancy manage the National Geologic Map Database (https://ngmdb.usgs.gov/ngm-bin/ngm_compsearch.pl?glx=1) and GEOLEX (https://ngmdb.usgs.gov/Geolex/search, the U.S. Geologic Names Lexicon, a national compilation of names and descriptions of geologic units), critical sources of geologic information for science, industry, and the American public.

We thank our colleagues and partners in the Geological Society of America (GSA) and Stewards Individual Placement Program for their continued support to the NPS with the placement of geologic interns and other ventures. A special thanks to Mario Caputo (Pacific Section, SEPM) for the permission to use figures in this publication. Additionally, we are grateful to Rory O'Connor-Walston and Alvin Sellmer from the NPS Technical Information Center in Denver for their assistance with locating hard-to-find publications.

Thanks to our NPS colleagues in the ARCN and various network parks including: Eric Wald and Scott Miller (ARCN), Ken Adkisson and Letty Hughes (BELA), Carlos Paez (CAKR, KOVA and NOAT), and Jeff Rasic (GAAR). Eric served as the peer review coordinator for this report. Additional thanks to James Lawler and Amanda Lanik (NPS Alaska Region) and Robert Blodgett for continued support for this and other important geology projects in the Alaska Region of the NPS.

This project is possible through the support from research associates and staff in the National Park Service Geologic Resources Division and we extend our thanks to Stephanie Gaswirth, Hal Pranger, Julia Brunner, Jason Kenworthy, Rebecca Port, Jim Wood, and the Geologic Resource Inventory Team.

Dedication

We are proud to dedicate the Arctic Inventory & Monitoring Network Geologic Type Section Inventory to two of our valued colleagues in Alaska: Amanda Lanik and Jeff Rasic. Amanda is a Geologist in the National Park Service Alaska Region who joined the NPS in 2016. One of Amanda's research projects involves the stratigraphy of the Arctic parks. Jeff is the Chief of Integrated Resources Management at Gates of the Arctic National Park and Preserve and Yukon-Charley Rivers National Preserve. Jeff joined the National Park Service in 1995 and has been a strong advocate for the stewardship and management of paleontological resources in Alaska's national parks, including those in the Arctic Network.

Jeff Rasic (left), archeologist, and Amanda Lanik (right), geologist, both at work in the field in Alaskan national parks.

Introduction

Documentation of stratotypes (i.e., type sections/type localities/type areas; see "Definitions" below) that occur within national park boundaries represents a significant component of a geologic resource inventory, as these designations serve as the standard for defining and recognizing geologic units (North American Commission on Stratigraphic Nomenclature 2021). The importance of stratotypes lies in the fact that they represent important comparative sites where past investigations can be built upon or re-examined, and can serve as teaching sites for the next generation of students (Brocx et al. 2019). The geoheritage significance of stratotypes is analogous to libraries and museums in that they are natural repositories of Earth history and record the physical and biologic evolution of our planet.

The NPS Geologic Type Section Inventory Project ("Stratotype Inventory Project") is a continuation of and complements the work performed by the Geologic Resources Inventory (GRI). The GRI is funded by the NPS Inventory & Monitoring Program and administered by the Geologic Resources Division (GRD). The GRI is designed to compile and present baseline geologic resource information available to park managers, and advance science-informed management of natural resources in the national parks. The goals of the GRI are to increase understanding and appreciation of the geologic features and processes in parks and provide robust geologic information for use in park planning, decision making, public education, and resource stewardship. Additional GRI information and products can be accessed on IRMA or the GRI publication page (https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm).

The goals of this project are to 1) systematically report the assigned stratotypes that occur within national park boundaries, 2) provide detailed descriptions of the stratotype exposures and their locations, and 3) reference the stratotype assignments from published literature. It is important to note that this project cannot verify a stratotype for a geologic unit if one has not been formally assigned and/or published. Additionally, numerous stratotypes are located geographically outside of national park boundaries, but only those within 48 km (30 mi) of park boundaries are presented in this report.

This geologic stratotype inventory for the parks of the Arctic Inventory & Monitoring Network (ARCN) follows standard practices, methodologies, and organization of information introduced in the Greater Yellowstone I&M Network stratotype inventory (Henderson et al. 2020). All network-specific reports are prepared, peer-reviewed, and submitted to the Natural Resources Stewardship and Science Publications Office for finalization. A small team of geologists and paleontologists from the NPS Geologic Resources Division and the NPS Paleontology Program has stepped up to undertake this important inventory for the NPS.

This inventory fills a void in basic geologic information compiled by the NPS at most parks. Instances where geologic stratotypes occur within NPS areas were determined through research of published geologic literature and maps. Sometimes the lack of specific locality or other data limited determination of whether a particular stratotype was located within NPS administered boundaries. Below are the primary justifications that warrant this inventory of NPS geologic stratotypes.

- Geologic stratotypes are a part of our national geologic heritage and are a cornerstone of the scientific value used to define the societal significance of geoheritage sites (https://www.nps.gov/articles/scientific-value.htm);
- Geologic stratotypes are important geologic landmarks and reference locations that define important scientific information associated with geologic strata. Geologic formations are frequently named after topographic or geologic features and landmarks that are recognizable to park staff;
- Geologic stratotypes are both historically and scientifically important components of earth science investigations and mapping;
- Understanding and interpreting the geologic record depends on the stratigraphic occurrences of mappable lithologic units (formations, members). These geologic units are the foundational attributes of geologic maps;
- Geologic maps are important tools for science, resource management, land use planning, and other areas and disciplines;
- Geologic stratotypes are similar in nature to type specimens in biology and paleontology, serving as the primary reference for defining distinctive characteristics and establishing accurate comparisons;
- Geologic stratotypes within NPS areas have not been previously inventoried and there is a general absence of baseline information for this geologic resource category;
- NPS staff may not be aware of the concept of geologic stratotypes and therefore would not understand the significance or occurrence of these natural references in the parks;
- Given the importance of geologic stratotypes as geologic references and geologic heritage resources, these locations should be afforded some level of preservation or protection when they occur within NPS areas;
- If NPS staff are unaware of geologic stratotypes within parks, the NPS cannot proactively monitor the stability, condition, or potential impacts to these locations during normal park operations or planning. This lack of information also hinders the protection of these localities from activities that may involve ground disturbance or construction.
- This inventory can inform important conversations on whether geologic stratotypes rise to the level of national register documentation. The NPS should consider if any other legal authorities (e.g., National Historic Preservation Act), policy, or other safeguards currently in place can help protect geologic stratotypes that are established on NPS administered lands. Through this inventory, the associated report, and close communication with park and I&M Network staff, we hope there will be an increased awareness about these important geologic landmarks in parks. In turn, the awareness of these resources and their significance may be recognized in park planning and operations, to ensure that geologic stratotypes are preserved and available for future study.

Geology and Stratigraphy of the ARCN I&M Network Parks

The Arctic Inventory & Monitoring Network (ARCN) consists of five National Park Service (NPS) units in northwestern and north-central Alaska (Figure 1). These parks include Bering Land Bridge National Preserve (BELA), Cape Krusenstern National Monument (CAKR), Gates of the Arctic National Park and Preserve (GAAR), Kobuk Valley National Park (KOVA), and Noatak National Preserve (NOAT). The parks of the ARCN includes some of the nation's largest national parks, with GAAR being the second largest national park covering 3,428,702 ha (8,472,506 acres), and NOAT being not far behind at 2,660,598 ha (6,574,481 acres). The ARCN parks are inaccessible by road and offer visitors tremendous opportunities for wilderness experiences. The parks associated with the Brooks Range offer an outstanding wilderness landscape with abundant wildlife and other natural resources. All of these parks, with the exception of BELA, lie north of the Arctic Circle and are in or directly adjacent to the Brooks Range, a broad area of uplifted Paleozoic bedrock that forms an east–west trending mountain range across northern Alaska. The geographic area covered by the ARCN can be divided into a series of east–west trending geologic provinces (Blodgett et al. 2002). These provinces are defined by stratigraphy, structural character, and degree of metamorphism. They primarily reflect the deformational history related to the formation of the Brooks Range.

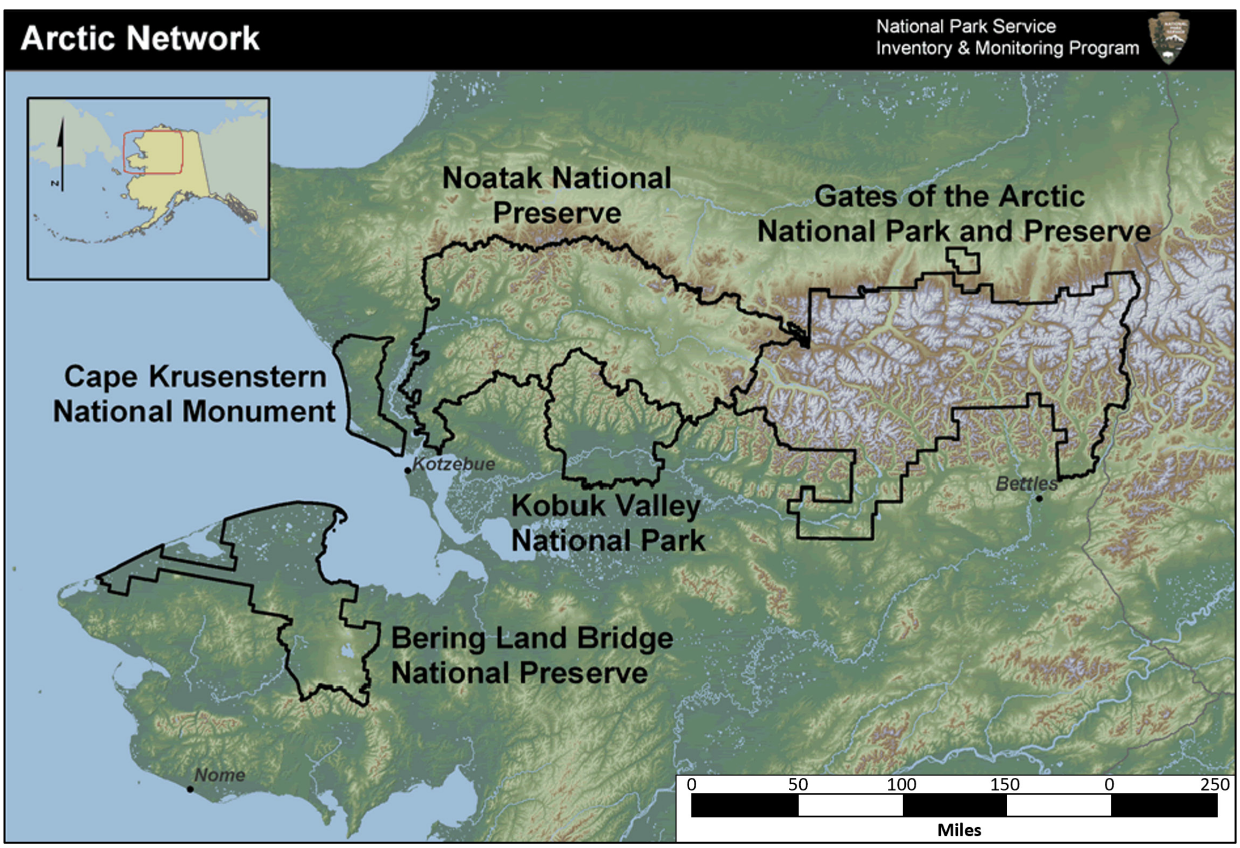


Figure 1. Map of Arctic I&M Network parks including Bering Land Bridge National Preserve (BELA), Cape Krusenstern National Monument (CAKR), Gates of the Arctic National Park and Preserve (GAAR), Kobuk Valley National Park (KOVA), and Noatak National Preserve (NOAT) (NPS).

Precambrian

Precambrian-age rocks are not well-represented in the parks of the ARCN (see Appendix B for a geologic time scale). The Erie Lake pluton in GAAR is believed to be Mesoproterozoic in age. Neoproterozoic metasedimentary and metavolcanic rocks occur within KOVA and NOAT. The Nome Complex metamorphic and metavolcanic rocks present in BELA span from the Precambrian into the middle Paleozoic.

Paleozoic

Lower Paleozoic rocks are found in every ARCN park. The Baird Group is a widespread Cambrian–Late Devonian unit exposed in CAKR, GAAR, KOVA, and NOAT. The Nome Complex is an upper Precambrian–Devonian-age unit exposed in BELA. Within KOVA the Skajit Limestone (Middle Ordovician–Middle Devonian) and informal "Twilight Zone" strata of Middle Ordovician–Early Mississippian age are also present.

The Devonian is well-exposed in all of the ARCN parks. Devonian-age metamorphic rocks of the Nome Complex underlie portions of BELA. The Late Devonian Kanayut Conglomerate and Hunt Fork Shale are mapped in CAKR, GAAR, and NOAT. The Noatak Sandstone is present in GAAR and NOAT. Additional Devonian units include the Beaucoup Formation (GAAR), and Eli Limestone and Kugururok Formation (NOAT).

The Carboniferous is also exposed in each of the network parks with the exception of BELA. The Mississippian and Pennsylvanian are represented by the Noatak Sandstone, Kayak Shale, Utukok Formation, and Kogruk Formation in CAKR; the Kayak Shale, Lisburne Group, Wachsmuth Limestone, Alapah Limestone, Kuna Formation, and Nuka Formation in GAAR; the Lisburne Group in KOVA; and the Kayak Shale, Lisburne Group, Utukok Formation, Kogruk Formation, Wachsmuth Limestone, Kuna Formation, Nuka Formation, and Siksikpuk Formation in NOAT.

Permian-age strata underlie two ARCN parks. The Siksikpuk Formation is mapped in both NOAT and GAAR. GAAR also has rocks of the Sadlerochit Group, and additional Permian units in NOAT include the Nuka Formation and Etivluk Group.

Mesozoic

The oldest Mesozoic rocks in the ARCN parks include the Middle–Late Triassic Shublik Formation in GAAR. The Otuk Formation is a Late Triassic–Middle Jurassic unit which is mapped in both GAAR and NOAT. The Early Cretaceous is represented by the Okpikruak Formation also exposed within GAAR and NOAT. Additional Early Cretaceous units in GAAR include an unnamed coquinoid limestone and the Fortress Mountain Formation. An unnamed sedimentary unit of Early–Late Cretaceous age is present at KOVA.

Cenozoic

The Cenozoic of the ARCN parks is represented by Neogene units spanning between the Miocene through the Holocene. The oldest Cenozoic units documented in the network are a sequence of Miocene–Pleistocene gravels at BELA. All of the network parks have unnamed Quaternary deposits (Hamilton 2010; Hamilton and Labay 2012).

National Park Service Geologic Resource Inventory

The Geologic Resources Inventory (GRI) provides digital geologic map data and pertinent geologic information on park-specific features, issues, and processes to support resource management and science-informed decision-making in more than 270 natural resource parks throughout the National Park System. The GRI is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division (GRD) of the NPS Natural Resource Stewardship and Science Directorate administers the GRI. The GRI team consists of a partnership between the GRD, the Colorado State University Department of Geosciences, and the University of Alaska Museum of the North to produce GRI products.

GRI Products

The GRI team undertakes four tasks for each park in the Inventory and Monitoring program: 1) conduct a scoping meeting and provide a summary document; 2) provide digital geologic map data in a geographic information system (GIS) format; 3) create posters to display the GRI GIS data; and 4) provide a GRI report. These products are designed and written for non-geoscientists. The scoping summary for the ARCN is complete (Thornberry-Ehrlich 2008), and the GRI GIS data is completed for all the ARCN parks. The GRI report and poster have been completed for BELA (Lanik et al. 2019) but the reports and posters for the other ARCN parks have not yet been completed.

Scoping meetings bring together park staff and geologic experts to review and assess available geologic maps, develop a geologic mapping plan, and discuss geologic features, processes, and resource management issues that should be addressed in the GRI report. A scoping session was held for the ARCN parks May 8–10, 2007.

Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan to GIS data in accordance with the GRI data model. After the map is completed, the GRI report team uses these data, as well as the scoping summary and additional research, to prepare the GRI report. As of 2022, a GRI report has been completed for BELA (Lanik et al. 2019); the other four parks are estimated for completion in FY 2024. The GRI team conducts no new field work in association with their products.

The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (§ 204), 2006 National Park Service Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75). Additional information regarding the GRI, including contact information, is available at https://www.nps.gov/subjects/geology/gri.htm.

Geologic Map Data

A geologic map in GIS format is the principal deliverable of the GRI program. GRI GIS data produced for the ARCN parks follows the selected source maps and includes components such as: faults, mine area features, mine point features, geologic contacts, geologic units (bedrock, surficial, glacial), geologic line features, structure contours, and so forth. These are commonly acceptable geologic features to include in a geologic map.

Posters display the data over imagery of the park and surrounding area. Complete GIS data are available at the GRI publications website: https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at, or beneath the land surface (Evans 2016). Color and sometimes symbols on geologic maps are used to distinguish geologic map units. The unit labels consist of an uppercase letter (or symbol for some ages) indicating the geologic age and lowercase letters indicating the formation's name. Other symbols depict structures such as faults or folds, locations of past geologic hazards that may be susceptible to future activity, and other geologic features. Anthropogenic features such as mines or quarries, as well as observation or collection locations, may be indicated on geologic maps. The American Geosciences Institute website (https://www.americangeosciences.org/environment/publications/mapping) and work by Bernknopf et al. (1993) provide more information about geologic maps and their uses.

Geologic maps are typically one of three types: surficial, bedrock, or a combination of both. Surficial geologic maps typically encompass deposits that are unconsolidated and which formed during the past 2.6 million years (the Quaternary Period). Surficial map units are differentiated by geologic process or depositional environment. Bedrock geologic maps encompass older, typically more consolidated sedimentary, metamorphic, and/or igneous rocks. Bedrock map units are differentiated based on age and/or rock type, geologic processes, and/or depositional environment. The GRI has produced various maps for the ARCN parks: 1) a bedrock map for BELA; 2) a combined bedrock map for CAKR, GAAR, KOVA, and NOAT; 3) a surficial map for NOAT; and 4) a surficial map for GAAR.

Source Maps

The GRI team does not conduct original geologic mapping. The team digitizes paper maps and compiles and converts digital data to conform to the GRI GIS data model. The GRI GIS dataset includes essential elements of the source maps such as map unit descriptions, a correlation chart of units, a map legend, map notes, cross sections, figures, and references. These items are typically included in an ancillary map information document (PDF) for a specific park. The GRI team uses a unique "GMAP ID" value for each geologic source map, and all sources to produce the GRI GIS datasets for the ARCN parks can be found in Appendix A.

GRI GIS Data

The GRI team standardizes map deliverables by using a data model. The most recent GRI GIS data for CAKR, GAAR, KOVA, and NOAT were compiled using data model version 2.3, which is available at https://www.nps.gov/articles/gri-geodatabase-model.htm; the BELA data are based on older data models and need to be upgraded to the most recent version. The data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI website (https://www.nps.gov/subjects/geology/gri.htm) provides more information about the program's products.

GRI GIS data are available on the GRI publications website (https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm) and through the NPS Integrated Resource Management Applications (IRMA) Data Store portal (https://irma.nps.gov/DataStore/Search/Quick). Enter "GRI" as the search text and select BELA, CAKR, GAAR, KOVA, or NOAT from the unit list.

The following components are part of the dataset:

- A GIS readme file that describes the GRI data formats, naming conventions, extraction instructions, use constraints, and contact information;
- Data in ESRI geodatabase GIS format;
- Layer files with feature symbology;
- Federal Geographic Data Committee (FGDC)-compliant metadata;
- An ancillary map information document that contains information captured from source maps such as map unit descriptions, geologic unit correlation tables, legends, cross-sections, and figures;
- ESRI map documents that display the GRI GIS data; and
- A version of the data viewable in Google Earth (.kml / .kmz file).

GRI Map Posters

Posters of the GRI GIS draped over shaded relief images of the park and surrounding area are included in GRI reports. Geographic information and selected park features have been added to the posters. Digital elevation data and added geographic information are not included in the GRI GIS data, but are available online from a variety of sources. Contact GRI for assistance locating these data.

Use Constraints

Graphic and written information provided in this report is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based upon the information provided. Please contact GRI with any questions.

Minor inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features on the posters. Based on the source map scales (1:100,000, 1:62,500, and 1:24,000) and US National Map Accuracy Standards, geologic features represented in the geologic map data are expected to be horizontally within 51 m (167 ft), 32 m (104 ft), and 12 m (40 ft), respectively, of their true locations.

Methods

Described here are the methods employed and definitions adopted during this inventory of geologic stratotypes located within the administrative boundaries of the parks in the ARCN. This report is part of an inventory of geologic stratotypes throughout the National Park System. Therefore, the methods, definitions, and challenges identified here pertain not only to the parks of the ARCN, but also to other inventory and monitoring networks and parks.

There are several considerations for this inventory. The most up-to-date information available is necessary, either found online or in published articles and maps. Occasionally, there is a lack of specific information which limits the information contained within the final report. This inventory does not include any new field work and is dependent on the existing information related to individual park geology and stratigraphy. Additionally, this inventory does not attempt to resolve any unresolved or controversial stratigraphic interpretations, which is beyond the scope of the project.

Stratigraphic nomenclature may change over time with refined stratigraphic field assessments and discovery of information through the expansion of stratigraphic mapping and measured sections. One important observation regarding stratigraphic nomenclature relates to differences in use of geologic names for units that transcend state boundaries. Geologic formations and other units that cross state boundaries may be referenced with different names in each of the states the units are mapped. An example is the Triassic Chugwater Formation in Wyoming, which is equivalent to the Spearfish Formation in the Black Hills of South Dakota.

The lack of a designated and formal type section, or inadequate and vague geospatial information associated with a type section, limits the ability to capture precise information for this inventory. The available information related to the geologic stratotypes is included in this report.

Finally, this inventory report is intended for a wide audience, including NPS staff who may not have a background in geology. Therefore, this document is developed as a reference document that supports science, resource management, and a historic framework for geologic information associated with NPS areas.

Methodology

The process of determining whether a specific stratotype occurs in an NPS area involves multiple steps. The process begins with an evaluation of the existing park-specific GRI map to prepare a full list of recognized map units (Figure 2).

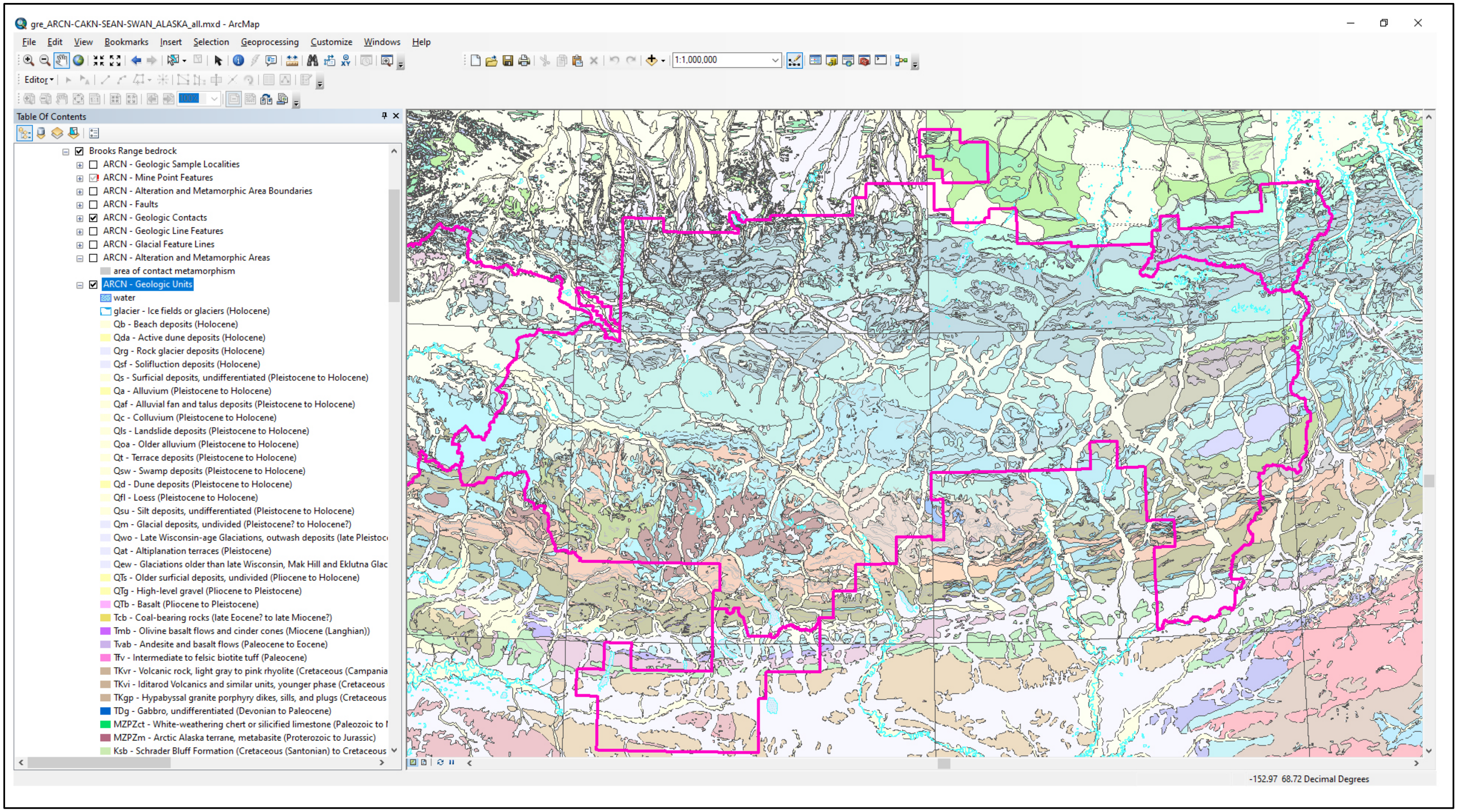


Figure 2. Screenshot of digital geologic map of Gates of the Arctic National Park and Preserve showing mapped units.

Each map unit name is then queried in the USGS Geologic Names Lexicon online database ("GEOLEX", a national compilation of names and descriptions of geologic units) at https://ngmdb.usgs.gov/Geolex/search. Information provided by GEOLEX includes unit name, stratigraphic nomenclature usage, geologic age, and published stratotype location descriptions, and the database provides a link to significant publications as well as the USGS Geologic Names Committee Archives (Wilmarth 1938; Keroher et al. 1966). Figure 3 below is taken from a search on the Kugururok Formation of the Baird Group.

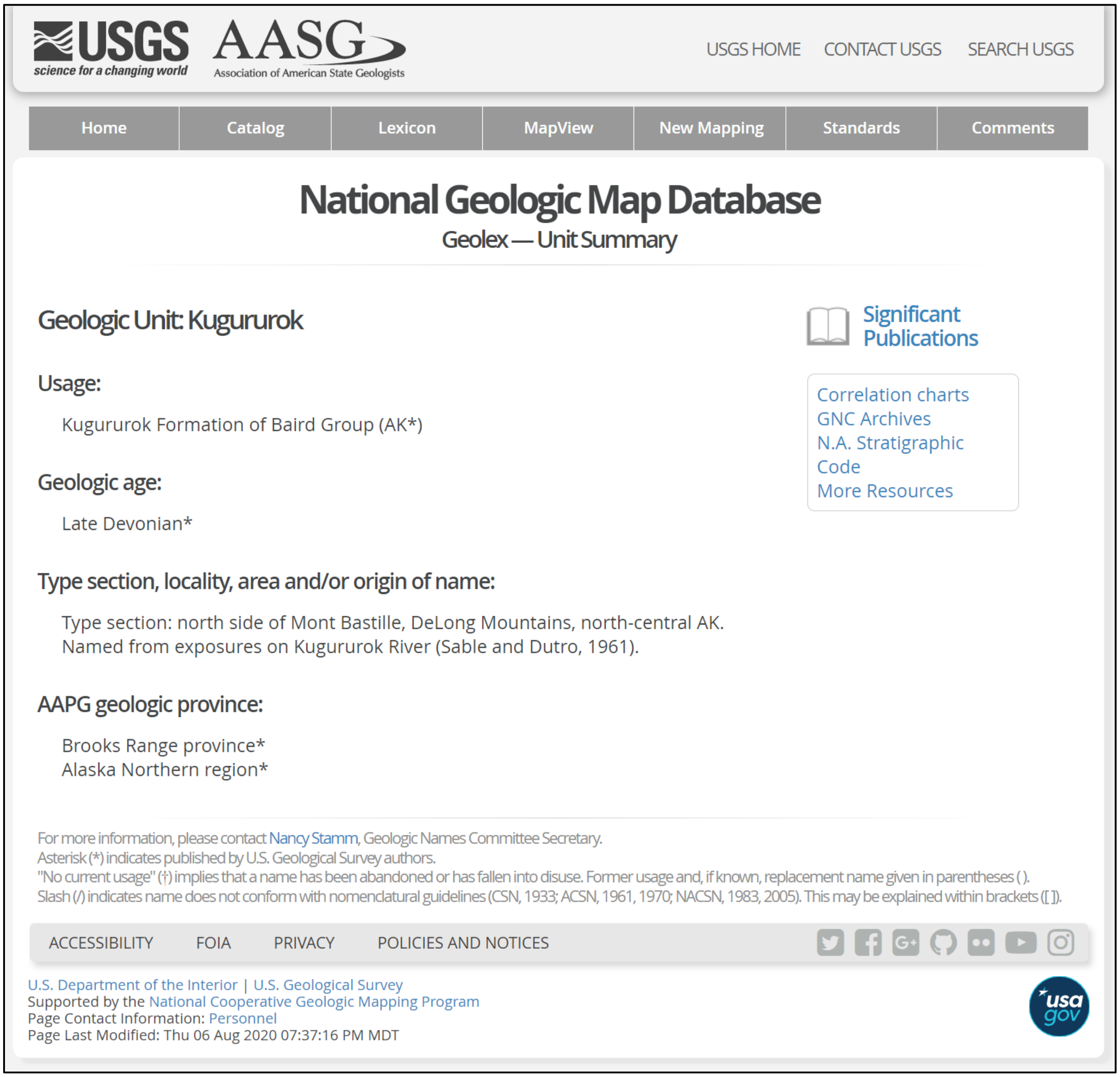
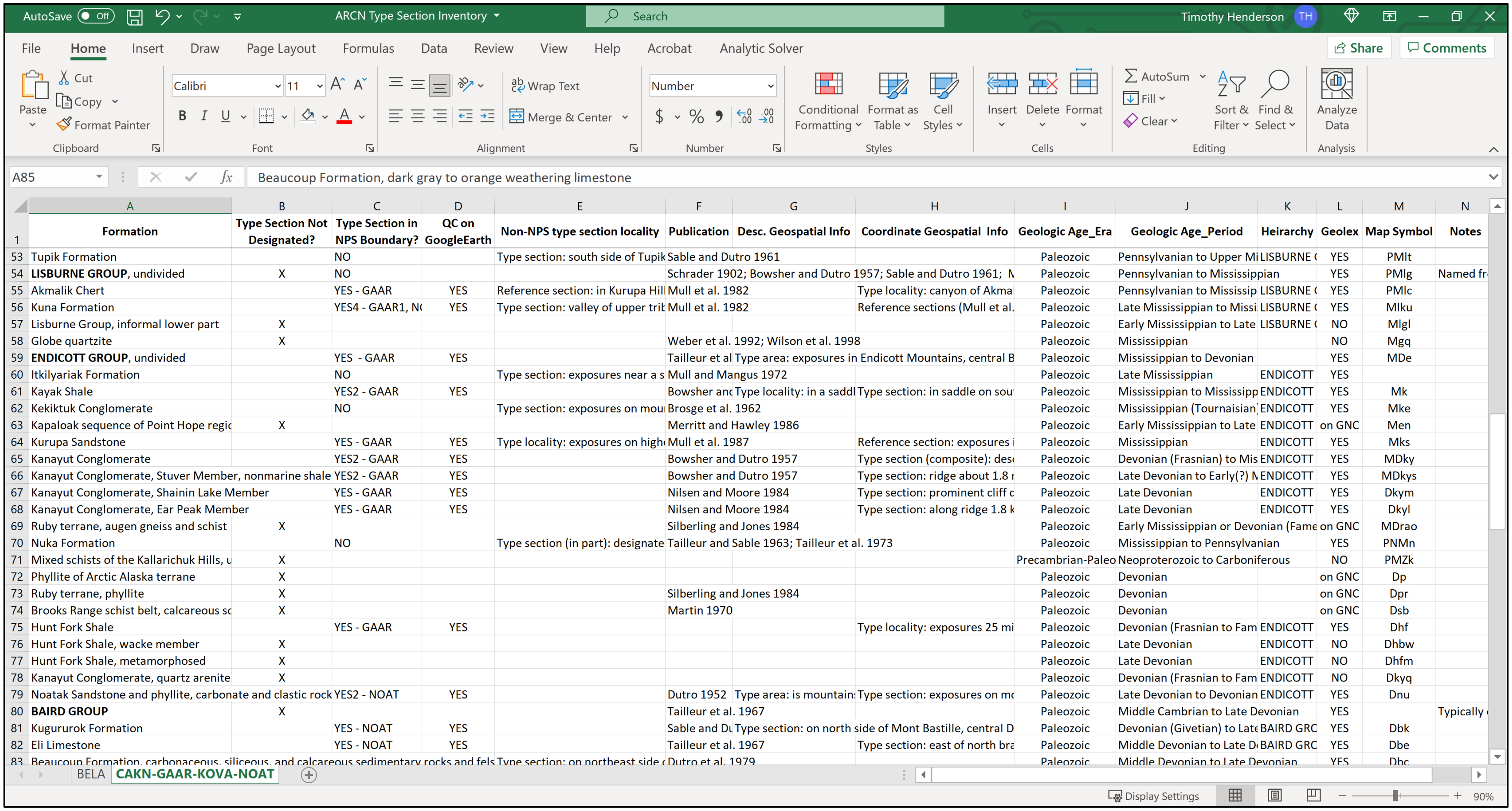


Figure 3. GEOLEX search result for the Kugururok Formation of the Baird Group.

Published GEOLEX stratotype spatial information is provided in three formats: 1) descriptive, using distance from nearby points of interest; 2) latitude and longitude coordinates; or 3)

Township/Range/Section (TRS) coordinates. TRS coordinates are based upon subdivisions of a single 93.2 km^2 (36 mi^2) township into 36 individual 2.59 km^2 (1 mi^2) sections, and were converted into Google Earth (.kmz file) locations using Earth Point (https://www.earthpoint.us/TownshipsSearchByDescription.aspx). They are typically presented in an abbreviated format such as “sec. [#], T. [#] [N. or S.], R. [#] [E. or W.]”. The most accurate GEOLEX descriptions using TRS coordinates can help locate features within 0.1618 km^2 (0.0625 mi^2). Once stratotype locality information provided for a given unit is geolocated using Google Earth, a GRI digital geologic map of the national park is draped over it. This step serves two functions: to improve accuracy in locating the stratotype, and validating the geologic polygon for agreement with GEOLEX nomenclature. Geolocations in Google Earth are then converted into an ArcGIS format using a “KML to Layer” conversion tool in ArcMap.

Upon accurately identifying the stratotypes, a Microsoft Excel spreadsheet is populated with information pertinent to the geologic unit and its stratotype attributes. Attribute data recorded in this way include: 1) whether a stratotype is officially designated; 2) whether the stratotype is on NPS land; 3) whether the stratotype location has undergone a quality control check in Google Earth; 4) reference of the publication citing the stratotype; 5) description of geospatial information; 6) coordinates of geospatial information; 7) geologic age (era, period, epoch, etc.); 8) hierarchy of nomenclature (supergroup, group, formation, member, bed, etc.); 9) whether the geologic unit was listed in GEOLEX; and 10) a generic notes field (Figure 4).



	Formation	Type Section Not Designated?	Type Section in NPS Boundary?	QC on GoogleEarth	Non-NPS type section locality	Publication	Desc. Geospatial Info	Coordinate Geospatial Info	Geologic Age_Era	Geologic Age_Period	Heirarchy	Geolex	Map Symbol	Notes
53	Tupik Formation		NO		Type section: south side of Tupik	Sable and Dutro 1961			Paleozoic	Pennsylvanian to Upper Mi	LISBURNE (	YES	PMlt	
54	**LISBURNE GROUP**, undivided	X	NO			Schrader 1902; Bowsher and Dutro 1957; Sable and Dutro 1961; M			Paleozoic	Pennsylvanian to Mississippian		YES	PMlg	Named fr
55	Akmalik Chert		YES - GAAR	YES	Reference section: in Kurupa Hill	Mull et al. 1982		Type locality: canyon of Akmal	Paleozoic	Pennsylvanian to Mississip	LISBURNE (	YES	PMlc	
56	Kuna Formation		YES4 - GAAR1, N(	YES	Type section: valley of upper trib	Mull et al. 1982		Reference sections (Mull et al.	Paleozoic	Late Mississippian to Missi	LISBURNE (	YES	Mlku	
57	Lisburne Group, informal lower part	X							Paleozoic	Early Mississippian to Late	LISBURNE (	NO	Mlgl	
58	Globe quartzite	X				Weber et al. 1992; Wilson et al. 1998			Paleozoic	Mississippian		NO	Mgq	
59	**ENDICOTT GROUP**, undivided		YES - GAAR	YES		Tailleur et al	Type area: exposures in Endicott Mountains, central B		Paleozoic	Mississippian to Devonian		YES	MDe	
60	Itkilyariak Formation		NO		Type section: exposures near a s	Mull and Mangus 1972			Paleozoic	Late Mississippian	ENDICOTT	YES		
61	Kayak Shale		YES2 - GAAR	YES		Bowsher anc	Type locality: in a saddl	Type section: in saddle on sou	Paleozoic	Mississippian to Mississipp	ENDICOTT	YES	Mk	
62	Kekiktuk Conglomerate		NO		Type section: exposures on mou	Brosge et al. 1962			Paleozoic	Mississippian (Tournaisian)	ENDICOTT	YES	Mke	
63	Kapaloak sequence of Point Hope regic	X				Merritt and Hawley 1986			Paleozoic	Early Mississippian to Late	ENDICOTT	on GNC	Men	
64	Kurupa Sandstone		YES - GAAR	YES	Type locality: exposures on high	Mull et al. 1987		Reference section: exposures i	Paleozoic	Mississippian	ENDICOTT	YES	Mks	
65	Kanayut Conglomerate		YES2 - GAAR	YES		Bowsher and Dutro 1957		Type section (composite): des	Paleozoic	Devonian (Frasnian) to Mis	ENDICOTT	YES	MDky	
66	Kanayut Conglomerate, Stuver Member, nonmarine shale		YES2 - GAAR	YES		Bowsher and Dutro 1957		Type section: ridge about 1.8 r	Paleozoic	Late Devonian to Early(?) M	ENDICOTT	YES	MDkys	
67	Kanayut Conglomerate, Shainin Lake Member		YES - GAAR	YES		Nilsen and Moore 1984		Type section: prominent cliff c	Paleozoic	Late Devonian	ENDICOTT	YES	Dkym	
68	Kanayut Conglomerate, Ear Peak Member		YES - GAAR	YES		Nilsen and Moore 1984		Type section: along ridge 1.8 k	Paleozoic	Late Devonian	ENDICOTT	YES	Dkyl	
69	Ruby terrane, augen gneiss and schist	X				Silberling and Jones 1984			Paleozoic	Early Mississippian or Devonian (Fame		on GNC	MDrao	
70	Nuka Formation		NO		Type section (in part): designate	Tailleur and Sable 1963; Tailleur et al. 1973			Paleozoic	Mississippian to Pennsylvanian		YES	PNMn	
71	Mixed schists of the Kallarichuk Hills, u	X							Precambrian-Paleo	Neoproterozoic to Carboniferous		NO	PMZk	
72	Phyllite of Arctic Alaska terrane	X							Paleozoic	Devonian		on GNC	Dp	
73	Ruby terrane, phyllite	X				Silberling and Jones 1984			Paleozoic	Devonian		on GNC	Dpr	
74	Brooks Range schist belt, calcareous sc	X				Martin 1970			Paleozoic	Devonian		on GNC	Dsb	
75	Hunt Fork Shale		YES - GAAR	YES				Type locality: exposures 25 mi	Paleozoic	Devonian (Frasnian to Fam	ENDICOTT	YES	Dhf	
76	Hunt Fork Shale, wacke member	X							Paleozoic	Late Devonian	ENDICOTT	NO	Dhbw	
77	Hunt Fork Shale, metamorphosed	X							Paleozoic	Late Devonian	ENDICOTT	NO	Dhfm	
78	Kanayut Conglomerate, quartz arenite	X							Paleozoic	Devonian (Frasnian to Fam	ENDICOTT	NO	Dkyq	
79	Noatak Sandstone and phyllite, carbonate and clastic rock		YES2 - NOAT	YES		Dutro 1952	Type area: is mountain:	Type section: exposures on mo	Paleozoic	Late Devonian to Devonian	ENDICOTT	YES	Dnu	
80	**BAIRD GROUP**	X				Tailleur et al. 1967			Paleozoic	Middle Cambrian to Late Devonian		YES		Typically (
81	Kugururok Formation		YES - NOAT	YES		Sable and Du	Type section: on north side of Mont Bastille, central D		Paleozoic	Devonian (Givetian) to Late	BAIRD GRC	YES	Dbk	
82	Eli Limestone		YES - NOAT	YES		Tailleur et al. 1967		Type section: east of north bra	Paleozoic	Middle Devonian to Late D	BAIRD GRC	YES	Dbe	
83	Beaucoup Formation, carbonaceous, siliceous, and calcareous sedimentary rocks and fels				Type section: on northeast side o	Dutro et al. 1979			Paleozoic	Middle Devonian to Late Devonian		YES	Dbc	

Figure 4. Stratotype inventory spreadsheet of the ARCN displaying attributes appropriate for geolocation assessment.

Definitions

In order to clarify, standardize, and consistently reference stratigraphic concepts, principles, and definitions, the North American Stratigraphic Code is recognized and adopted for this inventory. This code seeks to describe explicit practices for classifying and naming all formally defined geologic units. An important designation for a geologic unit is a ***stratotype***—the standard exposure(s) (original or subsequently designated) for a named geologic unit or boundary that constitutes the basis for definition or recognition of that unit or boundary (North American Commission on Stratigraphic Nomenclature 2021). There are several variations of stratotype referred to in the literature and this report, and they are defined as follows:

1) **Unit stratotype**: the **type section** for a stratified deposit or the **type area** for a non-stratified body that serves as the standard for recognition and definition of a geologic unit (North American Commission on Stratigraphic Nomenclature 2021). Once a unit stratotype is assigned, it is never changed. The term "unit stratotype" is commonly referred to as "type section" and "type area" in this report.
2) **Type locality**: the specific geographic locality encompassing the unit stratotype of a formally recognized and defined unit. On a broader scale, a type area is the geographic territory encompassing the type locality. Before development of the stratotype concept, only type localities and type areas were designated for many geologic units that are now long- and well-established (North American Commission on Stratigraphic Nomenclature 2021).
3) **Reference sections**: for well-established geologic units for which a type section was never assigned, a reference section may serve as an invaluable standard in definitions or revisions. A principal reference section may also be designated for units whose stratotypes have been destroyed, covered, or are otherwise inaccessible (North American Commission on Stratigraphic Nomenclature 2021). Multiple reference sections can be designated for a single unit to help illustrate heterogeneity or some critical feature not found in the stratotype. Reference sections can help supplement unit stratotypes in the case where the stratotype proves inadequate (North American Commission on Stratigraphic Nomenclature 2021).
4) **Lithodeme**: the term "lithodeme" is defined as a mappable unit of plutonic (igneous rock that solidified at great depth) or highly metamorphosed and pervasively deformed rock and is a term equivalent in rank to "formation" among stratified rocks (North American Commission on Stratigraphic Nomenclature 2021). The formal name of a lithodeme consists of a geographic name followed by a descriptive term that denotes the average modal composition of the rock (example: Cathedral Peak Granodiorite). Lithodemes are commonly assigned type localities, type areas, and reference localities.

Bering Land Bridge National Preserve (BELA)

Bering Land Bridge National Preserve (BELA) is located on the Seward Peninsula in the Northwest Arctic Borough and Nome Census Area of the Unorganized Borough, northwestern Alaska (Figure 5). Originally established as a national monument on December 1, 1978, the park unit was redesignated a national preserve on December 2, 1980 (National Park Service 2016). The preserve encompasses about 1,091,595 hectares (2,697,391 acres) and contains archeological, paleontological, and biological resources that record the history of the Bering land bridge that once connected Asia and North America during the last glacial period (Lanik et al. 2019). The namesake for BELA refers to a 1,000-km (620-mi) segment of land between Alaska and Siberia that, while shallowly submerged by the Bering and Chukchi seas today, was subaerially exposed during the glacial episodes of the Pleistocene Epoch (2.58 million–11,700 years ago) (Hopkins 1967). The first people to inhabit the BELA region were likely some of the first people to arrive in North America.

Much of the enabling legislation for establishing BELA is either geologic in nature or closely tied to the preserve's geology (Lanik et al. 2019). Geological resources of the preserve include volcanic lava flows and ash explosions, coastal formations, paleontological sites, and the Serpentine Hot Spring area. The bedrock of BELA can be subdivided into four groups based on rock type, age, tectonic affinity, and metamorphic history: 1) Nome Complex; 2) York terrane; 3) high-grade metamorphic and associated igneous rocks; and 4) Mesozoic and Cenozoic igneous rocks (Figures 6 and 7; Till et al. 2011). Rocks of the Nome Complex date back to the late Proterozoic Eon and represent the metamorphosed remains of an ancient carbonate platform. Strata of the York terrane are exposed near Ear Mountain in western BELA and have experienced low-grade metamorphism. High-grade metamorphic and associated igneous rocks are located in the Kigluaik, Bendeleben, and Darby mountains where they form metamorphic complexes that surround Cretaceous-age plutons (Lanik et al. 2019). Mesozoic and Cenozoic igneous rocks consist of several Cretaceous-age pluton suites and intrusive complexes in addition to volcanic rocks associated with the Imuruk and Espenberg volcanic fields (Hopkins 1963).

BELA contains four identified stratotypes that represent the Late Cretaceous Oonatut Granite Complex, Neogene–Pleistocene Imuruk Volcanics, Pleistocene(?) Camille Basalt, and the Holocene Lost Jim Basalt (Table 2; Figure 8). In addition to the designated stratotypes located within BELA, stratotypes located within 48 km (30 mi) of BELA boundaries include the Ordovician Casadepaga Schist (type area), Paleozoic(?) and Cretaceous(?) Spruce Creek Formation (type locality), and the Pleistocene Kougarok Gravel (type locality).

Figure 5. Park map of BELA, Alaska (NPS).

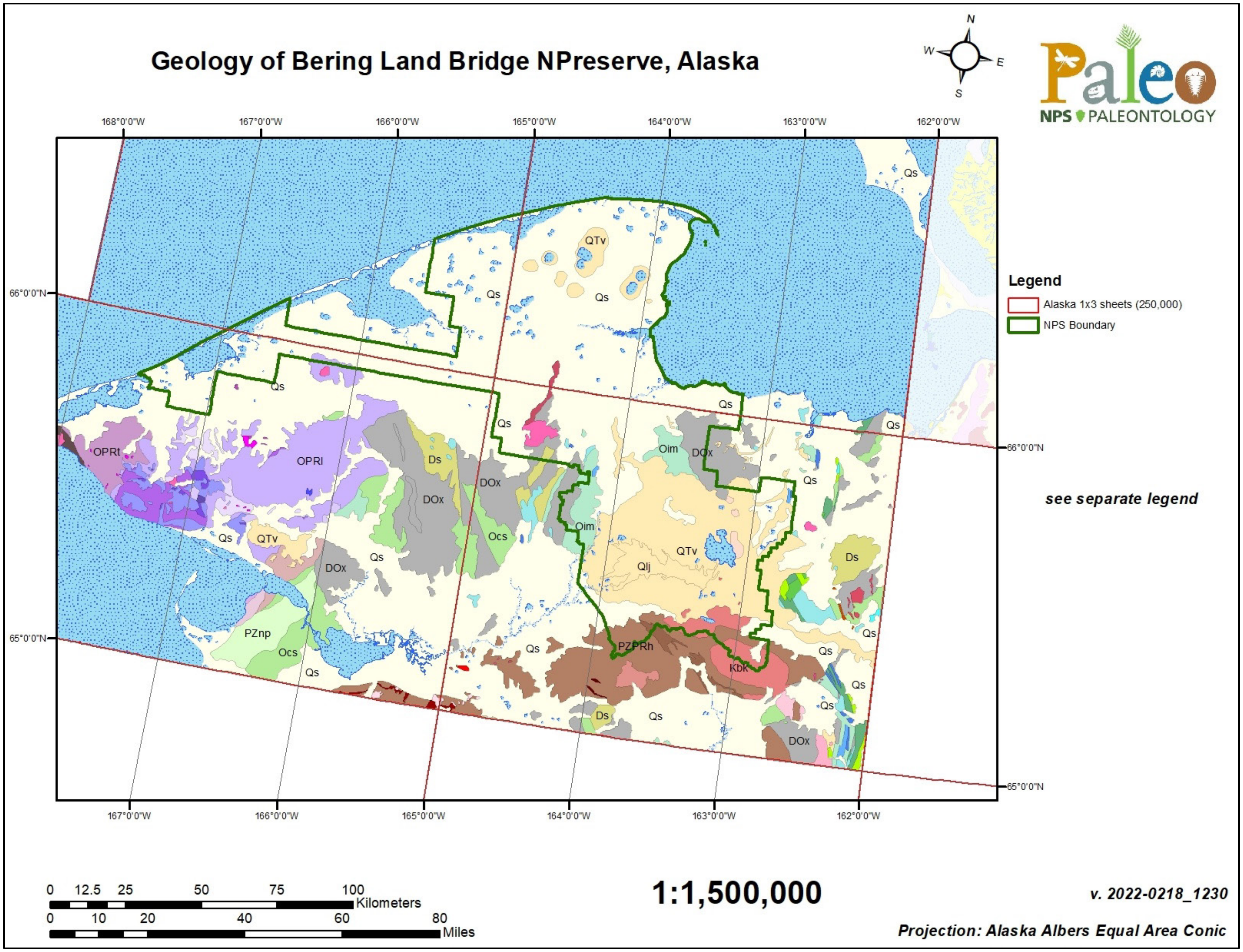


Figure 6. Geologic map of BELA, Alaska; see Figure 7 for legend.

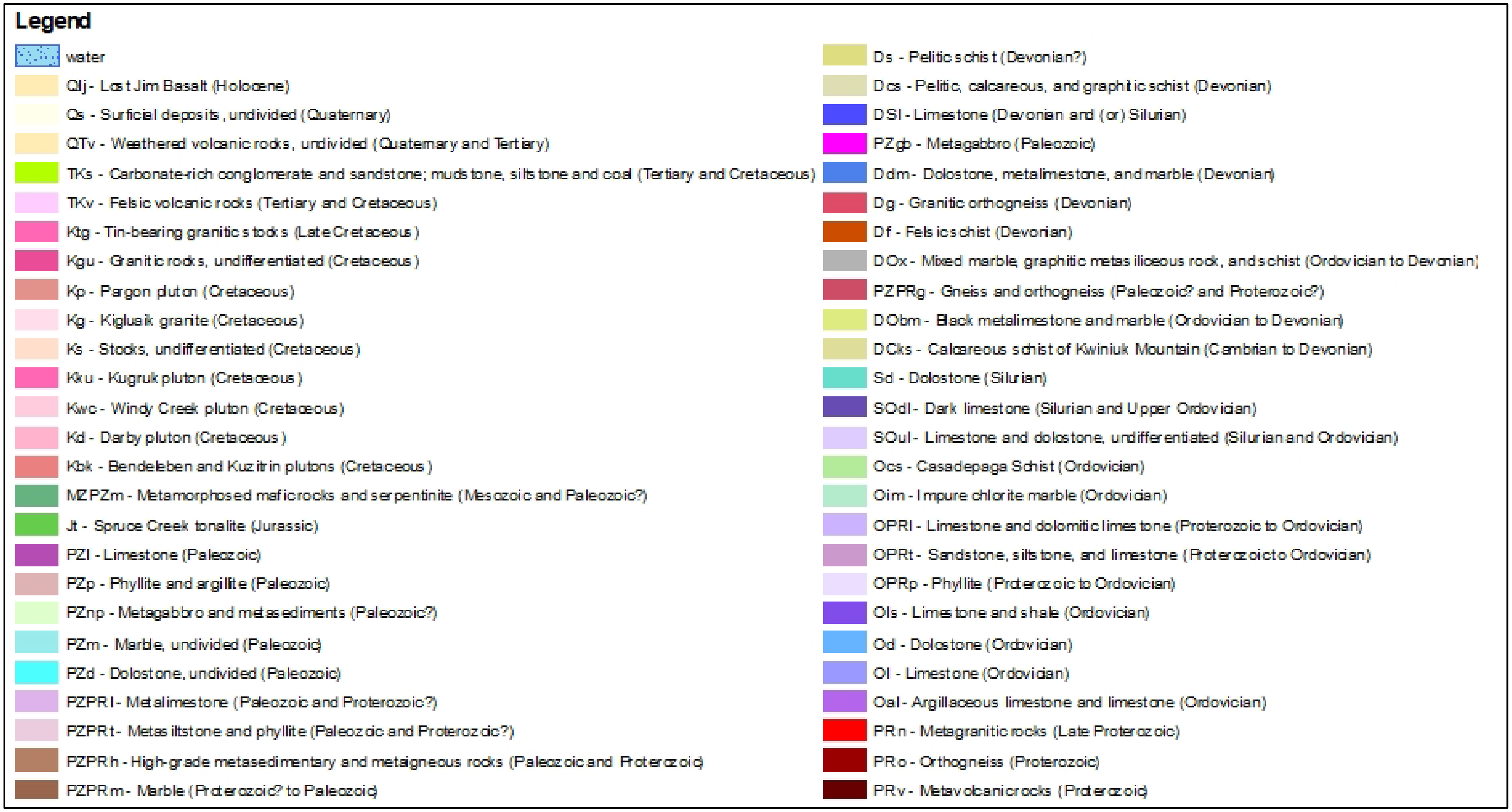


Figure 7. Geologic map legend of BELA, Alaska.

Table 2. List of BELA stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Lost Jim Basalt (Qlj)	Hopkins 1963	Type locality: Lost Jim Cone near Imuruk Lake, Seward Peninsula, AK.	Holocene
Camille Basalt	Hopkins 1963	Type locality: Camille Cone, in the Imuruk Lake area, Seward peninsula, AK.	Pleistocene(?)
Imuruk Volcanics	Hopkins 1963	Type locality: Canyon of Kugruk River, 5 km (3 mi) below Imuruk Lake [Bendeleben C-2 Quadrangle], Seward Peninsula, AK.	Neogene–middle Pleistocene
Oonatut Granite Complex (Ktg)	Hudson 1979	Type locality: designated as Serpentine Hot Springs area in headwater region of Serpentine River [Bendeleben D-6 and D-5 Quadrangles], north-central Seward Peninsula, AK.	Late Cretaceous

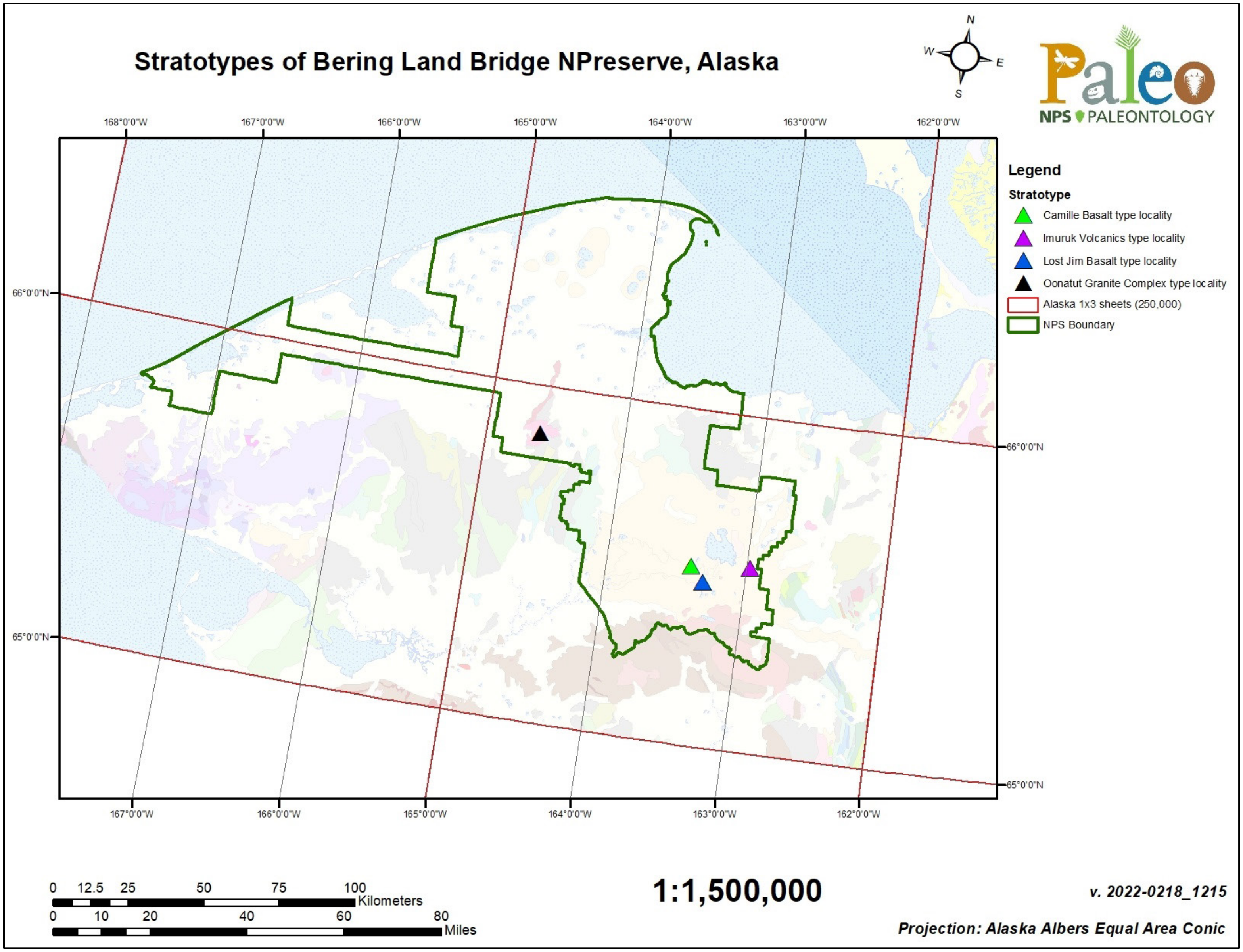


Figure 8. Modified geologic map of BELA showing stratotype locations. The transparency of the geologic units layer has been increased.

Oonatut Granite Complex

The Late Cretaceous Oonatut Granite Complex was named by Hudson (1979) after an indigenous term meaning "*place where hot water exists*". The type locality of the complex is designated as the Serpentine Hot Springs area in the headwater region of Serpentine River in the Bendeleben D-6 and D-5 Quadrangles, Alaska (Table 2; Figure 8; Hudson 1979). Surrounding the Serpentine Hot Springs area, the granite complex forms free-standing spires of rock called "tors" (Figures 9 and 10). The Oonatut Granite Complex is a texturally and compositionally zoned intrusion exposed over an area of 70 km^2 (27 mi^2) and consists of gray biotite granite that form stocks and peripheral dikes associated with tin mineralization (Hudson 1979). Different textural facies include: 1) equigranular (mineral crystals all the same size) granite; 2) porphyritic (mineral crystals are two distinct sizes) granite with 3–4 cm (1–1.5 in) long light-pink-gray potassium feldspar minerals; 3) medium- to very coarse-grained seriate (mineral crystals are different sizes) biotite granite; 4) porphyritic biotite granite; and 5) fine- to medium-grained equigranular to sub-equigranular biotite granite (Hudson 1979). The unit intrudes unnamed Precambrian(?) and Paleozoic metamorphic country rocks with a sharp, discordant contact.

Figure 9. Free-standing spires of rock called "tors" composed of jointed granite of the Oonatut Granite Complex near Serpentine Hot Springs (NPS/DEREK WIER).

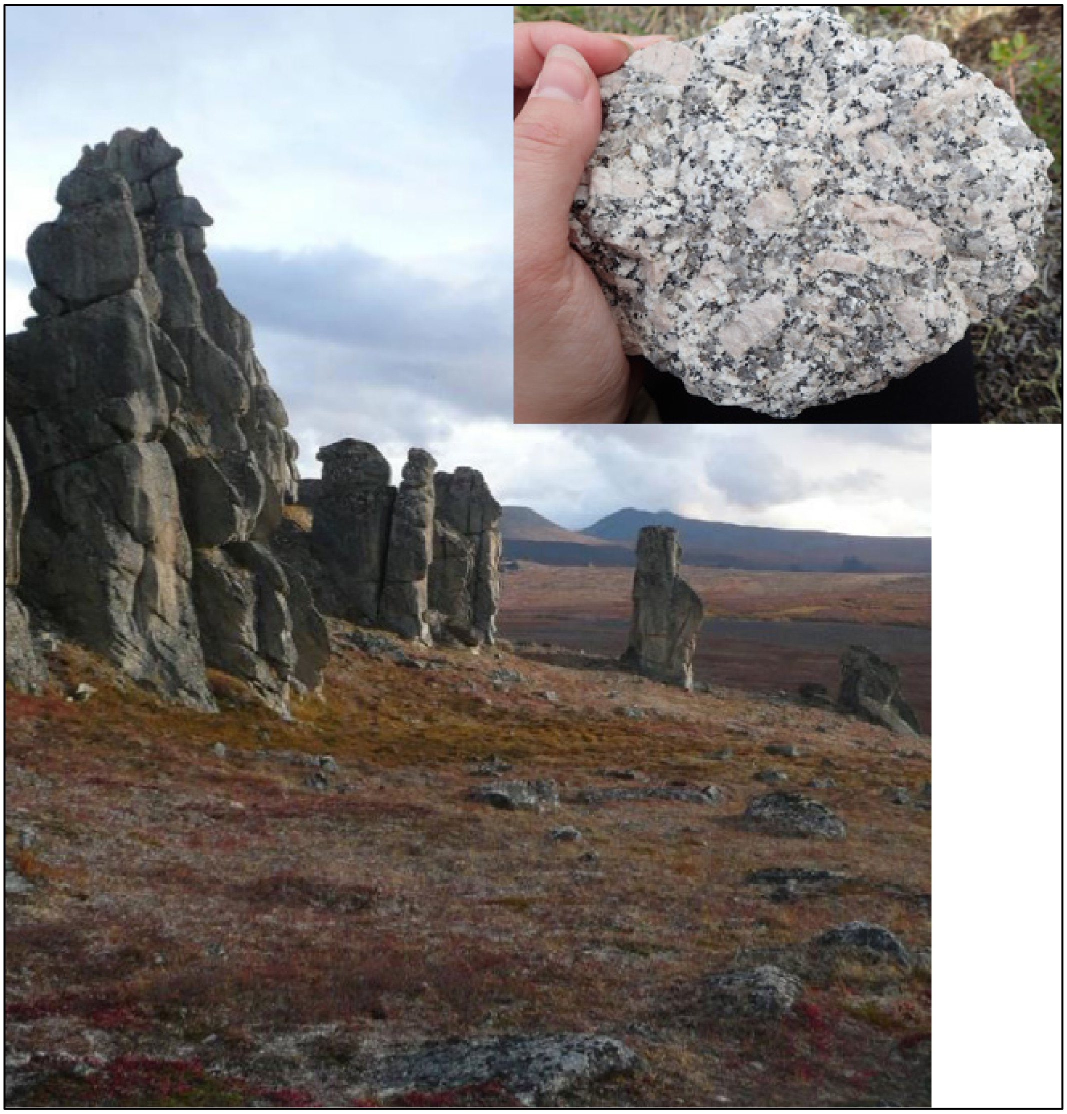


Figure 10. Tors composed of the Oonatut Granite Complex in the type locality around Serpentine Hot Springs. Inset photo shows porphyritic texture of the granite, showing large potassium feldspar crystals (NPS/AMANDA LANIK).

Imuruk Volcanics

The Neogene–middle Pleistocene Imuruk Volcanics was proposed by Hopkins (1963) and named for exposures near Imuruk Lake. The type locality is designated in the canyon of Kugruk River 5 km (3 mi) below Imuruk Lake in the Bendeleben C-2 Quadrangle, Seward Peninsula, Alaska (Table 2; Figure 8; Hopkins 1963). The Imuruk Volcanics consist of olivine basalt lava flows and their associated agglomerate cones, brecciated by frost action and mantled by silt 1–6 m (3–20 ft) thick (Figure 11; Hopkins 1963). Individual lava flows ranging from 3–15 m (10–50 ft) thick are generally of the pāhoehoe type, and are free of inclusions (Hopkins 1963). Thickness of the entire unit ranges from a few meters to more than 61 m (200 ft). At the type locality, the Imuruk Volcanics overlie deeply weathered lava flows of the Kugruk Volcanics (now considered synonymous with the Imuruk Volcanics) and underlie the Gosling Volcanics.

Figure 11. Spheroidal weathering in basaltic lava flow of the Imuruk Volcanics exposures in the canyon of Bilge Creek, northwest of the type locality. Figure 10 in Hopkins (1963).

Camille Basalt

The Pleistocene(?) Camille Basalt was named by Hopkins (1963) for a large pāhoehoe lava flow exposed discontinuously from Camille Cone to the junction of Goose Creek and the Noxapaga River, Seward Peninsula, Alaska. Hopkins (1963) designated the type locality at Camille Cone, where exposures of the basalt are about 30 m (100 ft) thick, thinning to less than 8 m (25 ft) elsewhere (Table 2; Figure 8; Hopkins 1963). The unit is described as a relatively flat, smooth, pāhoehoe flow that contains small and scarce pressure ridges and collapse depressions (Hopkins 1963). The surface of the Camille Basalt is oxidized and frost-rived (broken apart due to repeated freezing and thawing) to a limited degree that stands out in comparison to the pāhoehoe flows of the Lost Jim Basalt (Figures 12 and 13; Hopkins 1963). The Camille Basalt overlies flows of either the Gosling Volcanics or Imuruk Volcanics, and underlies the Lost Jim Basalt.

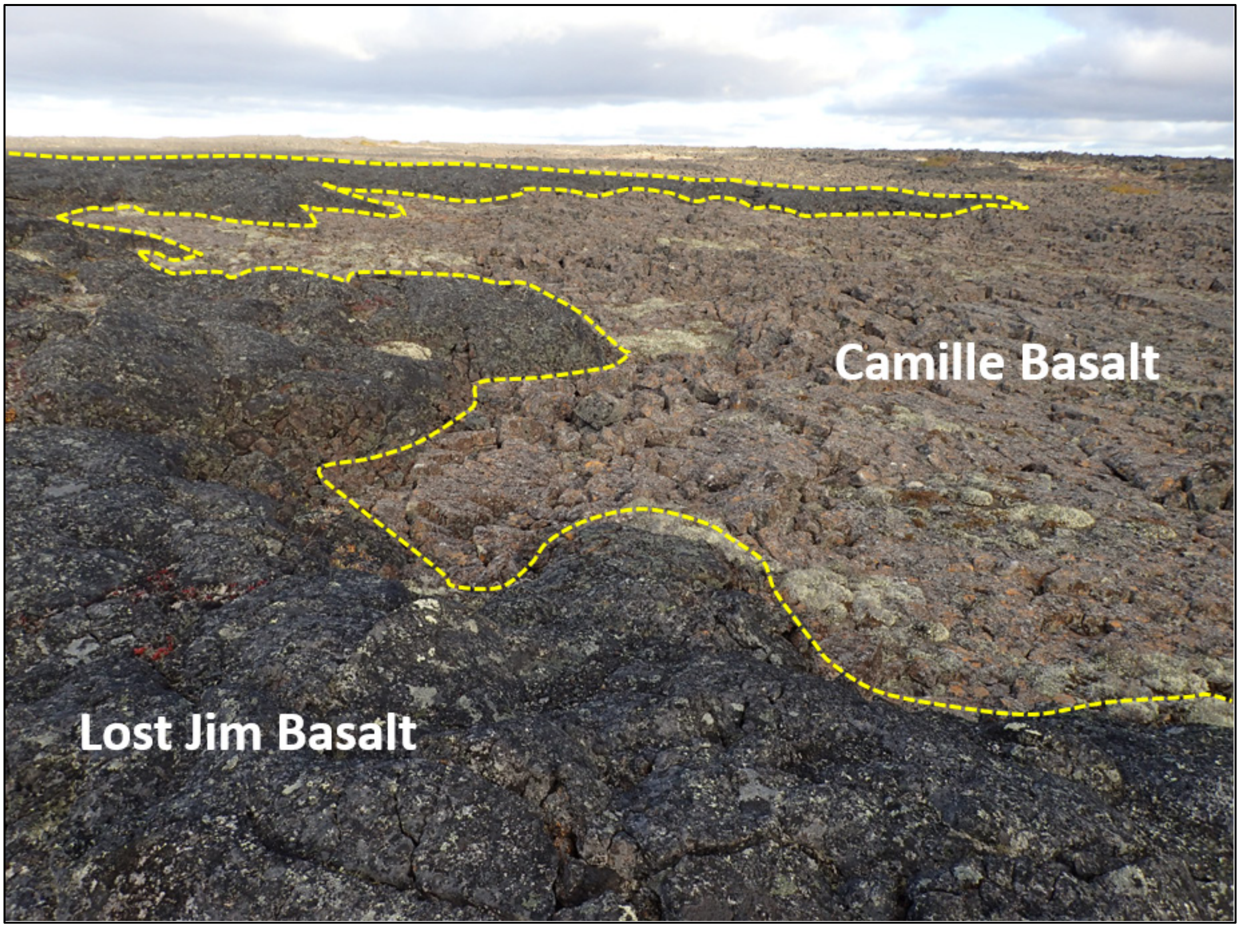


Figure 12. Contrasting lava flows of the Lost Jim Basalt and Camille Basalt. The weathered, unoxidized (darker colored) Lost Jim lava flow contrasts with the oxidized (lighter colored) Camille lava flow. The Lost Jim Basalt is unoxidized and displays little frost shattering. Frost action has broken the Camille Basalt into angular blocks (NPS/DAVID SWANSON).

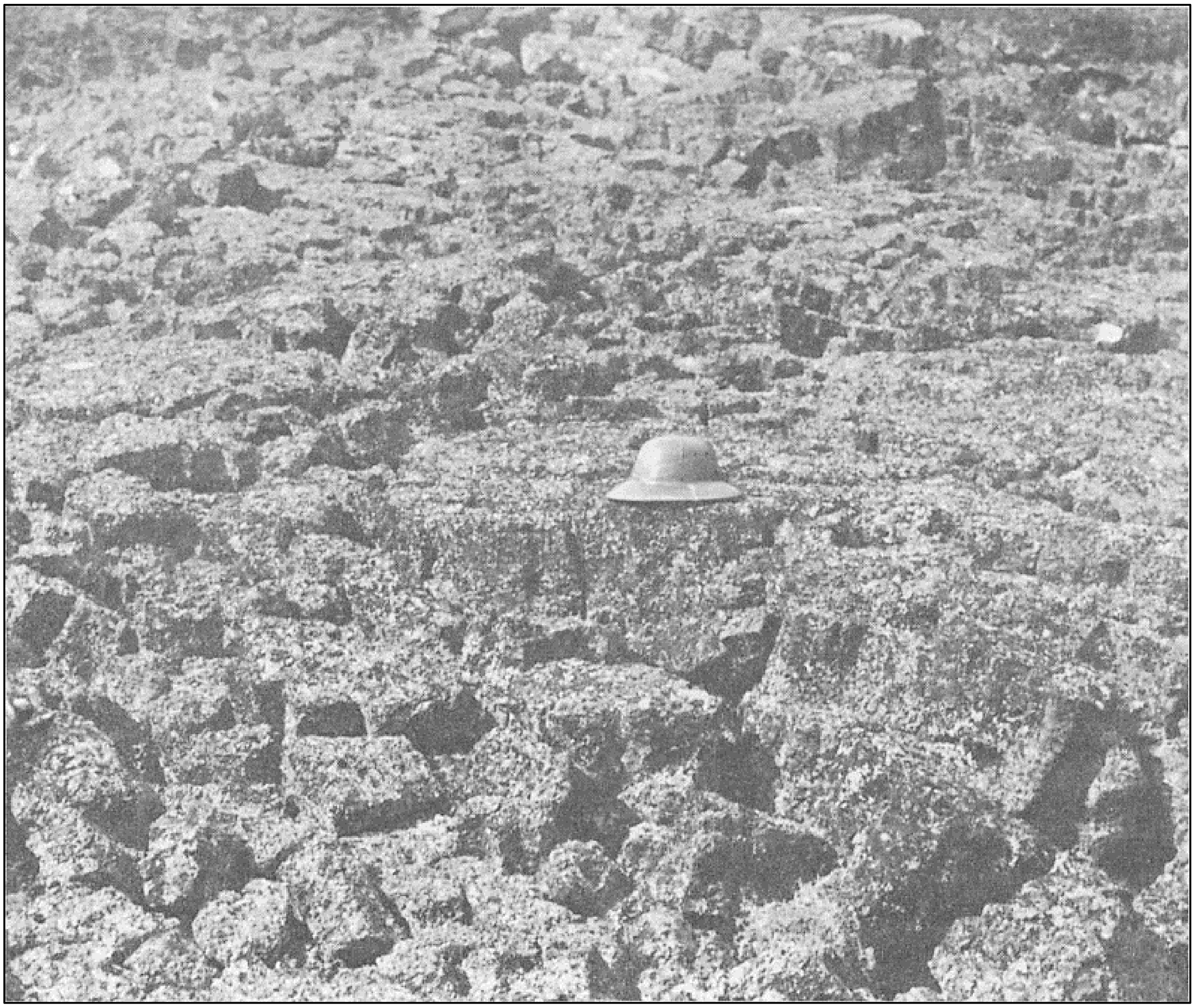


Figure 13. Frost-rived surfaces of the Camille Basalt about 1.6 km (1 mi) south of Lava Lake, BELA. Note the remnants of relatively undisturbed lava flow surface around hat. Figure 13B in Hopkins (1963).

Lost Jim Basalt

The Holocene Lost Jim Basalt was proposed by Hopkins (1956, 1963) and named after its type locality at Lost Jim Cone in the Imuruk Lake area, Seward Peninsula, Alaska (Table 2; Figures 8, 14, and 15). The Lost Jim Basalt is the youngest lava flow of the Imuruk Lake area and consists of a large olivine basalt pāhoehoe lava flow whose surface is largely undisturbed by frost weathering when compared to flows of the Camille Basalt or Gosling Volcanics (Figure 12; Hopkins 1956, 1963). Several geologic features such as lava tubes, lava rises, tumuli, and collapse depressions are formed by the unit (Figures 16 and 17). Lava tubes, lava rises, and tumuli form by the injection of lava that forms and progressively thickens a solid outer crust. Thickness of the basalt ranges from 3 m (10 ft) to a maximum thickness of about 45 m (150 ft) at Lost Jim Cone (Hopkins 1963). The Lost Jim Basalt overlies the older volcanic formations of the Camille Basalt, Imuruk Volcanics, and Gosling Volcanics.

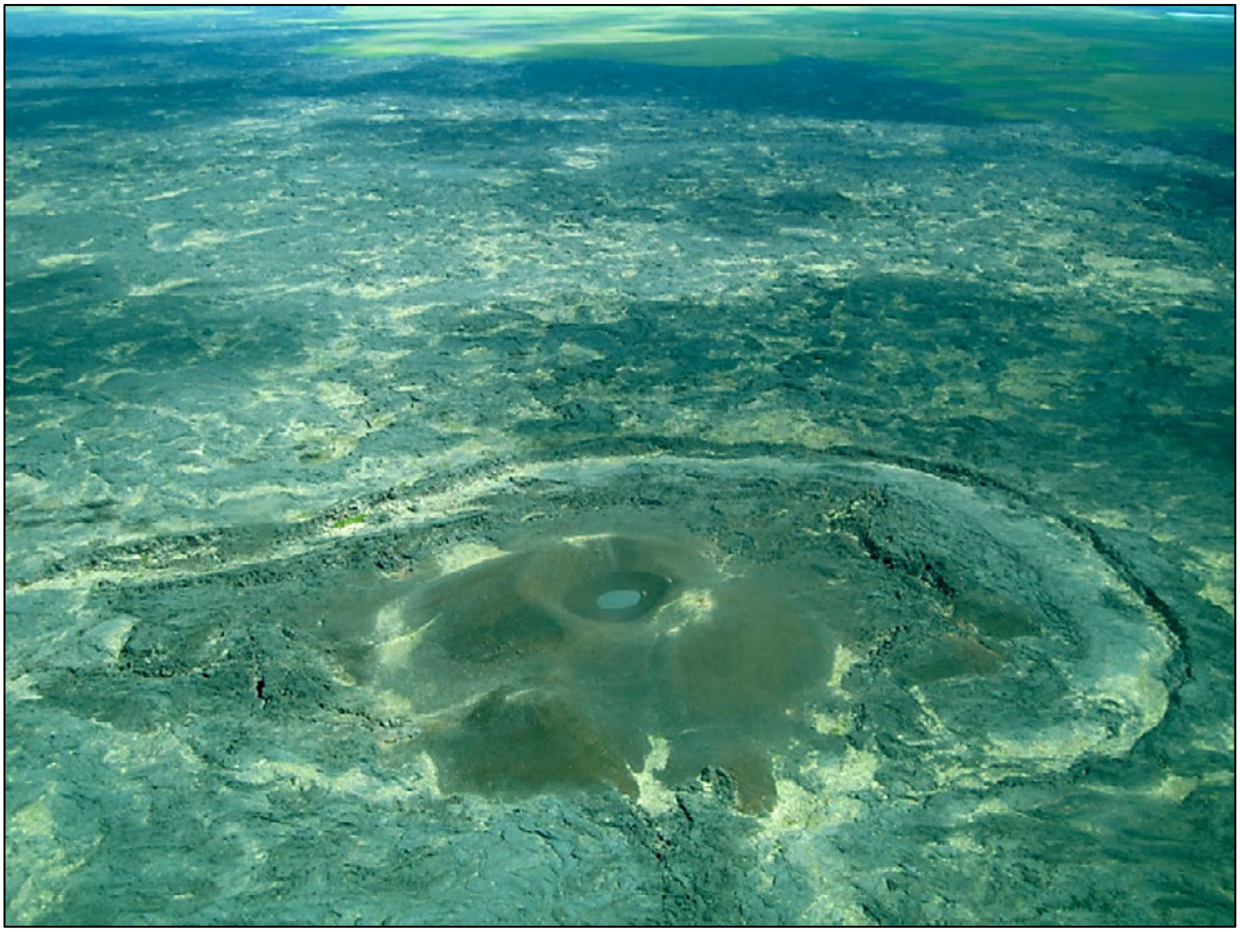


Figure 14. Aerial photograph of Lost Jim Cone, type locality of the Lost Jim Basalt. The Lost Jim Cone rises about 30 m (100 ft) above the surrounding plain. The crater is about 12 m (40 ft) deep and 30 m (100 ft) wide at the top and contains a small lake (NPS).

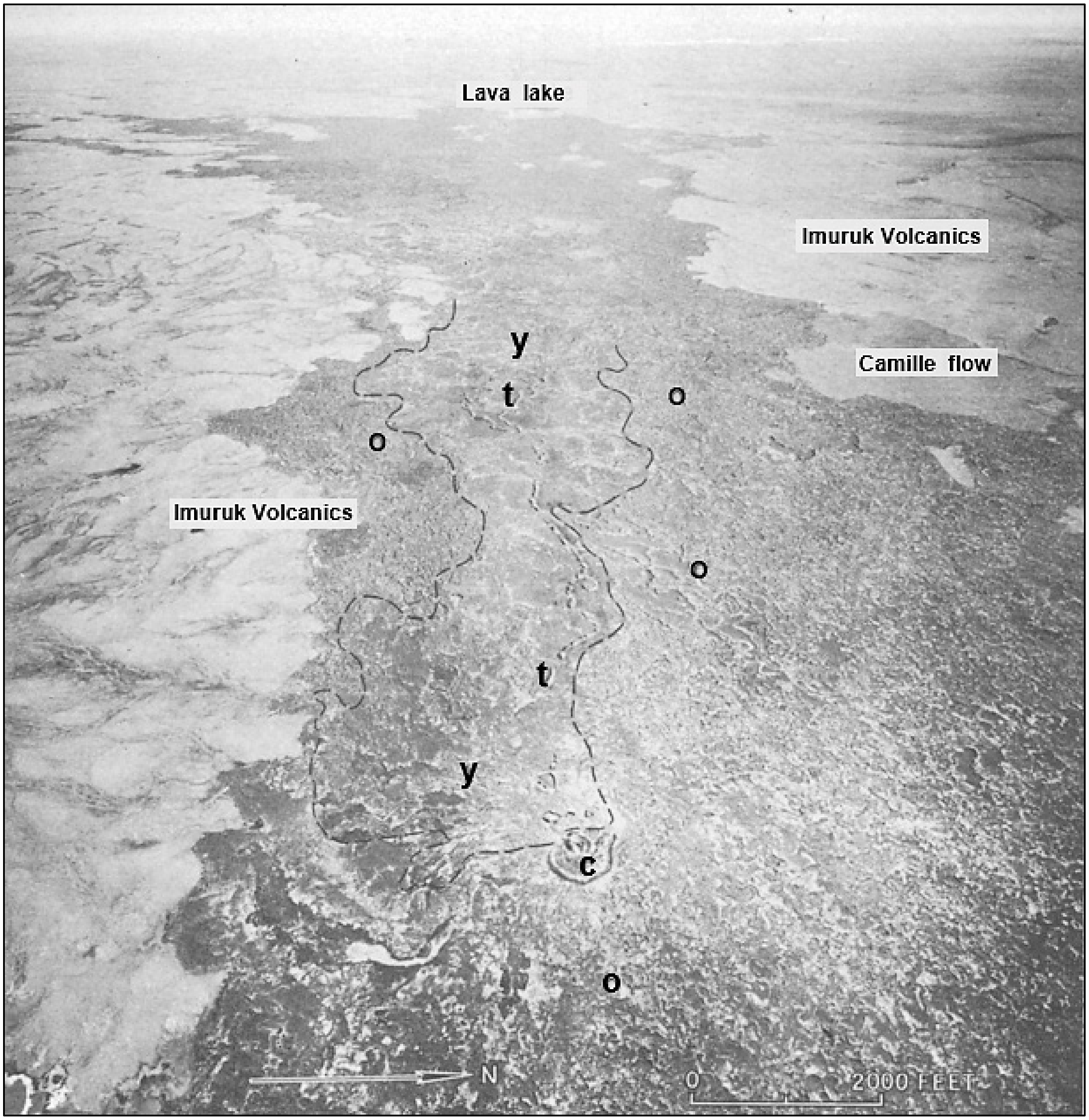


Figure 15. Aerial view looking west of the Lost Jim Basalt lava flow. Flow oriented at source vent beneath Lost Jim Cone (c). Areas beyond the dashed line (o) represent the rugged older parts of the Lost Jim flow, and areas within the dashed line (y) represent the smoother younger parts. The course of the great lava tube can be traced westward by line of deep collapse pits (t). Scale is for the foreground only. Annotated Figure 15 from Hopkins (1963).

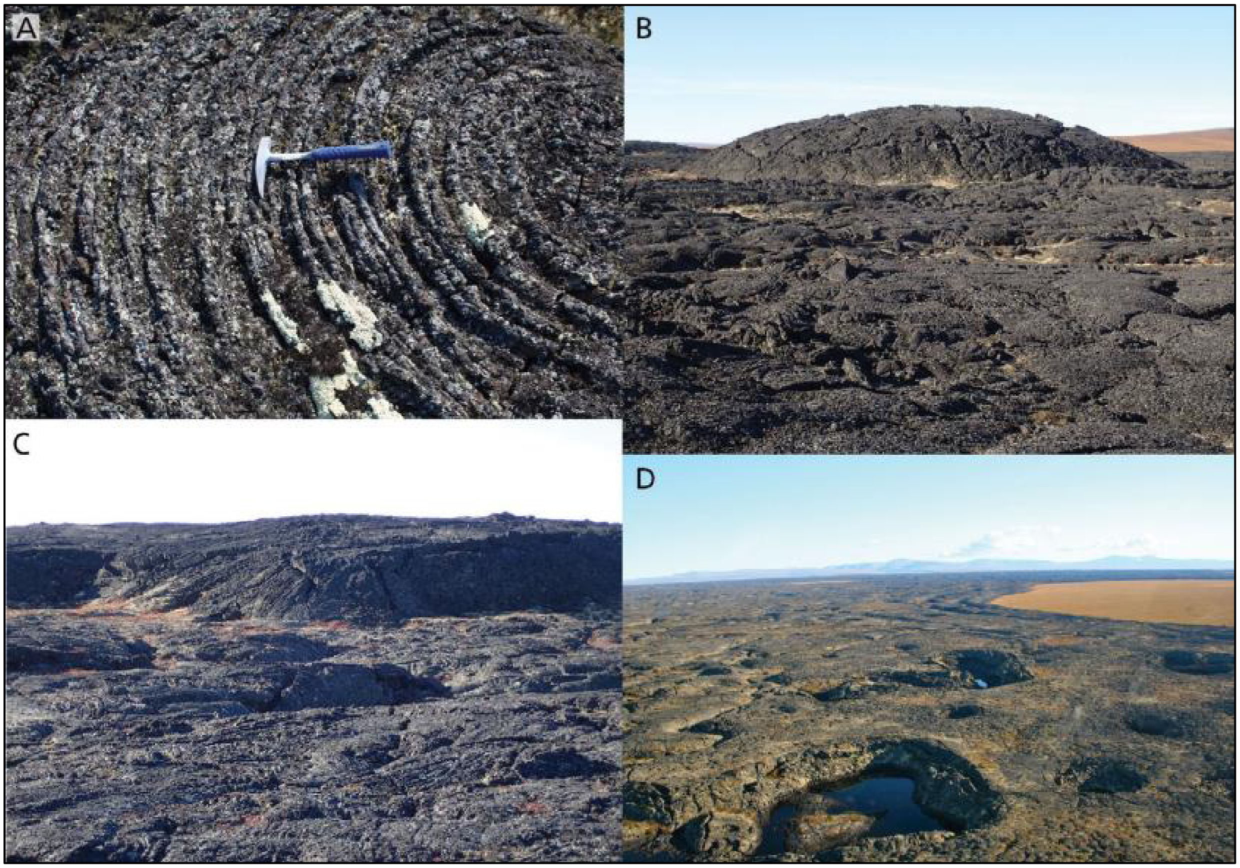


Figure 16. Photographs showing various features of the Lost Jim Basalt (NPS). **A.** Ropy surface texture typical of pāhoehoe lava. **B.** A tumulus about 70 m (230 ft) long and 10 m (33 ft) tall. **C.** Edge of a lava rise, a plateau-like feature similar to tumuli but over an extensive area. **D.** Lava flow collapse depressions.

Figure 17. Photograph of a tumulus that formed in the Lost Jim Basalt flow, BELA. Tumuli are common pāhoehoe features and form by injection of lava beneath a solidified crust, creating a domed structure (NPS/DAVID SWANSON).

Cape Krusenstern National Monument (CAKR)

Cape Krusenstern National Monument (CAKR) is located north of the Arctic Circle and approximately 64 km (40 mi) north of the Seward Peninsula in the Northwest Arctic Borough, Alaska (Figure 18). Proclaimed as a national monument on December 1, 1978, CAKR encompasses about 262,679 hectares (649,096 acres) and forms 113 km (70 mi) of shoreline on the Chukchi Sea (National Park Service 2016). The monument contains archeological sites located along a succession of 114 lateral beach ridges adjacent to Krusenstern Lagoon that record the cultural history of communities dating back 5,000 years (Giddings and Anderson 1986; National Park Service 2016). Sites on the bluff behind the ridges may date back as far as 9,000 years ago. The landscape of CAKR is composed of barrier islands, lagoons, wetlands, coastal plain, and beaches that provide habitat for fish, marine mammals, and migratory birds.

The bedrock geology of CAKR is predominantly composed of sedimentary formations associated with the Ordovician–Devonian Baird Group, Devonian–Mississippian Endicott Group, and the Mississippian–Pennsylvanian Lisburne Group (Figure 19). Rocks of the Baird Group are exposed in the southern half of CAKR, while strata of the Endicott and Lisburne Groups outcrop in the northern half of the monument. The youngest bedrock units in the monument are the Cretaceous Okpikruak and Fortress Mountain Formations located in east-central CAKR. Younger Cenozoic surficial deposits consist of Pleistocene terrace deposits, Pleistocene to Holocene alluvium, and Holocene beach deposits.

There are no designated stratotypes identified within the boundaries of CAKR. There are also no identified stratotypes located within 48 km (30 mi) of CAKR boundaries.

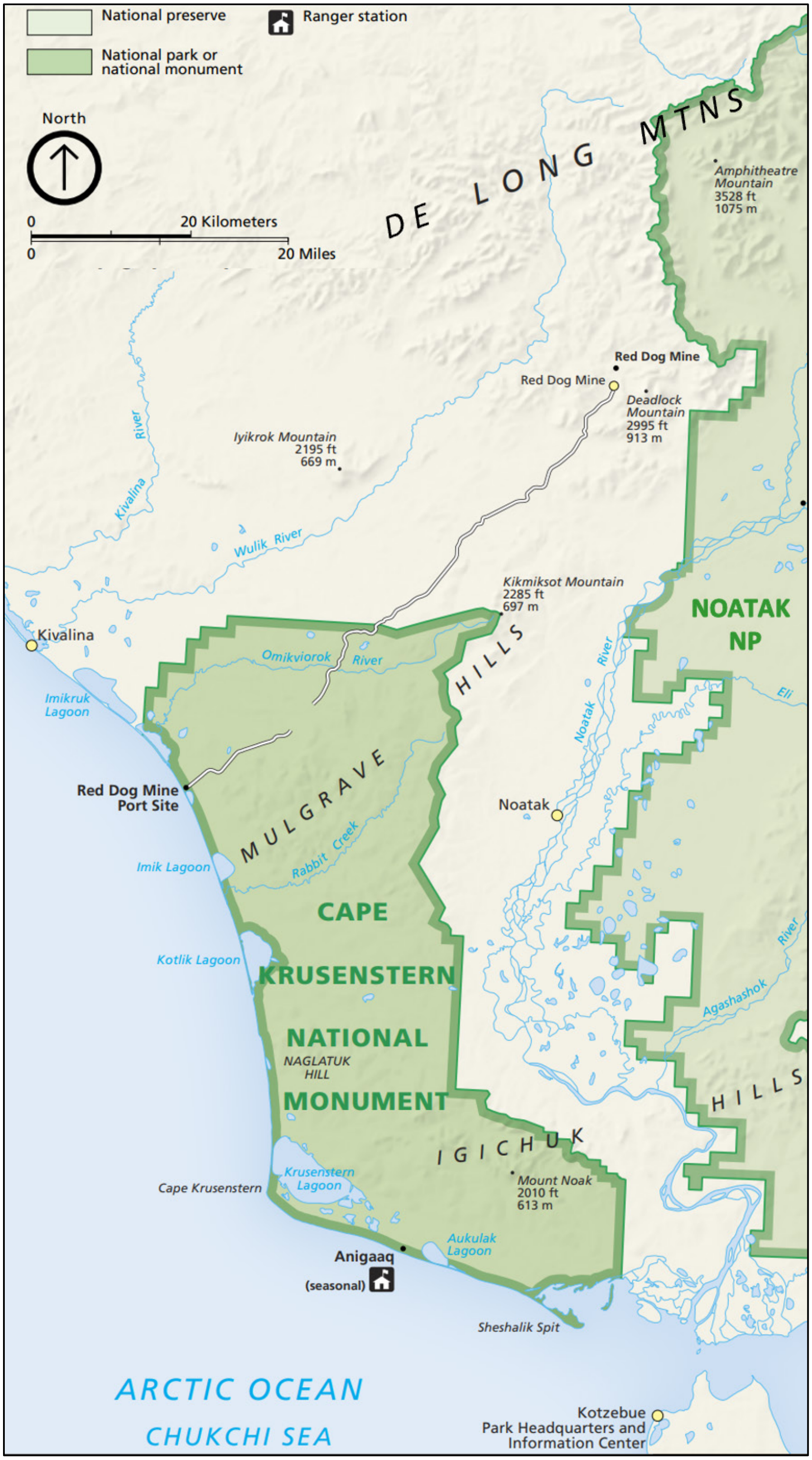


Figure 18. Park map of CAKR, Alaska (NPS).

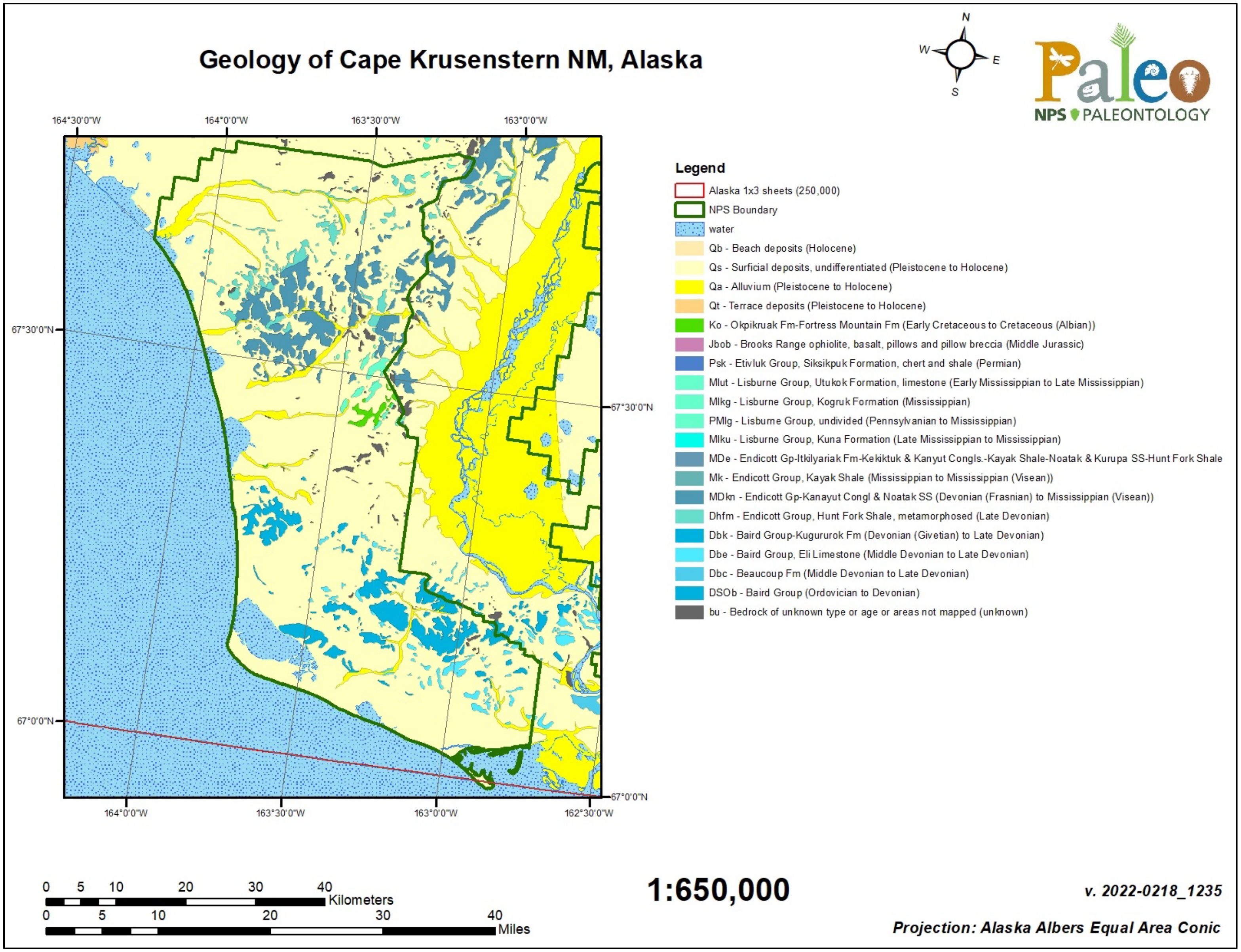


Figure 19. Geologic map of CAKR, Alaska.

Gates of the Arctic National Park and Preserve (GAAR)

Gates of the Arctic National Park and Preserve (GAAR) is located in the central Brooks Range north of the Arctic Circle in the North Slope Borough, Northwest Arctic Borough, and Yukon-Koyukuk Census Area of the Unorganized Borough, Alaska (Figure 20). Originally established as a national monument on December 1, 1978, the park unit was re-established as a national park and national preserve on December 2, 1980. Encompassing about 3,428,701 hectares (8,472,505 acres), GAAR contains a landscape characterized by jagged peaks, arctic valleys, wild rivers, and numerous lakes (National Park Service 2016). GAAR is managed to 1) maintain the wild and undeveloped character of the mountains, forelands, rivers, and lakes; 2) provide continued opportunities for mountain climbing, mountaineering, and other wilderness recreational activities; and 3) protect habitat for animal populations that include fish, birds, caribou, grizzly bears, Dall sheep, moose, and wolves. A portion of GAAR was designated a Biosphere Reserve in 1984.

The bedrock geology of northern GAAR is predominantly composed of sedimentary rocks of the Devonian–Mississippian Endicott Group, Mississippian–Pennsylvanian Lisburne Group, and Pennsylvanian–Triassic Etivluk Group (Figures 21 and 22). Younger Cretaceous units of the Fortress Mountain, Torok, and Okpikruak Formations are exposed in the northernmost area of the park. The southern portion of GAAR consists of a more complicated assemblage of pre-Mesozoic meta-sedimentary, meta-igneous, and igneous rocks. Some of the youngest units in the southernmost portion of GAAR include Jurassic and Cretaceous sedimentary and volcanic units of the Brookian and Koyukuk sequences. The landscape of GAAR has been heavily shaped by ice, as Pleistocene glaciers carved out sharp peaks, ridges, valleys, and lakes, leaving behind surficial glacial deposits.

GAAR contains 20 identified stratotypes that are subdivided into eight type sections, seven type localities, one type area, and four reference sections (Table 3; Figures 23–26). In addition to the designated stratotypes located within GAAR, stratotypes located within 48 km (30 mi) of GAAR boundaries include the Silurian–Devonian Skajit Limestone (type area); Mississippian Kurupa Sandstone (type locality) and Akmalik Chert (reference section); Pennsylvanian–Jurassic Etivluk Group (type locality) and Imnaitchiak Chert (type locality); Permian Siksikpuk Formation (type locality); Triassic–Jurassic Otuk Formation (type section and reference section); Jurassic Blankenship Member of the Otuk Formation (principal reference section and reference section); Jurassic–Cretaceous Okpikruak Formation (type section); and Cretaceous Nanushuk Formation (three reference sections), Chandler Formation (type locality), Tuktu Formation (type locality), and Torok Formation (type section).

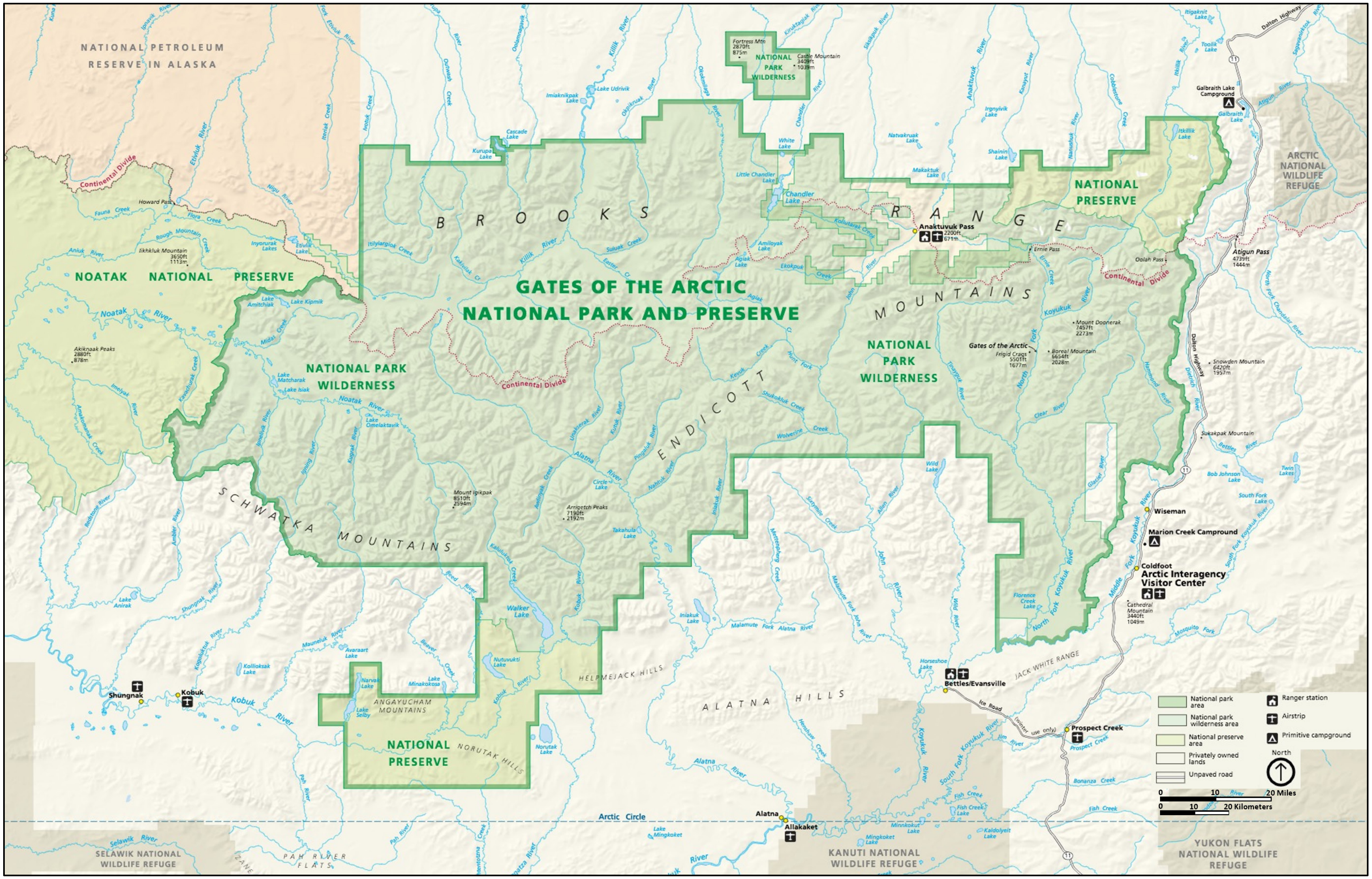


Figure 20. Park map of GAAR, Alaska (NPS).

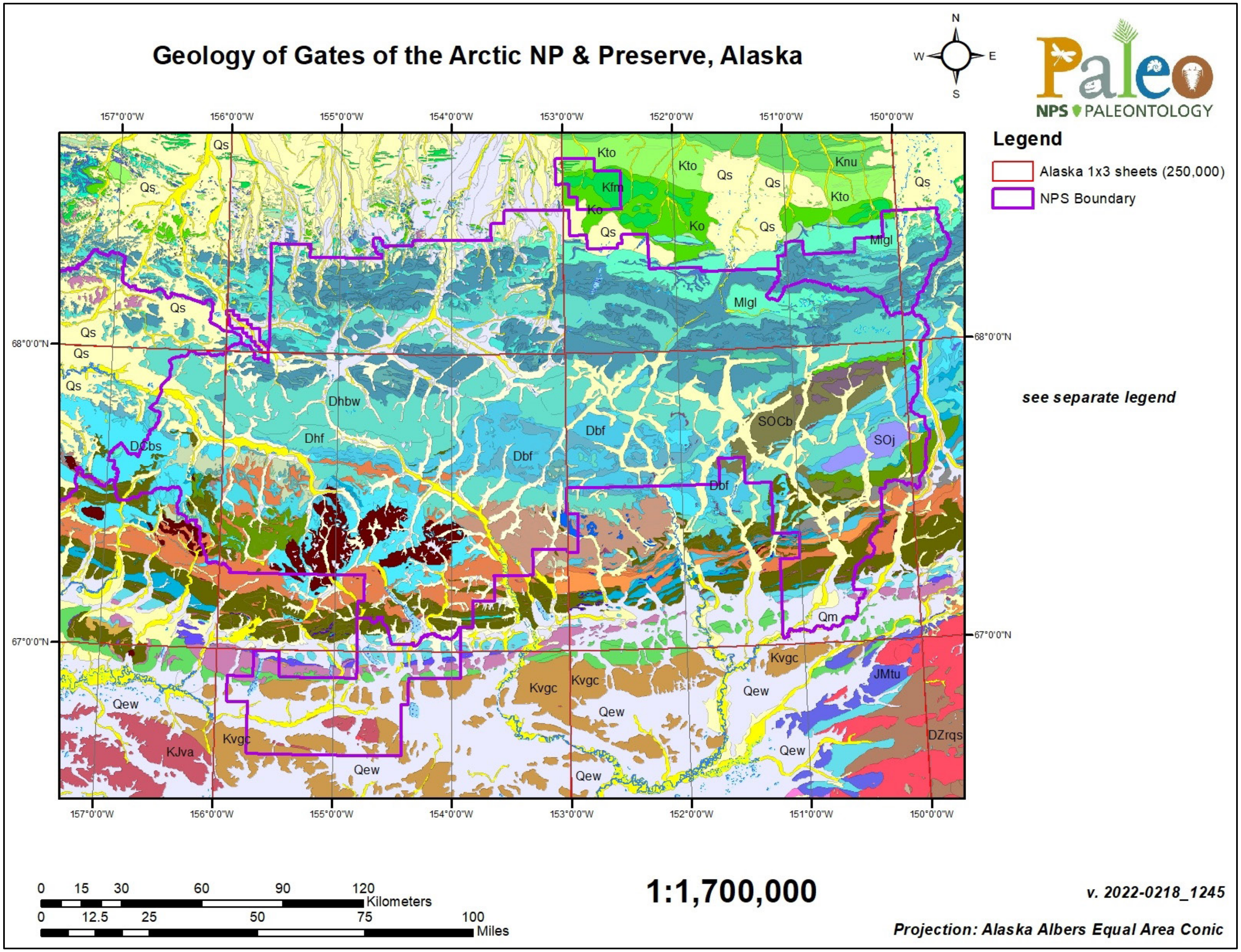


Figure 21. Geologic map of GAAR, Alaska; see Figure 22 for legend.

Figure 22. Geologic map legend of GAAR, Alaska.

Table 3. List of GAAR stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Fortress Mountain Formation (Kfm)	Patton 1956	Type section (composite): partial sections along Kiruktagiak River and on Castle Mountain, Chandler Lake Quadrangle, northern AK.	Early Cretaceous (Albian)
Otuk Formation, Etivluk Group (JTRrcs)	Mull et al. 1982	Principal reference section: Monotis Creek [in NE/4 sec. 29, T. 12 S., R. 4 W., western Chandler Lake Quadrangle], Endicott Mountains, AK.	Early Triassic (Olenekian)–Middle Jurassic (Bajocian)
Imnaitchiak Chert, Etivluk Group (TRPNic)	Mull et al. 1986	Reference section: on south side of hill along lower Akmalik Creek [in NE/4 sec. 27, T. 12 S., R. 10 W., Umiat Meridian], AK.	Pennsylvanian–Triassic
Kuna Formation, Lisburne Group (Mlku)	Mull et al. 1982	Reference section: exposures along Ekokpuk Creek [in SW/4 sec. 11, T. 16 S., R. 4 W., Umiat Meridian, Chandler Lake Quadrangle], eastern Endicott Mountains, AK.	Late Mississippian–Middle Pennsylvanian
Alapah Limestone, Lisburne Group (PNMl)	Bowsher and Dutro 1957	Type section (composite): 1) along ridge top of Sugarloaf Hill, west slope of Mount Wachsmuth; and 2) at west end of North Ridge, Mount Wachsmuth, central Brooks Range, AK. Type locality: on northern part of Mount Wachsmuth, Shainin Lake area, central Brooks Range, AK.	Middle–Late Mississippian
Wachsmuth Formation, Lisburne Group (Mlw)	Bowsher and Dutro 1957	Type section (composite): 1) south face of Mount Wachsmuth, 2) along west slope of Mount Wachsmuth and up the south face of Sugarloaf Hill, central Brooks Range, northern AK. Type locality: Mount Wachsmuth, AK.	Early–Late Mississippian
Akmalik Chert, Lisburne Group (PMlc)	Mull et al. 1986	Type locality: canyon of Akmalik Creek about 3 km (2 mi) southwest of Kikiktat Mountain [in sec. 30, T. 12 S., R. 10 W., Umiat Meridian, Killik River Quadrangle], central Brooks Range, northern AK.	Early–Late Mississippian (middle Osagean–probably late Meramecian)
Kayak Shale, Endicott Group (Mk)	Bowsher and Dutro 1957	Type section: in saddle on south side of Mount Wachsmuth, about 2.9 km (1.8 mi) east of Shainin Lake camp at latitude 68°19′19″ N., longitude 150°54′29″ W. (approximate), AK. Type locality: near the foot of the south slope of Mount Wachsmuth, AK.	Early Mississippian (Visean)

Table 3 (continued). List of GAAR stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Kurupa Sandstone, Endicott Group (Mks)	Mull et al. 1986	Reference section: exposures in canyon of Akmalik Creek, 3 km (2 mi) southwest of Kikiktat Mountain [in sec. 30, T. 12 S., R. 10 W., Umiat Meridian, Killik River Quadrangle], north-central AK.	Early Mississippian
Stuver Member, Kanayut Conglomerate, Endicott Group (MDkys)	Bowsher and Dutro 1957; Nilsen and Moore 1984	Type section: located about 1 km (0.6 mi) south-southeast of Mount Wachsmuth [sec. 16, T. 13 S., R. 5 E.] on a ridge about 2.9 km (1.8 mi) east of the camp on Shainin Lake, central Brooks Range, northern AK. Type locality: on the ridge 1.1 km (0.7 mi) south of Mount Wachsmuth, AK.	Late Devonian–Early(?) Mississippian
Shainin Lake Member, Kanayut Conglomerate, Endicott Group (Dkym)	Nilsen and Moore 1984	Type section: prominent cliff directly south of confluence of Kayak and Alapah Creeks, about 8 km (5 mi) south-southeast of Shainin Lake [in sec. 4, T. 14 S., R. 5 E., Umiat Meridian, Chandler Lake Quadrangle], northern AK.	Late Devonian
Ear Peak Member, Kanayut Conglomerate, Endicott Group (Dkyl)	Nilsen and Moore 1984	Type section: along ridge 1.8 km (1.1 mi) southeast of Ear Peak [in secs. 13 and 24, T. 13 S., R. 5 E., and in sec. 18, T. 13 S., R. 6 E., Umiat Meridian, Chandler Lake Quadrangle], northern AK.	Late Devonian
Kanayut Conglomerate, Endicott Group (MDky)	Bowsher and Dutro 1957	Type section (composite): 1) section along the east side of Alapah Creek about 11.4 km (7.1 mi) S. 30° E. of the camp on Shainin Lake; 2) 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 3) ridge section about 2.9 km (1.8 mi) miles east of the camp on Shainin Lake. Type locality: exposures on ridge east of Alapah Creek, south of Mount Wachsmuth, Shainin Lake area, central Brooks Range, AK.	Late Devonian (Frasnian)–Early Mississippian (Tournaisian)
Hunt Fork Shale, Endicott Group (Dhf)	Chapman et al. 1964	Type locality: exposures 40 km (25 mi) east of Killik River, along Fire Creek, east-flowing tributary of Okokmilaga River, central Brooks Range, AK.	Late Devonian (Frasnian–Famennian)
Endicott Group (MDe)	Tailleur et al. 1967	Type area: exposures in Endicott Mountains, central Brooks Range, northern AK.	Late Devonian–early Permian

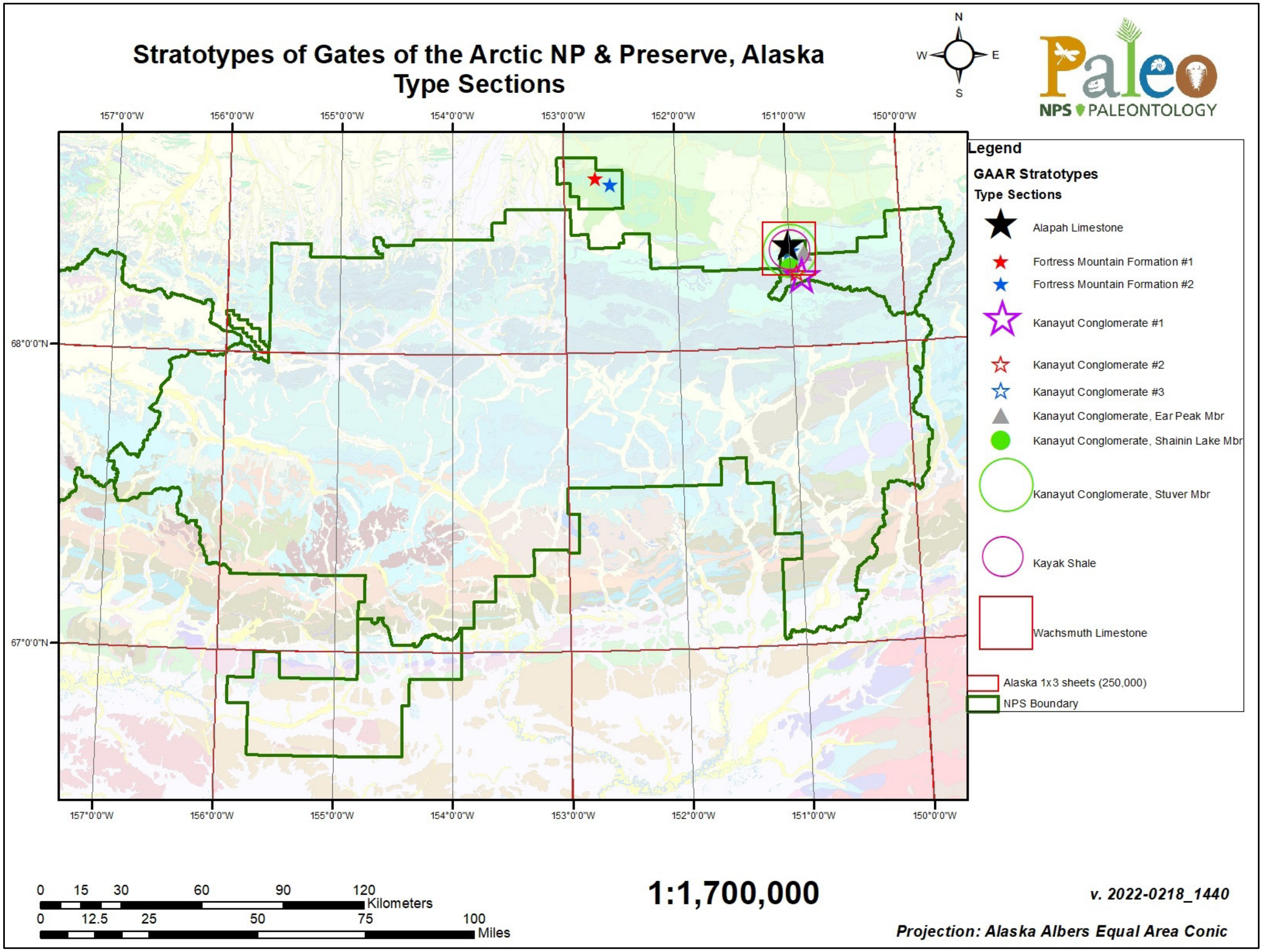


Figure 23. Modified geologic map of GAAR showing type section locations. The transparency of the geologic units layer has been increased.

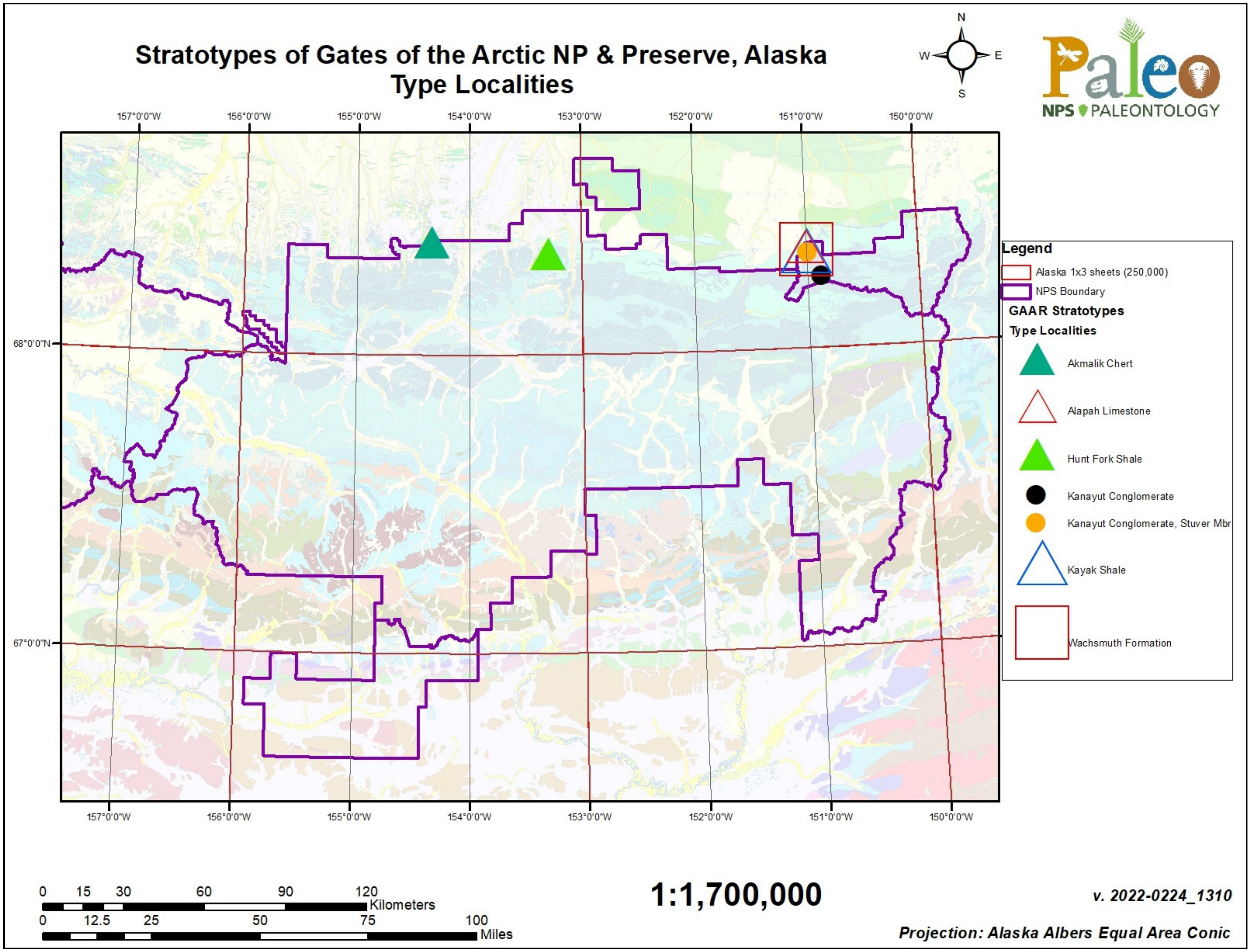


Figure 24. Modified geologic map of GAAR showing type locality locations. The transparency of the geologic units layer has been increased.

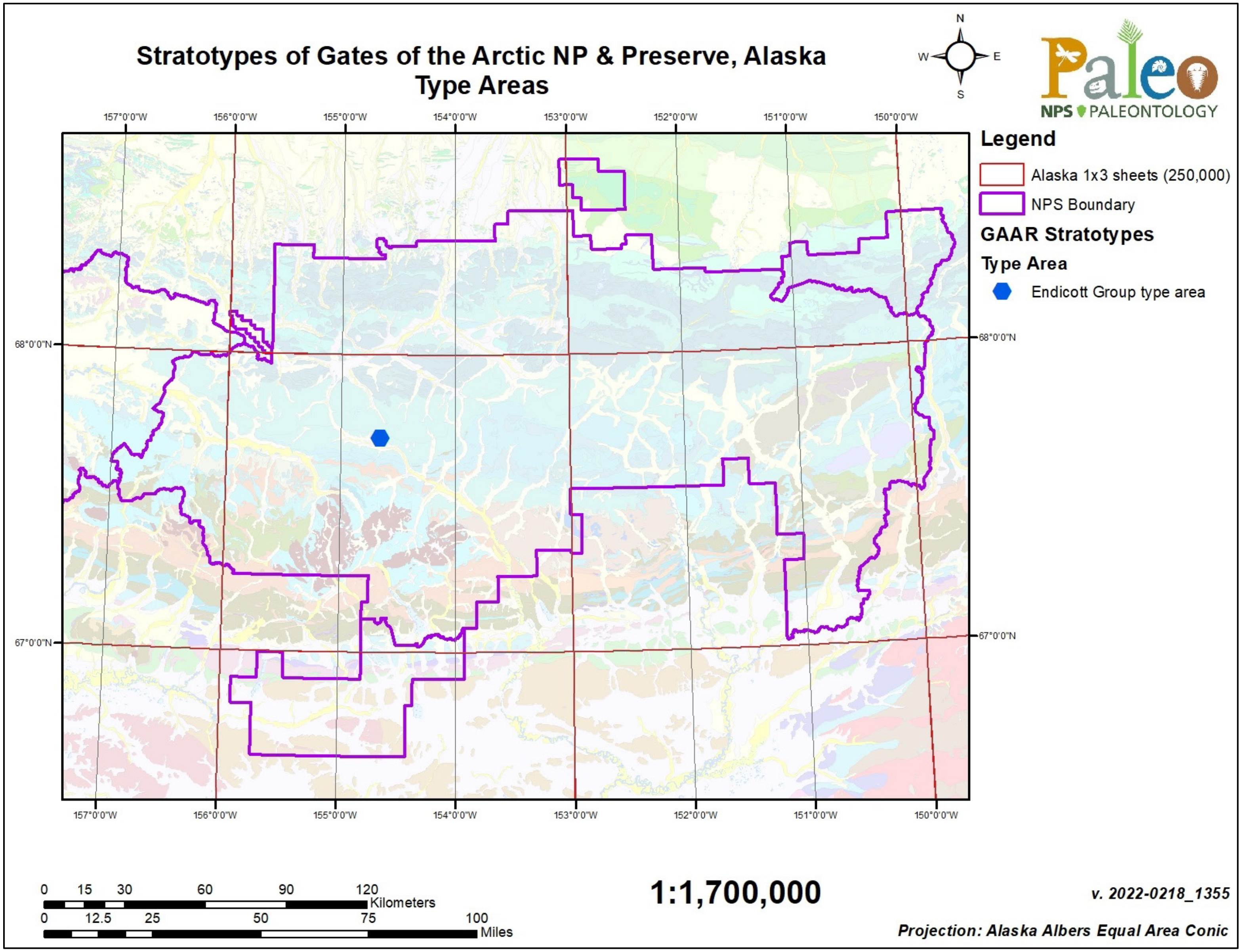


Figure 25. Modified geologic map of GAAR showing type area locations. The transparency of the geologic units layer has been increased.

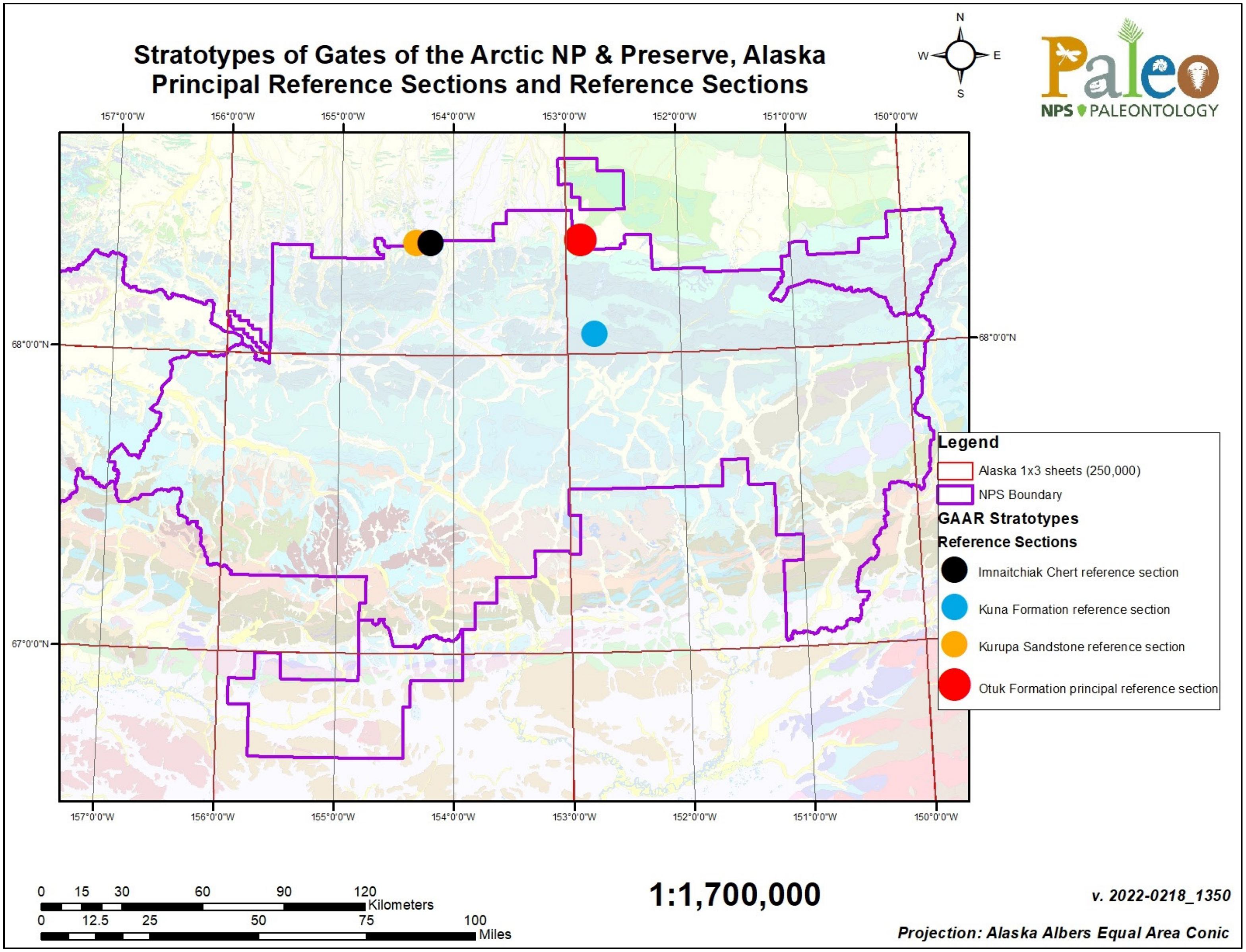


Figure 26. Modified geologic map of GAAR showing reference section locations. The transparency of the geologic units layer has been increased.

Endicott Group

The Late Devonian–early Permian Endicott Group was named by Tailleur et al. (1967) for a thick succession of sedimentary rocks in the type area in the Endicott Mountains of the central Brooks Range, Alaska (Table 3; Figure 25). Thickness of the group ranges from 2,000–4,400 m (6,560–14,430 ft) and consists of shale (or mudstone), sandstone, and conglomerate (Tailleur et al. 1967). The group is composed of (ascending): Hunt Fork Shale, Noatak Sandstone, Kanayut Conglomerate, Kurupa Sandstone, Kayak Shale, Kekiktuk Conglomerate, and Itkilyariak Formation (Tailleur et al. 1967; Mull and Mangus 1972; Mull et al. 1987). Strata of the Endicott Group overlie the Baird Group and underlie the Lisburne Group.

Hunt Fork Shale

The Late Devonian Hunt Fork Shale of the Endicott Group was proposed by Chapman et al. (1964) to describe a well-defined, thick sequence of shale in the central Brooks Range. The type locality is designated 40 km (25 mi) east of the Killik River at latitude 68°18′ N. and longitude 153°20′ W., along Fire Creek, an east-flowing tributary of the Okokmilaga River (Table 3; Figure 24; Chapman et al. 1964). Type locality exposures are about 975 m (3,200 ft) thick and predominantly consist of dark gray shale, locally metamorphosed to slate, with minor amounts of interbedded grayish-green sandstone and siltstone (Chapman et al. 1964). At the type locality the Hunt Fork Shale underlies the Kanayut Conglomerate and overlies Middle Devonian meta-sedimentary rocks of the central Brooks Range (Chapman et al. 1964).

Kanayut Conglomerate

The Late Devonian–Early Mississippian Kanayut Conglomerate of the Endicott Group was named by Bowsher and Dutro (1957) after the Kanayut River in the Shainin Lake area, Alaska. The type locality of the formation is located on the ridge south of Mount Wachsmuth, where exposures are about 1,006 m (3,300 ft) thick and consist of light- to dark-gray chert-pebble conglomerate, dark-gray sandstone, and gray, red, and green shale (Table 3; Figures 24, 27, and 28; Bowsher and Dutro 1957). A composite type section of the unit is as follows: 1) section along the east side of Alapah Creek about 11.4 km (7.1 mi) S. 30° E. of the camp on Shainin Lake; 2) 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 3) ridge section about 2.9 km (1.8 mi) east of the camp on Shainin Lake (Table 3; Figure 23; Bowsher and Dutro 1957). The formation unconformably underlies the Kayak Shale and overlies the Noatak Sandstone (Bowsher and Dutro 1957; Nilsen and Moore 1984).

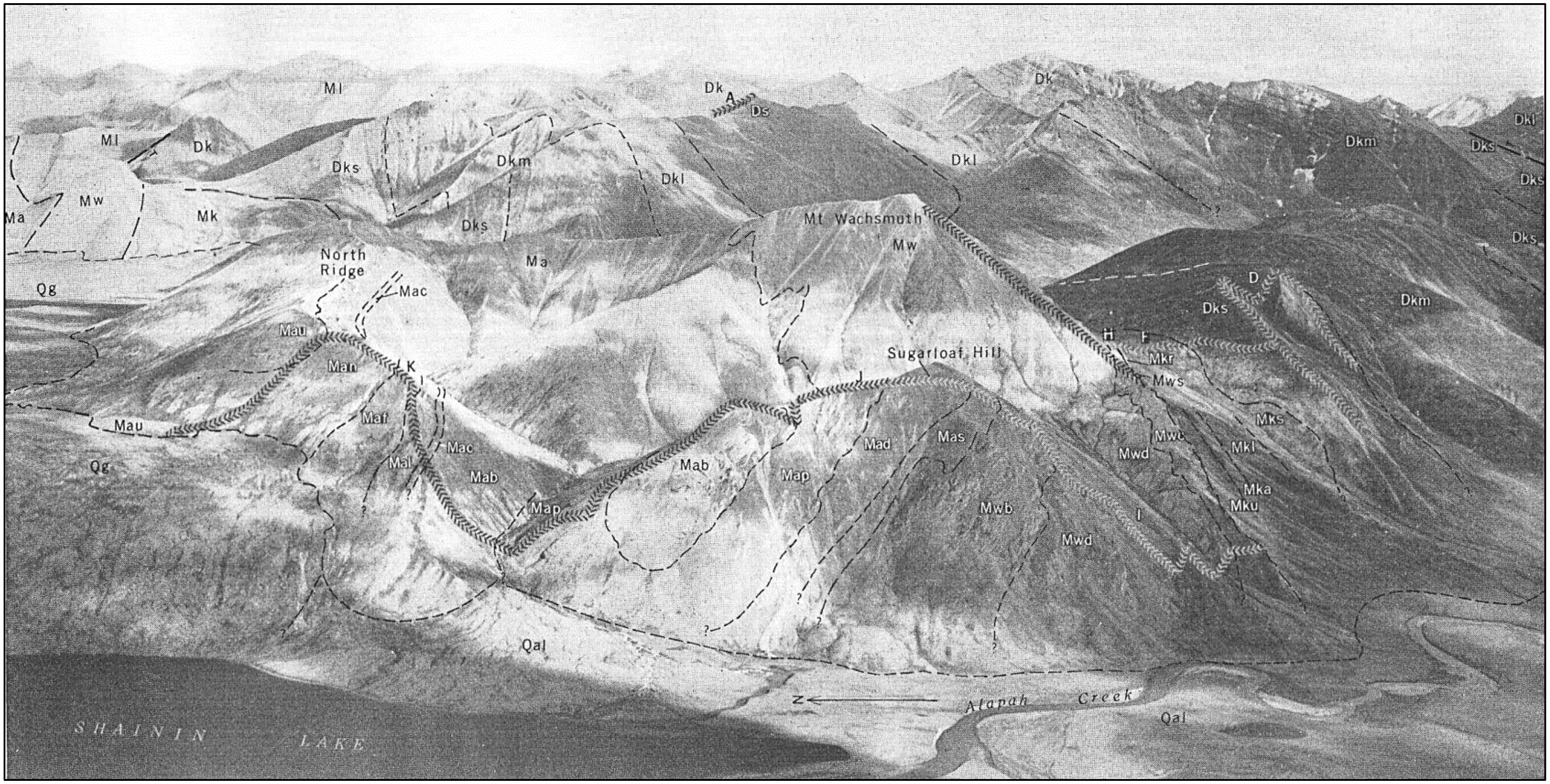


Figure 27. Aerial photograph looking east at Mount Wachsmuth, including the southeast corner of Shainin Lake, Alapah Creek, Sugarloaf Hill, and North Ridge. Type sections of the Kanayut Conglomerate, Kayak Shale, Wachsmuth Limestone, and Alapah Limestone are measured along the chevron lines and represent sections A, D, F, H, I, J, and K in Bowsher and Dutro (1957). Heavy dashed lines are boundaries of formations and thrust faults (T). Light dashed lines are boundaries of members. Ds, Unnamed Devonian shale. Dk, Kanayut Conglomerate, undivided; Dkl, Ear Peak Member; Dkm, Shainin Lake Member; Dks, Stuver Member. Mk, Kayak Shale, undivided; Mkl, lower black shale member; Mka, argillaceous limestone member; Mku, upper black shale member; Mkr, red limestone member. Ml, Lisburne Group, undivided. Mw, Wachsmuth Limestone, undivided; Mws, shaly limestone member; Mwc, crinoidal limestone member Mwd, dolomite member; Mwb, banded chert-limestone member. Ma, Alapah Limestone; Mas, shaly limestone member; Mad, dark limestone member; Map, platy limestone member; Mab, banded limestone member; Mac, black chert-shale member; Mal, light-gray limestone member; Maf, fine-grained limestone member; Man, chert-nodule member; Mau, upper limestone member. Qs, high-level gravels. Qal, alluvium. Plate 1 in Bowsher and Dutro (1957).

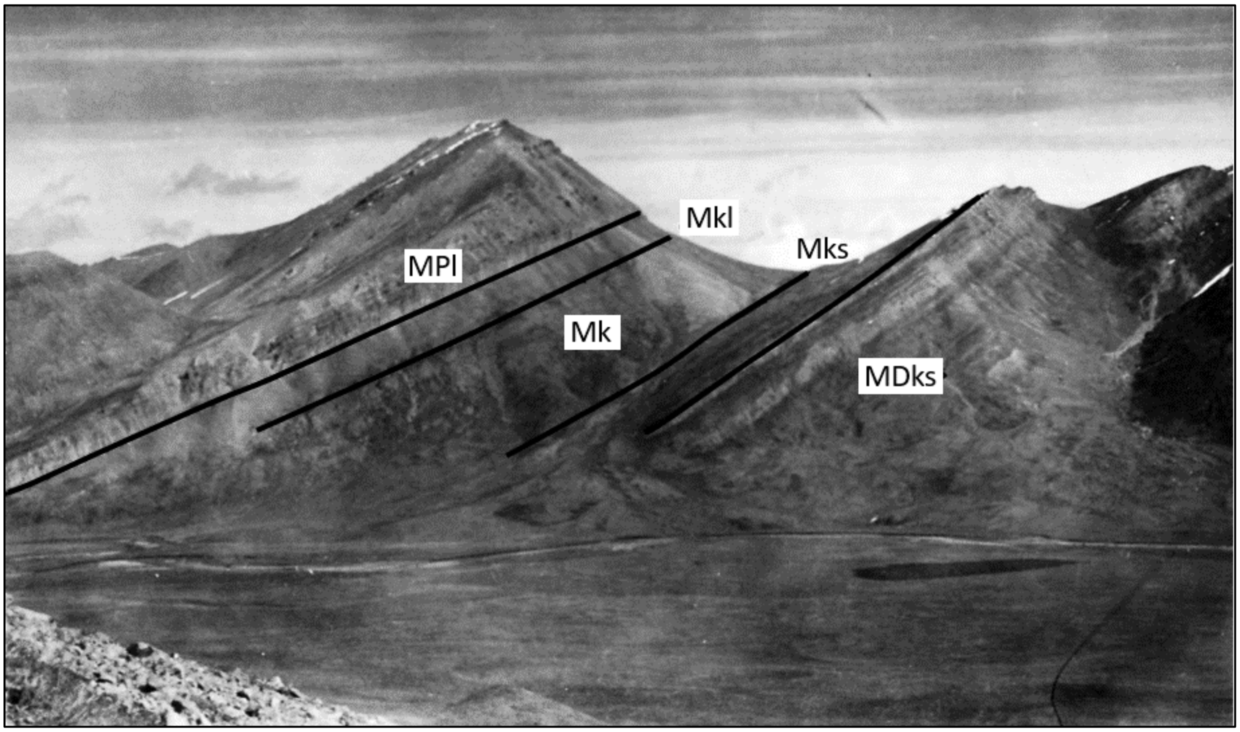


Figure 28. East wall of Kanayut Valley, type sections of both the Kayak Formation and Kanayut Conglomerate. MPl, Lisburne Group; Mkl, limestone member of Kayak Formation; Mk, lower black shale member of Kayak Formation; Mks, basal sandstone member of Kayak Formation; MDks, Stuver Member of Kanayut Conglomerate. Modified Plate 5 from Dutro (1952).

Ear Peak Member, Kanayut Conglomerate

The Late Devonian Ear Peak Member is the lowermost member of the Kanayut Conglomerate and was first proposed by Nilsen and Moore (1984). The member is named after its type section designation along the southernmost spur of an east-facing ridge 1.8 km (1.2 mi) southeast of Ear Peak [secs. 13 and 24, T. 13 S., R. 5 E., and in sec. 18, T. 13 S., R. 6 E.], in the Chandler Lake Quadrangle, Alaska (Table 3; Figures 23 and 29; Nilsen and Moore 1984). The type section measures about 512 m (1,680 ft) thick and is composed of fluvial conglomerate, conglomeratic sandstone, trough-cross-stratified sandstone, and ripple-marked siltstone and shale that conformably overlie the Hunt Fork Shale and underlie the Shainin Lake Member of the Kanayut Conglomerate (Nilsen and Moore 1984). The type section consists of 35 major fining-upward stream-channel sequences that average about 15 m (49 ft) in thickness (Nilsen and Moore 1984).

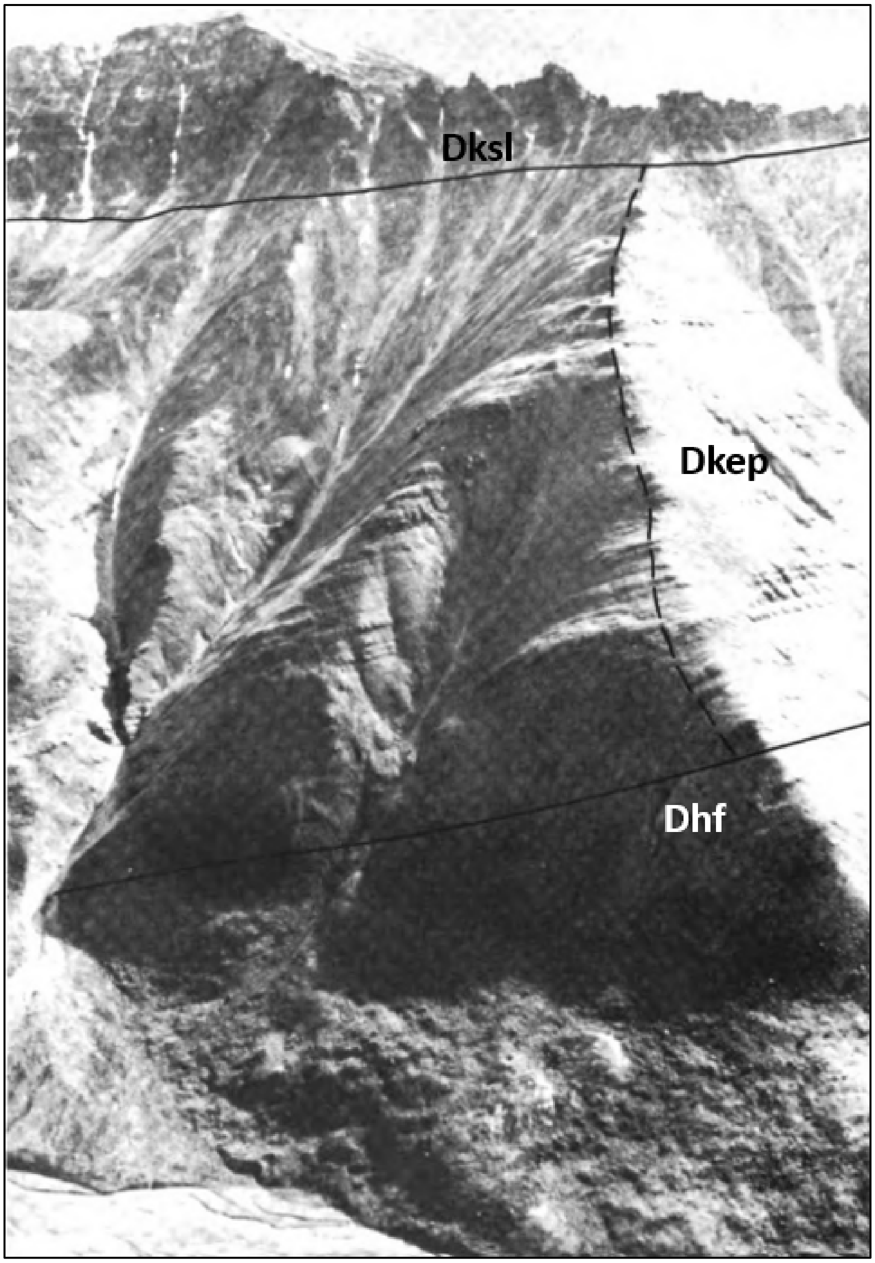


Figure 29. Westward view of the measured type section of the Ear Peak Member of the Kanayut Conglomerate at Ear Peak. Type section measured along the dotted line. Dhf, Hunt Fork Shale; Dkep, Ear Peak Member; Dksl, Shainin Lake Member. Modified Figure 10 from Nilsen and Moore (1984).

Shainin Lake Member, Kanayut Conglomerate

The Late Devonian Shainin Lake Member of the Kanayut Conglomerate was named by Nilsen and Moore (1984) for exposures several kilometers or miles south of Shainin Lake, Alaska. The type section of the unit was measured on the prominent cliff directly south of the confluence of Kayak and Alapah Creeks, about 8 km (5 mi) south-southeast of Shainin Lake [in sec. 4, T. 14 S., R. 5 E.] in the Chandler Lake Quadrangle (Table 3; Figures 23 and 30; Nilsen and Moore 1984). The type section is about 526 m (1,725 ft) thick and consists of massive conglomerate, parallel-stratified conglomeratic sandstone, and medium- to coarse-grained, trough-cross-stratified sandstone with minor intervals of shale (Nilsen and Moore 1984). The Shainin Lake Member conformably occurs between the overlying Stuver Member and underlying Ear Peak Member of the Kanayut Conglomerate.

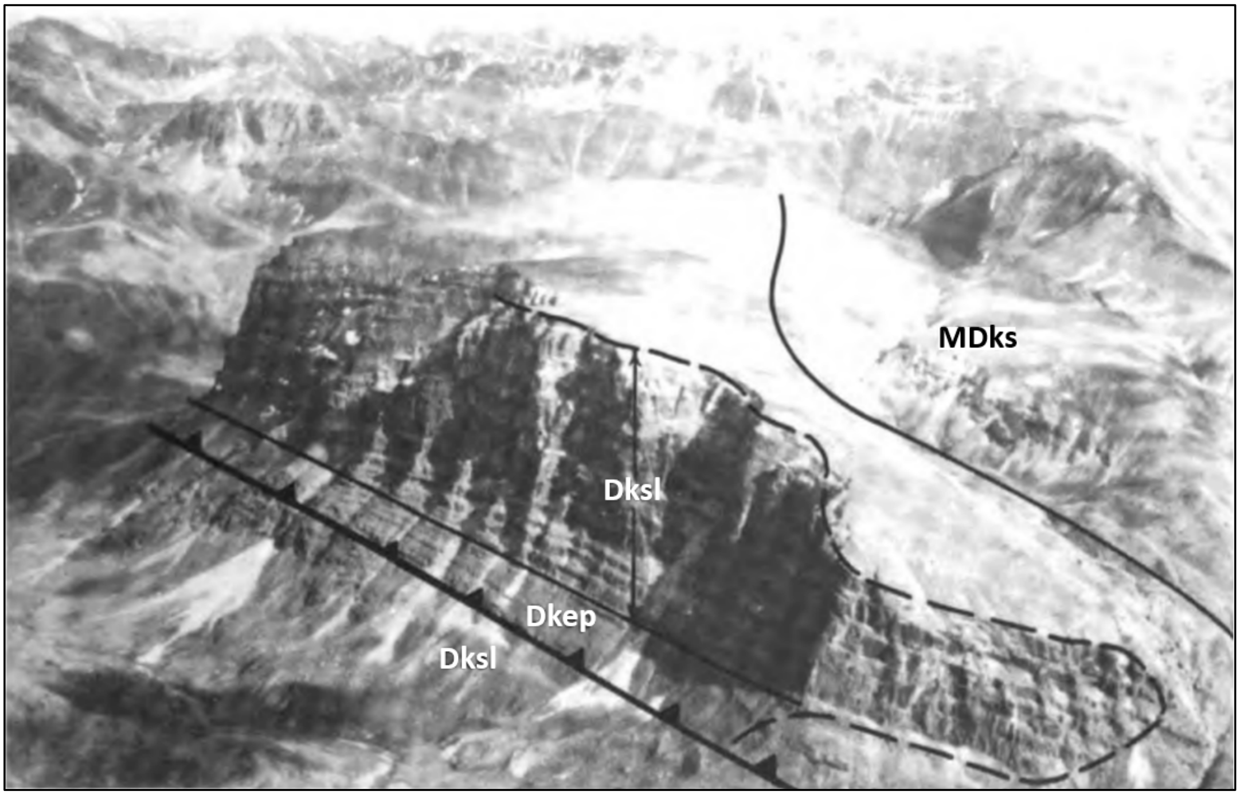


Figure 30. Type section cliff exposure of the Shainin Lake Member of the Kanayut Conglomerate located south of Shainin Lake. View is looking southeast. Barbed line denotes location of thrust fault. Type section measured along the dashed line. Dkep, Ear Peak Member; Dksl, Shainin Lake Member; MDks, Stuver Member. Modified Figure 12 from Nilsen and Moore (1984).

Stuver Member, Kanayut Conglomerate

The Late Devonian–Early Mississippian Stuver Member of the Kanayut Conglomerate was first described as the Stuver series by Schrader (1902) before it was redesignated and redefined by Bowsher and Dutro (1957). Schrader (1902) derived the name from Mount Stuver, Alaska (approximate latitude 68°12′ N., longitude 151°91′ W.). The type section of the Stuver Member is located about 1 km (0.6 mi) south-southeast of Mount Wachsmuth [sec. 16, T. 13 S., R. 5 E.] on a ridge about 2.9 km (1.8 mi) east of the camp on Shainin Lake in the central Brooks Range (Table 3; Figures 23 and 31; Bowsher and Dutro 1957; Nilsen and Moore 1984). The type section measures 262 m (860 ft) thick and consists of gray sandstone, light-gray conglomerate, and gray, red, and green shale that unconformably underlie the Kayak Shale and conformably overlie the Shainin Lake Member of the Kanayut Conglomerate (Bowsher and Dutro 1957; Nilsen and Moore 1984).

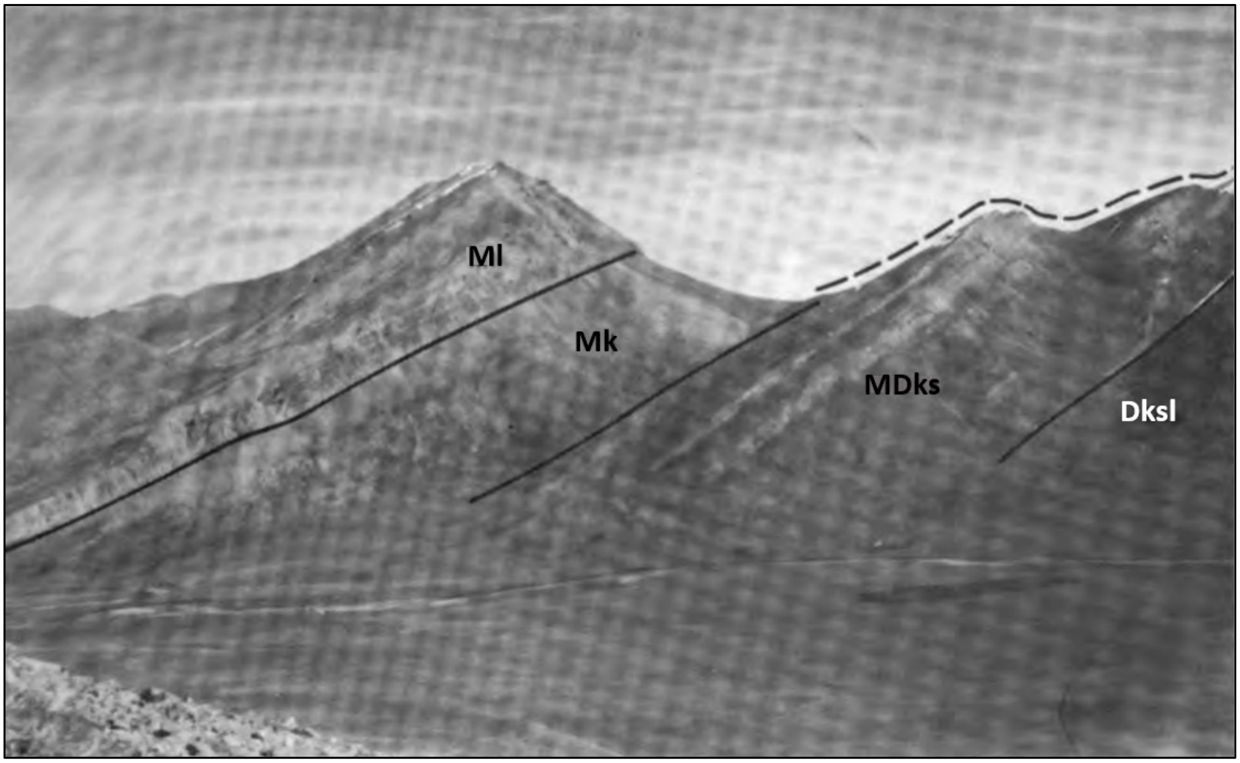


Figure 31. Type section of the Stuver Member of the Kanayut Conglomerate along a ridge southeast of Shainin Lake. View is looking westward. Type section measured along the dashed line. Dksl, Shainin Lake Member; MDks, Stuver Member; Mk, Kayak Shale; Ml, Lisburne Group. Modified Figure 14 from Nilsen and Moore (1984).

Kurupa Sandstone

The Early Mississippian Kurupa Sandstone of the Endicott Group was named by Mull et al. (1986) for exposures that form a number of imbricate thrust sheets in the Kurupa Hills, about 8 km (5 mi) west of Kurupa Lake in the central Killik River Quadrangle. A reference section of the unit is located in GAAR along the eastern canyon of Akmalik Creek, approximately 3 km (2 mi) southwest of Kikiktat Mountain [sec. 30, T. 12 S., R. 10 W., Umiat Meridian] (Table 3; Figures 23, 32, and 33; Mull et al. 1986, 1987). Exposures of the formation have an average thickness of about 40 m (130 ft) and consist of thin- to medium-bedded sandstone intervals with shale interbeds that are predominantly turbidites (Mull et al. 1986). The Kurupa Sandstone is underlain by the Hunt Fork Shale and overlain by the Kayak Shale.

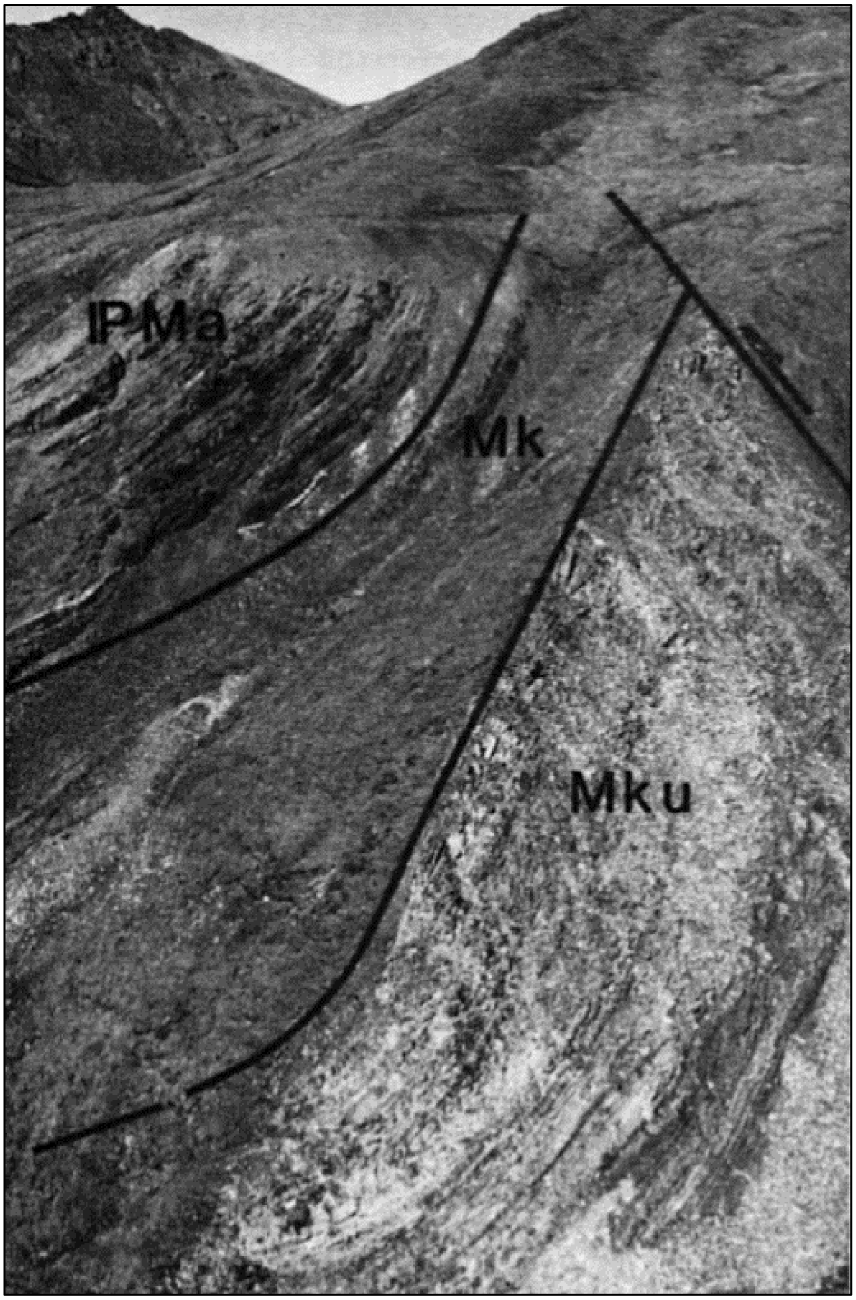


Figure 32. Kurupa Sandstone reference section and overlying Kayak Shale and Akmalik Chert on the east side of Akmalik Creek canyon. Mku, Kurupa Sandstone; Mk, Kayak Shale; IPMa, Akmalik Chert (type section). Canyon wall is about 75 m (250 ft) high. Figure 9 from Mull et al. (1987). Reproduced with permission from Pacific Section SEPM (Society for Sedimentary Geology).

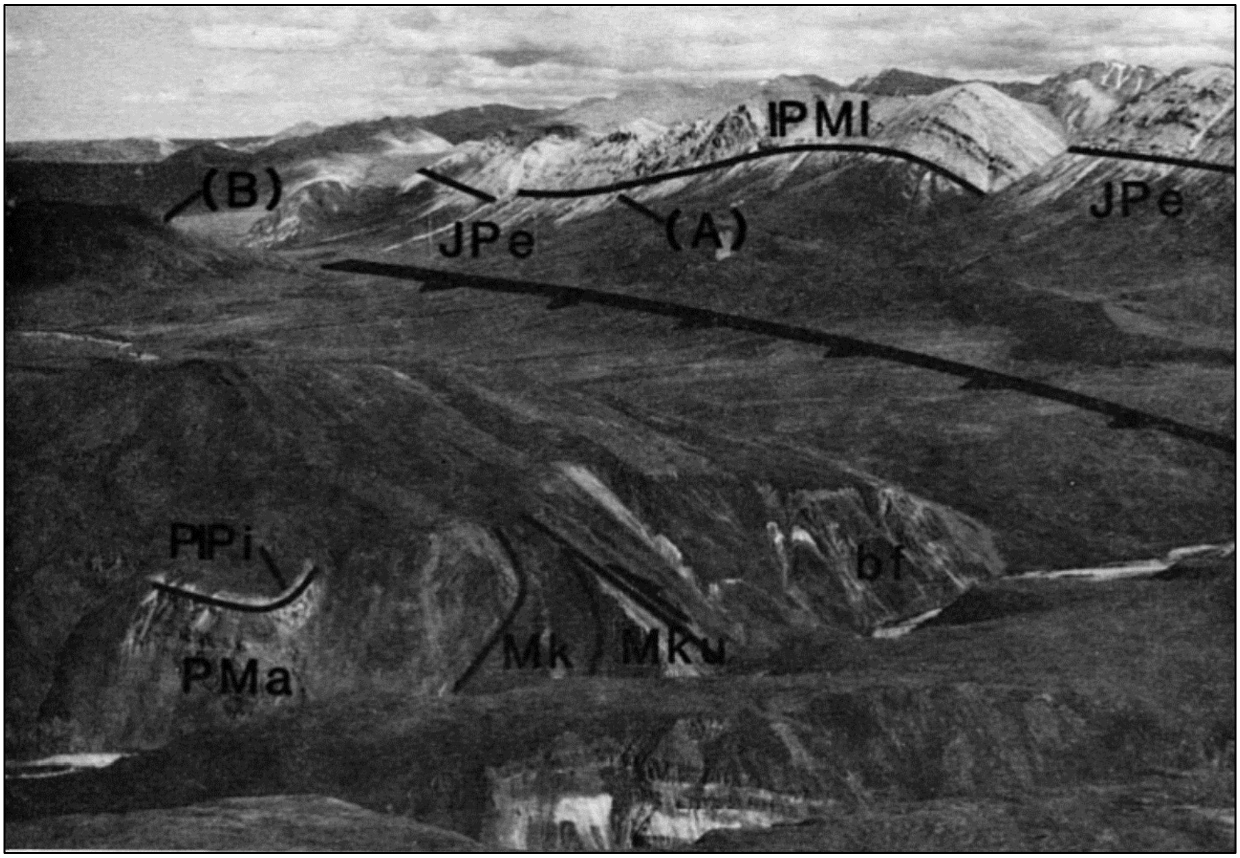


Figure 33. View southeast to Akmalik Creek canyon and Endicott Mountains front. Approximate trace of thrust zone represented by thick solid line. IPMa, Akmalik Chert (type section); PIPi, Imnaitchiak Chert; Mk, Kayak Shale; Mku, Kurupa Sandstone (reference section); bf, broken formation; IPMl, Lisburne Group; JPe, Etivluk Group (Siksikpuk Formation and Otuk Formation). Measured section of Lisburne Group and Etivluk Group is at (A). Imnaitchiak Chert reference section is on the shoulder of the hill at (B). Figure 8 from Mull et al. (1987). Reproduced with permission from Pacific Section SEPM (Society for Sedimentary Geology).

Kayak Shale

The Early Mississippian Kayak Shale of the Endicott Group was proposed by Bowsher and Dutro (1957) and named after Kayak Creek, which joins Alapah Creek south of Shainin Lake, Alaska. Bowsher and Dutro (1957) designated the type locality on the south slope of Mount Wachsmuth, where the formation consists of five informal members (Table 3; Figure 24). The type section is located in a saddle on the south side of Mount Wachsmuth about 2.9 km (1.8 mi) east of the Shainin Lake camp [approximate latitude 68°19′19″ N., longitude 150°54′29″ W.] and measures about 292 m (960 ft) thick (Table 3; Figures 23, 27, and 28; Bowsher and Dutro 1957). At the type section, the informal members include (in ascending order): 1) reddish-brown to gray, fine-grained sandstone 40 m (130 ft) thick; 2) lower black fissile shale 181 m (595 ft) thick; 3) argillaceous limestone 24 m (80 ft) thick; 4) upper black fissile shale 42 m (140 ft) thick; and 5) red limestone 3–5 m (10–15 ft) thick (Bowsher and Dutro 1957). The Kayak Shale type section unconformably occurs between the overlying Wachsmuth Limestone and underlying Stuver Member of the Kanayut Conglomerate.

Akmalik Chert

The Early–Late Mississippian Akmalik Chert of the Lisburne Group was named by Mull et al. (1985, 1986) after its type locality exposures in the canyon of Akmalik Creek about 3 km (2 mi) southwest of Kikiktat Mountain [in sec. 30, T. 12 S., R. 10 W., Umiat Meridian] in the Killik River Quadrangle, central Brooks Range, Alaska (Table 3; Figures 24, 33, and 34). The formation ranges in thickness from 70–79 m (230–260 ft) and consists almost entirely of bedded black chert with minor amounts of black mudstone and interbedded black shale (Mull et al. 1986). At the type locality, the chert is situated in a shallow east–west trending syncline that crosses the canyon about 91 m (300 ft) downstream from the resistant Kurupa Sandstone (Mull et al. 1986). The Akmalik Chert underlies the Imnaitchiak Chert and overlies the Kayak Shale.

Figure 34. Akmalik Chert type section exposure on the east side of Akmalik Creek Canyon. Note thin white weathering limestone bed near the base of the section. Light weathering interval near the top of the bluff is basal Imnaitchiak Chert. Height of bluff is about 75 m (250 ft). Figure 13 from Mull et al. (1987). Reproduced with permission from Pacific Section SEPM (Society for Sedimentary Geology).

Wachsmuth Limestone

The Early–Late Mississippian Wachsmuth Limestone of the Lisburne Group was proposed by Bowsher and Dutro (1957) and named after its type locality exposures at Mount Wachsmuth, Alaska (Table 3; Figure 24). At the type locality the formation is divided into four informal members consisting of (in ascending order) shaly limestone, crinoidal limestone, dolomite, and banded chert-limestone (Figure 27; Bowsher and Dutro 1957). Bowsher and Dutro (1957) designated a composite type section at the following locations: 1) the south face of Mount Wachsmuth; and 2) along the west slope of Mount Wachsmuth and up the south face of Sugarloaf Hill (Table 3; Figures 23 and 27). Total thickness of the composite type section is 375 m (1,230 ft). The type section of the Wachsmuth Limestone disconformably occurs between the overlying Alapah Limestone and underlying Kayak Shale.

Alapah Limestone

The Middle–Late Mississippian Alapah Limestone of the Lisburne Group was named by Bowsher and Dutro (1957) to describe a sequence of shale, chert, and limestone overlying the Wachsmuth Limestone near Alapah Creek, which flows into southern Shainin Lake, Alaska. The type locality of the Alapah Limestone is located on the northern part of Mount Wachsmuth in the central Brooks Range (Table 3; Figure 24; Bowsher and Dutro 1957). A composite type section of the formation measures about 295 m (970 ft) thick and is located at the following: 1) along the ridge top of Sugarloaf Hill, west slope of Mount Wachsmuth; and 2) at west end of North Ridge of Mount Wachsmuth in the central Brooks Range (Table 3; Figures 23 and 27; Bowsher and Dutro 1957). The Alapah Limestone disconformably overlies the Wachsmuth Limestone and underlies the Siksikpuk Formation.

Kuna Formation

The Late Mississippian–Middle Pennsylvanian Kuna Formation of the Lisburne Group was named by Mull et al. (1982) after exposures in the Kuna River valley in the western Endicott Mountains, Alaska. The formation predominantly consists of black carbonaceous shale, black chert, fine-grained limestone, and dolomite with variable thickness from 45–100 m (148–328 ft) (Mull et al. 1982). A reference section for the formation occurs along Ekokpuk Creek [in SW/4 sec. 11, T. 16 S., R. 4 W., Umiat Meridian] in the Chandler Lake Quadrangle (Table 3; Figure 26; Mull et al. 1982). In the Endicott Mountains the Kuna Formation underlies the Siksikpuk Formation, intertongues with the Wachsmuth Limestone and Alapah Limestone, and gradationally overlies the Kayak Shale (Mull et al. 1982).

Imnaitchiak Chert

The Pennsylvanian–Triassic Imnaitchiak Chert of the Etivluk Group was proposed by Mull et al. (1985, 1986) and named after its occurrence in the Imnaitchiak Creek area in the Killik River Quadrangle, Alaska. A reference section of the formation was designated by Mull et al. (1986) on the south side of the hill along the lower Akmalik Creek [in NE/4 sec. 27, T. 12 S., R. 10 W., Umiat Meridian], GAAR (Table 3; Figures 26 and 34). The Imnaitchiak Chert reaches a maximum thickness of about 76 m (250 ft) and is dominantly composed of gray and green chert and maroon siliceous shale with minor amounts of siltstone and very fine-grained sandstone (Mull et al. 1986).

The unit overlies the Akmalik Chert and although it underlies a thrust fault in most locations, it is overlain by graywacke of the Okpikruak Formation in the canyon of Akmalik Creek (Mull et al. 1986).

Otuk Formation

The Triassic–Jurassic Otuk Formation of the Etivluk Group was named by Mull et al. (1982) after Otuk Creek, a tributary of the East Fork of the Etivluk River in the western Killik River Quadrangle, Alaska. A principal reference section for the formation is located along Monotis Creek [in NE/4 sec. 29, T. 12 S., R. 4 W.] in the western Chandler Lake Quadrangle of the Endicott Mountains (Table 3; Figure 26; Mull et al. 1982). The unit consists of rhythmically interbedded chert, siliceous shale, and silicified limestone, weathering to form yellowish-gray to orangish-gray slopes (Mull et al. 1982). Mull et al. (1982) estimated the thickness of the Otuk Formation to be 50–100 m (164–328 ft) in the western and central Brooks Range, where it overlies the Siksikpuk Formation and underlies rocks of Jurassic or Cretaceous age.

Fortress Mountain Formation

The Early Cretaceous Fortress Mountain Formation was proposed by Patton (1956) and named after exposures on Fortress Mountain, Alaska. Patton (1956) designated a composite type section along the Kiruktagiak River and on Castle Mountain in the Chandler Lake Quadrangle (Table 3; Figure 23). The composite type section is about 3,048 m (10,000 ft) thick and consists of dark gray shale and greenish-gray coarse-grained graywacke sandstone and conglomerate (Patton 1956). At the type section, the Fortress Mountain Formation overlies the Tiglukpuk Formation but locally overlies the Okpikruak Formation. Although the top part of the formation at the type section has been eroded away, the unit presumably underlies the Torok Formation or Nanushuk Group (Patton 1956).

Kobuk Valley National Park (KOVA)

Kobuk Valley National Park (KOVA) is located 56 km (35 mi) north of the Arctic Circle in Northwest Arctic Borough, Alaska and shares its northern boundary with Noatak National Preserve (Figure 35). Originally established as a national monument on December 1, 1978, KOVA was redesignated a national park on December 2, 1980 (National Park Service 2016). The park encompasses about 708,489 hectares (1,750,716 acres) and protects the boreal forest and rivers of the central Kobuk River valley, the Great Kobuk Sand Dunes, and archeological resources such as Onion Portage. The Kobuk River bisects KOVA and has a cultural history dating back 9,000 years, as ancient civilizations would come to Onion Portage to harvest caribou.

The geologic history recorded in the rocks of KOVA dates back more than 1 billion years to the Neoproterozoic, with some of the oldest units consisting of meta-sedimentary and meta-igneous rocks of Mount Angayukaqsraq (Figures 36 and 37). The northern portion of the park consists of an assemblage of Neoproterozoic–Devonian meta-sedimentary rocks, the Mississippian–Devonian Endicott Group, the Ordovician–Devonian Baird Group, and the Devonian Beaucoup Formation. Bedrock strata exposed in the southern region of KOVA include igneous rocks of the Mississippian–Early Jurassic Angayucham assemblage, Jurassic–Cretaceous mélange (a poorly sorted large-scale jumble of angular rock fragments) of the Arctic Alaska and Ruby terranes, and Cretaceous sedimentary rocks. Younger surficial deposits consist of Pleistocene to Holocene glacial and dune deposits, alluvium, and Holocene dune deposits of the Great Kobuk Sand Dunes. The Great Kobuk Sand Dunes, along with the smaller Little Kobuk Sand Dunes and Hunt River Sand Dunes, are a relic of the Ice Age. Fine-grained sand and silt that make up the dunes were originally deposited by glaciers that subsequently washed into the Kobuk River valley (National Park Service 2010).

There are no designated stratotypes identified within the boundaries of KOVA. There are also no identified stratotypes located within 48 km (30 mi) of KOVA boundaries.

Figure 35. Park map of KOVA, Alaska (NPS).

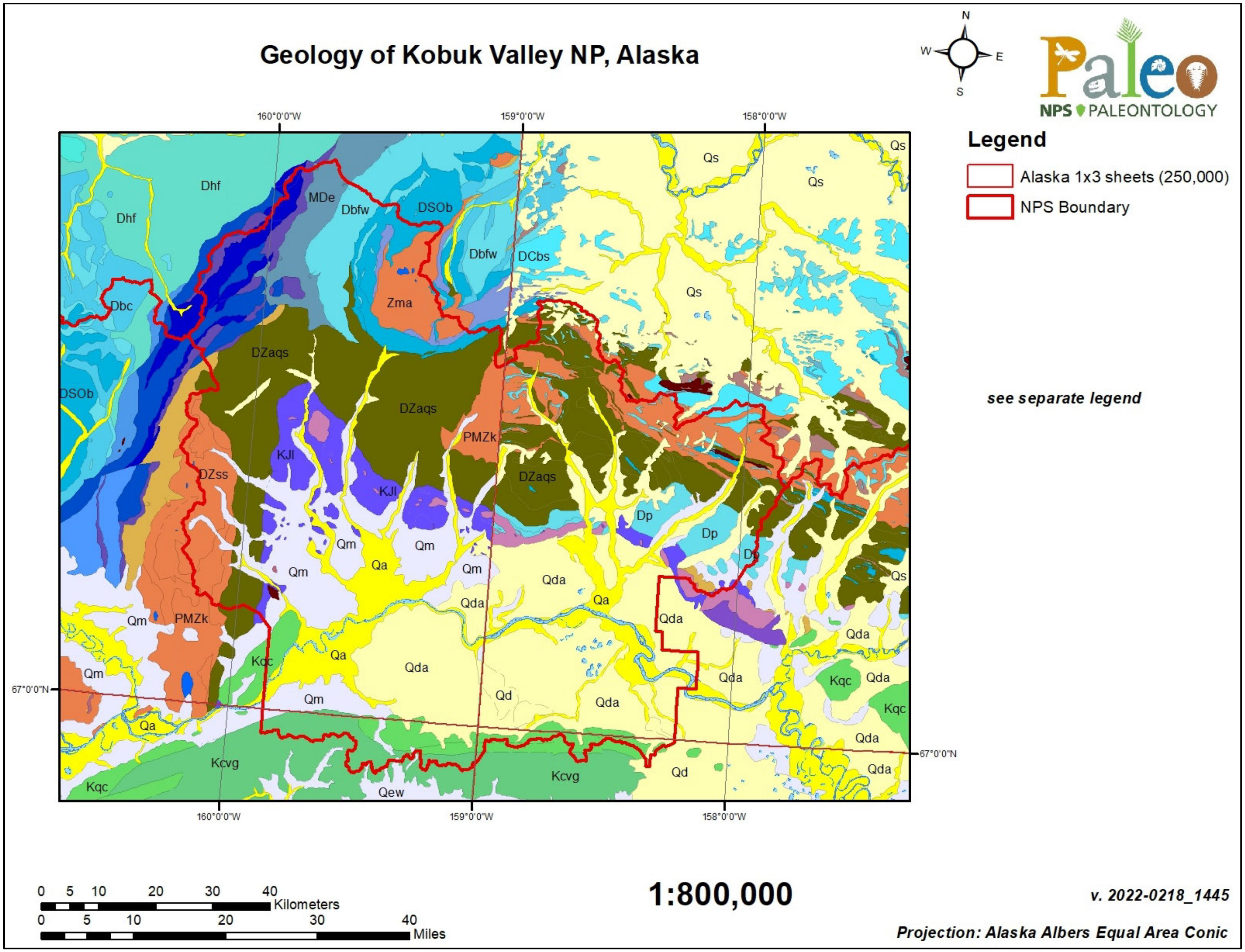


Figure 36. Geologic map of KOVA, Alaska; see Figure 37 for legend.

Figure 37. Geologic map legend of KOVA, Alaska.

Noatak National Preserve (NOAT)

Noatak National Preserve (NOAT) is almost completely enclosed by the Baird and DeLong Mountains of the Brooks Range in the North Slope and Northwest Arctic Boroughs, Alaska (Figure 38). Originally established as a national monument on December 1, 1978, the park unit was redesignated a national preserve on December 2, 1980. The preserve encompasses approximately 2,665,693 hectares (6,587,071 acres) and was enacted to 1) protect the nation’s largest unaltered river basin and watershed; 2) protect habitat for a diverse array of flora and fauna; 3) preserve archeological sites; and 4) provide opportunities for subsistence and scientific study. The namesake Noatak River is classified as a national wild and scenic river, and archeologists surveying the tributaries of the river have discovered a cultural history that dates back more than 11,000 years. In 1976, NOAT was designated a Biosphere Reserve.

The bedrock geology of NOAT is predominantly composed of formations associated with the Cambrian–Devonian Baird Group, Devonian–Mississippian Endicott Group, and Mississippian Lisburne Group (Figures 39 and 40). The southern portion of the preserve contains Ordovician–Devonian-age schists and quartzites, as well as the Devonian Beaucoup Formation. Exposures of the Jurassic ophiolite (a displaced fragment of oceanic crust and upper mantle) of the Brooks Range occur in western and northwestern NOAT. Some of the youngest bedrock units in the preserve include the Cretaceous Okpikruak and Fortress Mountain Formations that occur along the northwestern and north-central boundaries. A variety of surficial deposits occur in the preserve, including Pleistocene–Holocene glacial deposits, dune deposits, terrace deposits, landslide deposits, colluvium, and alluvium (Hamilton 2010).

NOAT contains eight identified stratotypes that are subdivided into three type sections, one type area, and four reference sections (Table 4; Figure 41). In addition to the designated stratotypes located within NOAT, stratotypes located within 48 km (30 mi) of NOAT boundaries include the Mississippian Utukok Formation (type section), Kugruk Formation (type section), and Kurupa Sandstone (type locality); Mississippian–Pennsylvanian Tupik Formation (type section), Nuka Formation (type section and reference section), and Kuna Formation (type section and reference section); Pennsylvanian–Jurassic Etivluk Group (type locality); Triassic–Jurassic Otuk Formation (type section); Jurassic Blankenship Member of the Otuk Formation (type section and principal reference section); Jurassic–Cretaceous Ipewik Formation (two reference sections) and Tingmerkpuk Sandstone Member of the Ipewik Formation (type locality); and the Cretaceous Mount Kelly Graywacke Tongue of the Fortress Mountain Formation (type locality).

Figure 38. Park map of NOAT, Alaska (NPS).

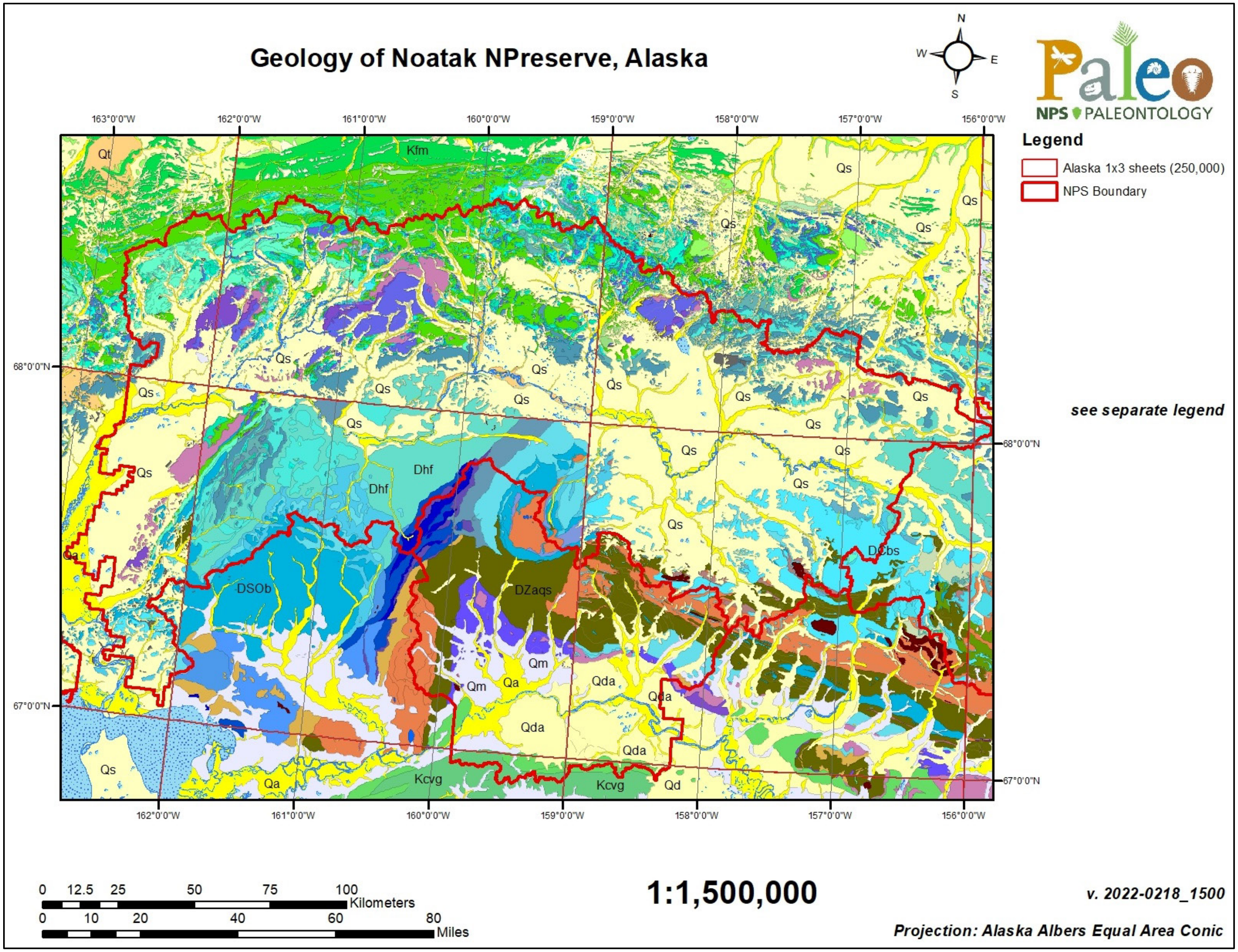


Figure 39. Geologic map of NOAT, Alaska; see Figure 40 for legend.

Figure 40. Geologic map legend of NOAT, Alaska.

Table 4. List of NOAT stratotype units sorted by age with associated reference publications and locations.

Unit Name (GRI map symbol)	Reference	Stratotype Location	Age
Otuk Formation (JTRrcs)	Mull et al. 1982	Reference section: exposures along tributary of Kelly River [in SW/4 sec. 16, T. 12 S., R. 45 W. western DeLong Mountains Quadrangle], AK.	Early Triassic (Olenekian)–Middle Jurassic (Bajocian)
Kuna Formation, Lisburne Group (Mlku)	Mull et al. 1982	Principal reference section: upper Otuk Creek [in SE/4 sec. 19, T. 34 N., R. 4 E., Kateel River Meridian, Killik River Quadrangle], central Endicott Mountains, AK. Reference sections: 1) tributary of Wrench Creek [in NW/4 sec. 26, T. 32 N., R. 17 W., Kateel River Meridian, eastern DeLong Mountains Quadrangle], AK; and 2) Pupik Hills [in SW/4, sec. 35, T. 33 N., R. 5 E., Kateel River Meridian, Howard Pass Quadrangle], western Endicott Mountains, AK.	Late Mississippian–Middle Pennsylvanian
Noatak Sandstone, Endicott Group (Dnu)	Smith and Mertie 1930; Dutro 1952	Type section: exposures on mountain-side 7.2 km (4.5 mi) N. 15° W. of junction of Nimiuktuk and Noatak rivers, Misheguk Mountain Quadrangle, Brooks Range, AK. Type area: mountains immediately west of Nimiuktuk River (Kingasivik Mountains) and south of DeLong Mountains [in Misheguk Mountain Quadrangle], western Brooks Range, AK.	Late Devonian–Early Mississippian
Kugururok Formation, Baird Group (Dbk)	Sable and Dutro 1961	Type section: on north side of Mont Bastille, central DeLong Mountains, northern AK.	Middle (Givetian)–Late Devonian
Eli Limestone, Baird Group (Dbe)	Tailleur et al. 1967	Type section: east of north branch of Eli River (east of Ahaliknak River, at latitude 67°47′30″ N., longitude 161°51′00″ W.) western Baird Mountains, northern AK.	Middle–Late Devonian

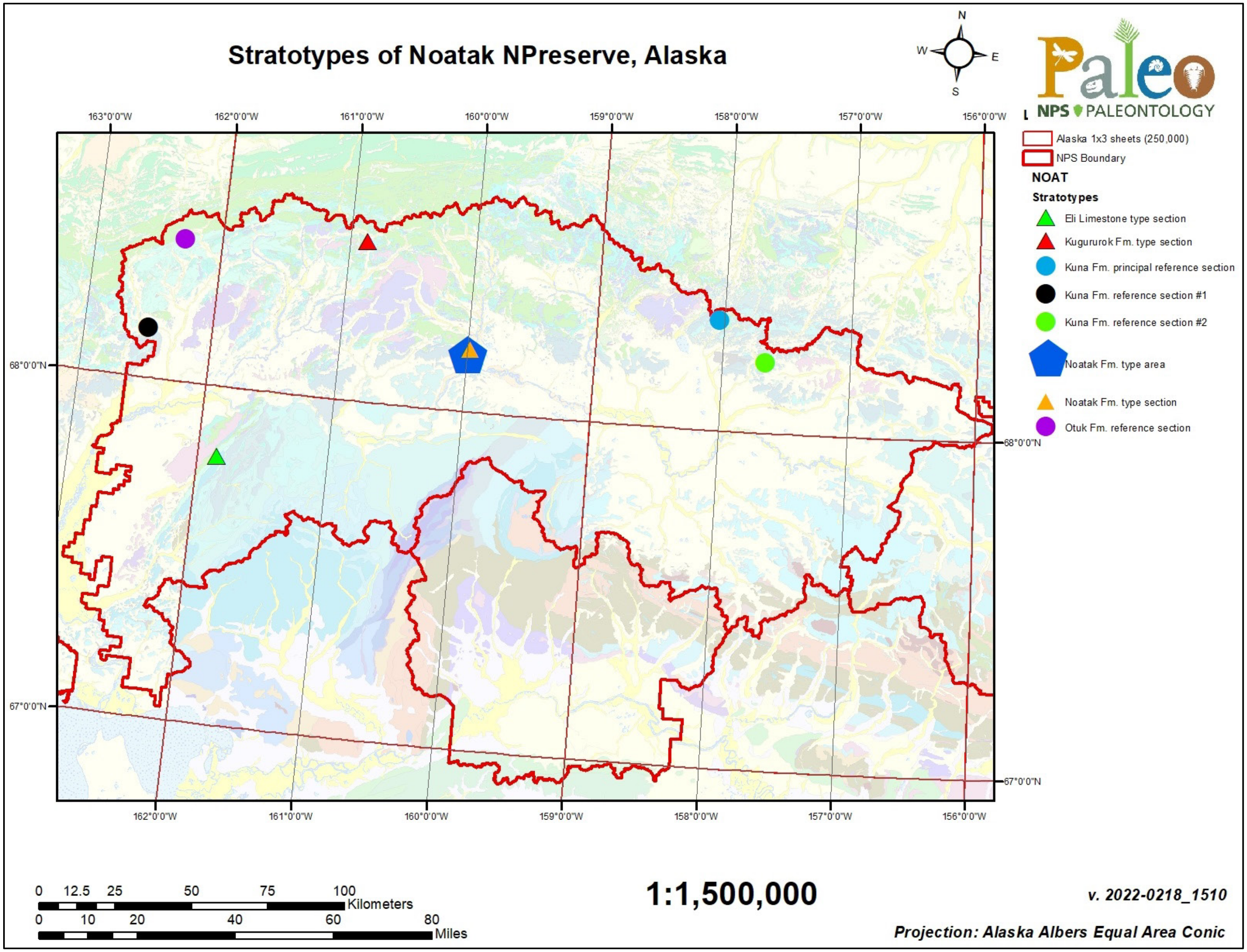


Figure 41. Modified geologic map of NOAT showing stratotype locations. The transparency of the geologic units layer has been increased.

Eli Limestone

The Middle–Late Devonian Eli Limestone of the Baird Group was named by Tailleur et al (1967) after its type section exposure measured east of the north branch of the Eli River [east of Ahaliknak River] in the western Baird Mountains, Alaska (Table 4; Figure 41). The type section is about 50 m (165 ft) thick and consists of well-stratified, grayish-orange and brown, ferruginous (iron-bearing) muddy limestone and interbeds of shale that locally include sandstone (Tailleur et al. 1967). The Eli Limestone overlies and intertongues with the Skajit Limestone and underlies the Lisburne Group.

Kugururok Formation

The Middle–Late Devonian Kugururok Formation of the Baird Group was proposed by Sable and Dutro (1961) after well-developed exposures that occur in the drainage area of the Kugururok River, Alaska. The type section is designated on the north side of Mount Bastille and consists of a 420 m (1,380 ft) thick sequence of shale with interbedded sandstone, conglomerate, siltstone, limestone, calcarenite (limestone made of sand-sized particles), and distinctive yellowish-weathering cross-bedded dolomite (Table 4; Figures 41 and 42; Sable and Dutro 1961). The type section is in basal fault contact with Mississippian(?) carbonate rocks and unconformably underlies shales of Jurassic or Early Cretaceous age or locally by the Utukok Formation (Sable and Dutro 1961).

Figure 42. Exposed carbonate sequence of the Kugururok Formation near the type section at Mount Bastille (ROBERT BLODGETT).

Noatak Sandstone

The Late Devonian–Early Mississippian Noatak Sandstone of the Endicott Group was first named by Smith (1913) after Noatak basin, Alaska and later redesignated by Smith and Mertie (1930). The type area of the formation is designated in the western part of Noatak Valley in the Kingasivik Mountains immediately west of Nimiuktuk River in the Misheguk Mountain Quadrangle of the western Brooks Range (Table 4; Figures 41 and 43; Smith and Mertie 1930; Dutro 1952). The type section is exposed on a mountainside 7.2 km (4.5 mi) N. 15° W. of the junction of the Nimiuktuk and Noatak rivers in the Misheguk Mountain Quadrangle (Table 4; Figure 41; Dutro 1952). The type section measures about 263 m (534 ft) thick and is composed of very fine- to medium-grained, bluish-gray sandstone with minor amounts of gray shale and conglomerate (Dutro 1952). In the type area, the Noatak Sandstone underlies the Utukok Formation and overlies the Hunt Fork Shale.

Figure 43. Hills west of Nimiuktuk River near the junction with Noatak River, the type area of the Noatak Formation. Cn, Noatak Sandstone; Cu, Utukok Formation; Cl, Lisburne Formation (now Lisburne Group); Qal, Quaternary alluvium; Qg, Quaternary gravels; meta, metamorphic rocks; ma, unknown. Plate 4 from Dutro (1952).

Kuna Formation

The Late Mississippian–Middle Pennsylvanian Kuna Formation of the Lisburne Group was proposed by Mull et al. (1982) to describe exposures in the Kuna River valley in the western Endicott Mountains, Alaska. The formation predominantly consists of black carbonaceous shale, black chert, fine-grained limestone, and dolomite with variable thickness from 45–100 m (148–328 ft). The principal reference section of the unit is designated in upper Otuk Creek [in SE/4 sec. 19, T. 34 N., R. 4 E., Kateel River Meridian], in the Killik River Quadrangle of the central Endicott Mountains (Table 4; Figure 41; Mull et al. 1982). Two supplementary reference sections were also measured by Mull et al. (1982) in the following locations: 1) along a tributary of Wrench Creek [in NW/4 sec. 26, T. 32 N., R. 17 W., Kateel River Meridian), in the eastern DeLong Mountains Quadrangle; and 2)

Pupik Hills [in SW/4, sec. 35, T. 33 N., R. 5 E., Kateel River Meridian], in the Howard Pass Quadrangle (Table 4; Figure 41). In the Endicott Mountains the Kuna Formation underlies the Siksikpuk Formation, intertongues with the Wachsmuth Limestone and Alapah Limestone, and gradationally overlies the Kayak Shale (Mull et al. 1982).

Otuk Formation

The Triassic–Jurassic Otuk Formation of the Etivluk Group was named by Mull et al. (1982) after Otuk Creek, a tributary of the East Fork of the Etivluk River in the western Killik River Quadrangle, Alaska. The unit consists of rhythmically interbedded chert, siliceous shale, and silicified limestone that weather to form yellowish-gray to orangish-gray slopes (Mull et al. 1982). A reference section of the formation was measured by Mull et al. (1982) along a tributary of Kelly River [in SW/4 sec. 16, T. 12 S., R. 45 W.], in the western DeLong Mountains Quadrangle (Table 4; Figure 41). The thickness of the Otuk Formation is estimated to be 50–100 m (164–328 ft) in the western and central Brooks Range, where it overlies the Siksikpuk Formation and underlies rocks of Jurassic or Cretaceous age (Mull et al. 1982).

Recommendations

See also protocols in Brocx et al. (2019), from which several of these recommendations were adapted:

1) The NPS Geologic Resources Division should work with park and network staff to increase their awareness and understanding about the scientific, historic and geologic heritage significance of geologic stratotypes (type sections/localities/areas, reference sections, lithodemes). *Stratotypes represent unique geologic exposures and should be considered extremely important to protect for the advancement of the scientific community for future generations.*
2) Once the ARCN Geologic Type Section Inventory report is finalized, the NPS Geologic Resources Division should schedule a briefing for the staff of the ARCN and respective network parks.
3) The Pleistocene Gosling Volcanics were named by Hopkins (1963) after Gosling Cone in the Imuruk Lake area in BELA. The unit consists of a group of basaltic and andesitic lava flows that cover an extensive area and reach a thickness of nearly 91 m (300 ft) near Gosling Cone (Hopkins 1963). However, no formal stratotype designation has been identified. Therefore, we recommend a formal type section be designated in order to A) provide a standard reference for scientific research; B) educate park staff and visitors about the geoheritage significance of the unit; and C) help safeguard the exposure.
4) The NPS Geologic Resources Division should work with park and network staff to ensure they are aware of the location of stratotypes in park areas. This information would be important to ensure that proposed park activities or development would not adversely impact the stability and condition of these geologic exposures. Preservation of stratotypes should not limit availability for future scientific research but help safeguard these exposures from infrastructural development.
5) The NPS Geologic Resources Division should work with park and network staff, the U.S. Geological Survey, state geological surveys, academic geologists, and other partners to formally assess potential new stratotypes as to their significance (international, national, or statewide), based on lithology, stratigraphy, fossils or notable features using procedural code outlined by the North American Commission on Stratigraphic Nomenclature (after Brocx et al. 2019).
6) From the assessment in (5), NPS staff should focus on registering new stratotypes at state and local government levels where current legislation allows, followed by a focus on registering at federal and state levels where current legislation allows (after Brocx et al. 2019).
7) The NPS Geologic Resources Division should work with park and network staff to compile and update a central inventory of all designated stratotypes and potential future nominations (after Brocx et al. 2019).
8) The NPS Geologic Resources Division should ensure the park-specific Geologic Type Section Inventory Reports are widely distributed and available online.

9) The NPS Geologic Resources Division should work with park and network staff to regularly monitor geologic type sections to identify any threats or impacts to these geologic heritage features in parks.

10) The NPS Geologic Resources Division should work with park and network staff to obtain good photographs of each geologic type section within the parks. In some cases, where there may be active geologic processes (rock falls, landslides, coastal erosion, etc.), the use of photogrammetry may be considered for monitoring of geologic type sections. GPS locations should also be recorded and kept in a database when the photographs are taken.

11) The NPS Geologic Resources Division should work with park and network staff to consider the collection and curation of geologic samples from type sections within NPS areas. Samples collected from type section exposures can be useful as reference specimens to support future studies, especially where stratotypes may be lost through natural processes or human activities.

12) The NPS Geologic Resources Division should work with park and network staff to utilize selected robust internationally and nationally significant type sections as formal teaching/education sites and for geotourism so that the importance of the national- and international-level assets are more widely (and publicly) known, using information boards and walkways (after Brocx et al. 2019).

13) The NPS Geologic Resources Division should work with park and network staff in developing conservation protocols of significant type sections, either by appropriate fencing, walkways, and information boards or other means (e.g., phone apps) (after Brocx et al. 2019).

Literature Cited

Bailey, R. G. 1976. Ecoregions of the United States (map). US Department of Agriculture, US Forest Service, Intermountain Region, Ogden, Utah.

Bernknopf, R. L., D. S. Brookshire, D. R. Soller, M. J. McKee, J. F. Sutter, J. C. Matti, and R. H. Campbell. 1993. Societal value of geologic maps. U.S. Geological Survey, Reston, Virginia. Circular 1111. Available at: https://pubs.er.usgs.gov/publication/cir1111 (accessed February 24, 2022).

Blodgett, R. B., D. M. Rohr, and A. J. Boucot. 2002. Paleozoic links among some Alaskan accreted terranes and Siberia based on megafossils. Pages 273–290 *in* E. L. Miller, A. Grantz, and S. L. Klemperer, editors. Tectonic evolution of the Bering Shelf-Chukchi Sea-Arctic Margin and adjacent landmasses. Geological Society of America, Boulder, Colorado. Special Paper 360.

Bowsher, A. L., and J. T. Dutro, Jr. 1957. The Paleozoic section in the Shainin Lake area, central Brooks Range, Alaska, U.S. Geological Survey, Washington, D.C. Professional Paper 303-A. Available at: https://pubs.er.usgs.gov/publication/pp303A (accessed February 24, 2022).

Brocx, M., C. Brown, and V. Semeniuk. 2019. Geoheritage importance of stratigraphic type sections, type localities and reference sites—review, discussion and protocols for geoconservation. Australian Journal of Earth Sciences 66(6):823–836.

Dutro, J. T., Jr. 1952. Stratigraphy and paleontology of the Noatak and associated formations, Brooks Range, Alaska; Geologic Investigations, Naval Petroleum Reserve No. 4, Alaska. U.S. Geological Survey, Washington, D.C. Alaska Special Report 33. Available at: https://pubs.er.usgs.gov/publication/70210468 (accessed February 24, 2022).

Evans, T. J. 2016. General standards for geologic maps. Section 3.1 *in* M. B. Carpenter and C. M. Keane, compilers. The geoscience handbook 2016. AGI Data Sheets, 5th edition. American Geosciences Institute, Alexandria, Virginia.

Fenneman, N. M. 1946. Physical divisions of the United States (map). U.S. Geological Survey, Washington, D.C. Unnumbered. Scale 1:7,000,000. Available at: https://pubs.er.usgs.gov/publication/70207506 (accessed February 24, 2022).

Giddings, J. L. and D. D. Anderson. 1986. Beach ridge archeology of Cape Krusenstern: Eskimo and pre-Eskimo Settlements around Kotzebue Sound, Alaska. National Park Service, Washington, D.C. Publications in Archaeology 20.

Gradstein, F. M., J. G. Ogg, M. D. Schmitz, and G. M. Ogg, editors. 2020. Geologic time scale 2020. Elsevier, Amsterdam, Netherlands.

Hamilton, T. D. 2010. Surficial geologic map of the Noatak National Preserve, Alaska. U.S. Geological Survey, Reston, Virginia. Scientific Investigations Map 3036. Scale 1:250,000. Available at: https://pubs.usgs.gov/sim/3036/ (accessed February 24, 2022).

Hamilton, T. D., and K. A. Labay. 2012. Surficial geologic map of the Gates of the Arctic National Park and Preserve, Alaska. U.S. Geological Survey, Reston, Virginia. Scientific Investigations Map 3125. Scale 1:300,000. Available at: https://pubs.usgs.gov/sim/3125/ (accessed February 24, 2022).

Henderson, T., V. L. Santucci, T. Connors, and J. S. Tweet. 2020. National Park Service geologic type section inventory: Greater Yellowstone Inventory & Monitoring Network. Natural Resource Report NPS/GRYN/NRR—2020/2198. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2280034 (accessed February 24, 2022).

Hopkins, D. M. 1956. Structure and history of a basalt lava flow in Alaska. Proceedings of the 4th Alaskan Science Conference, Juneau, Alaska, September 28–October 3, 1953:237.

Hopkins, D. M. 1963. Geology of the Imuruk Lake area, Seward Peninsula, Alaska. U.S. Geological Survey, Washington, D.C. Bulletin 1141-C. Available at: https://pubs.er.usgs.gov/publication/b1141C (accessed February 24, 2022).

Hopkins, D. M. 1967. The Bering Land Bridge. Stanford University Press, Stanford, California.

Hudson, T. L. 1979. Igneous and metamorphic rocks of the Serpentine Hot Springs area, Seward Peninsula, Alaska. U.S. Geological Survey, Washington, D.C. Professional Paper 1079. Available at: https://pubs.er.usgs.gov/publication/pp1079 (accessed February 24, 2022).

Keroher, G. C., and others. 1966. Lexicon of geologic names of the United States for 1936–1960. U.S. Geological Survey, Washington, D.C. Bulletin 1200. Available at: https://pubs.er.usgs.gov/publication/b1200 (accessed February 24, 2022).

Lanik, A., D. K. Swanson, and R. D. Karpilo, Jr. 2019. Bering Land Bridge National Preserve: Geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2019/2024. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2266921 (accessed February 24, 2022).

Mull, C. G., and M. D. Mangus. 1972. Itkilyariak Formation, new Mississippian formation of Endicott Group, Arctic slope of Alaska. American Association of Petroleum Geologists Bulletin 56(8):1364–1369.

Mull, C. G., I. L. Tailleur, C. F. Mayfield, I. Ellersieck, and S. M. Curtis. 1982. New upper Paleozoic and lower Mesozoic stratigraphic units, central and western Brooks Range, Alaska. American Association of Petroleum Geologists Bulletin 66(3):348–362.

Mull, C. G., K. E. Adams, D. A. Bodnar, and J. P. Slok. 1985. Stratigraphy of Endicott Mountains and Picnic Creek allochthons, Killik River and Chandler Lake Quadrangles, north-central Brooks Range, Alaska. American Association of Petroleum Geologists Bulletin 69(4):671.

Mull, C. G., R. K. Crowder, J. P. Siok, K. E. Adams, D. A. Bodnar, E. E. Harris, R. A. Alexander, and D. N. Solie. 1986. Stratigraphy and structural setting of the Picnic Creek Allochthon, Killik

River Quadrangle, central Brooks Range, Alaska: a summary. Alaska Division of Geological & Geophysical Surveys, Fairbanks, Alaska. Public Data File 86-33B. Available at https://dggs.alaska.gov/pubs/id/1208 (accessed February 24, 2022).

Mull, C. G., R. K. Crowder, K. E. Adams, J. P. Siok, D. A. Bodnar, E. E. Harris, R. R. Alexander, and D. N. Solie. 1987. Stratigraphy and structural setting of the Picnic Creek allochthon, Killik River Quadrangle, central Brooks Range, Alaska. Pages 650–662 *in* I. Tailleur and P. Weimer, editors. Alaskan North Slope geology, volumes I and II. Society for Sedimentary Geology, Pacific Section, Bakersfield, California, and Alaska Geological Society, Anchorage, Alaska. Pacific Section SEPM Field Trip Guidebook 50.

National Park Service. 2010. Kobuk Valley National Park, Alaska. National Park Service Foundation Document. Available at: http://npshistory.com/publications/foundation-documents/kova-fs-2010.pdf (accessed February 24, 2022).

National Park Service. 2016. National Parks Index: 2012-2016. Official Index of the National Park Service. Available at: https://www.nps.gov/aboutus/upload/npindex2012-2016.pdf (accessed February 24, 2022).

Nilsen, T. H., and T. E. Moore. 1984. Stratigraphic nomenclature for the Upper Devonian and Lower Mississippian(?) Kanayut Conglomerate, Brooks Range, Alaska. U.S. Geological Survey, Washington, D.C. Bulletin 1529-A. Available at: https://pubs.er.usgs.gov/publication/b1529A (accessed February 24, 2022).

North American Commission on Stratigraphic Nomenclature. 2021. North American stratigraphic code. Stratigraphy 18(3):153–204.

Omernik, J. M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77(1):118–125.

Patton, W. W., Jr. 1956. New and redefined formations of Early Cretaceous age. Pages 219–223 *in* G. Gryc and others. Mesozoic sequence in Colville River region, northern Alaska. American Association of Petroleum Geologists Bulletin 40(2):209–254.

Sable, E. G., and J. T. Dutro, Jr. 1961. New Devonian and Mississippian formations in DeLong Mountains, northern Alaska. American Association of Petroleum Geologists Bulletin 45(5):585–593.

Schrader, F. C. 1902. Geologic section of the Rocky Mountains in northern Alaska. Geological Society of America Bulletin 13:233–252.

Smith, P. S. 1913. The Noatak Kobuk region, Alaska. U.S. Geological Survey, Washington, D.C. Bulletin 536. Available at: https://pubs.er.usgs.gov/publication/b536 (accessed February 24, 2022).

Smith, P. S., and J. B. Mertie, Jr. 1930. Geology and mineral resources of northwestern Alaska. U.S. Geological Survey, Washington, D.C. Bulletin 815. Available at: https://pubs.er.usgs.gov/publication/b815 (accessed February 24, 2022).

Tailleur, I. L., W. P. Brosge, and H. N. Reiser. 1967. Palinspastic analysis of Devonian rocks in northwestern Alaska. Pages 1345–1361 *in* D. H. Oswald, editor. International symposium on the Devonian System. Alberta Society of Petroleum Geologists, Calgary, Alberta. Volume 2.

Thornberry-Ehrlich, T. 2008. Geologic Resource Evaluation Scoping Summary, Arctic Network. Geologic Resources Inventory Scoping Report, Colorado State University, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2250178 (Accessed February 24, 2022).

Till, A. B., J. A. Dumoulin, M. B. Werdon, and H. A. Bleick. 2011. Bedrock geologic map of the Seward Peninsula, Alaska, and accompanying conodont data U.S. Geological Survey, Anchorage, Alaska. Scientific Investigations Map 3131. Scale 1:500,000. Available at: https://pubs.usgs.gov/sim/3131/ (accessed February 24, 2022).

Wilmarth, M. G. 1938. Lexicon of geologic names of the United States (including Alaska). U.S. Geological Survey, Washington, D.C. Bulletin 896. Available at: https://pubs.er.usgs.gov/publication/b896 (accessed February 24, 2022).

Appendix A: Source Information for GRI Maps of ARCN Parks

- GMAP 2283: Hamilton, T. D., and K. A. Labay. 2012. Surficial geologic map of the Gates of the Arctic National Park and Preserve, Alaska. U.S. Geological Survey, Reston, Virginia. Scientific Investigations Map 3125. Scale 1:300,000. Available at: https://pubs.usgs.gov/sim/3125/ (accessed February 24, 2022).
- GMAP 23483: Hudson, T. 1998. Alaska Resource Data File, Bendeleben Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 99-332. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 2417: Williams, A. 2000. Alaska Resource Data File, Kotzebue Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 99-579. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 2554: Britton, J. M. 2000. Alaska Resource Data File, Chandalar Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2000-357. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 2555: Britton, J. M. 2000. Alaska Resource Data File, Philip Smith Mountains Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2000-291. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 2575: Nelson, S. M. 1997. Alaska Resource Data File, Ambler River Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 97-856. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 2719: Williams, A. 2000. Alaska Resource Data File, Baird Mountains Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2000-24. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 2720: Williams, A. 2000. Alaska Resource Data File, Selawik Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2000-5. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 2721: Williams, A. 2000. Alaska Resource Data File, Shungnak Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2000-22. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 2838: Dover, J. 1997. Alaska Resource Data File, Howard Pass Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 97-296. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 2839: Dover, J. 1997. Alaska Resource Data File, Misheguk Mountain, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 97-297. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).

- GMAP 2842: Williams, A. 2000. Alaska Resource Data File, De Long Mountains Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2000-23. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 3042: Kelly, K. 1997. Alaska Resource Data File, Chandler Lake Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 97-265. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 3043: Kelly, K. 1997. Alaska Resource Data File, Killik River Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 97-266. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 3046: Nelson, S. M. 2000. Alaska Resource Data File, Survey Pass Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2000-328. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 39380: Hudson, T. 1998. Alaska Resource Data File, Teller Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 98-328. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 39381: Britton, J. M. 2000. Alaska Resource Data File, Beaver Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2000-308. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 54852: Britton, J. M. 2003. Alaska Resource Data File, Bettles Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2003-52. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 55354: Britton, J. M. 2003. Alaska Resource Data File, Hughes Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2003-58. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 62518: Britton, J. M. 2003. Alaska Resource Data File, Wiseman Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2003-447. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).
- GMAP 75596: Wilson, F. H., N. B. Shew, G. D. DuBois, and S. Dadisman. 1999. Alaska radiometric ages, Alaska. U.S. Geological Survey, Reston, Virginia. Unpublished data. Scale 1:250,000. Available at: https://mrdata.usgs.gov/akages/ (accessed February 24, 2022).
- GMAP 75612: Hamilton, T. D. 2010. Surficial geologic map of the Noatak National Preserve, Alaska. U.S. Geological Survey, Reston, Virginia. Scientific Investigations Map 3036. Scale 1:250,000. Available at: https://pubs.usgs.gov/sim/3036/ (accessed February 24, 2022).
- GMAP 75659: Till, A. B., J. A. Dumoulin, M. B. Werdon, and H. A. Bleick. 2011. Bedrock geologic map of the Seward Peninsula, Alaska, and accompanying conodont data U.S. Geological Survey, Anchorage, Alaska. Scientific Investigations Map 3131. Scale 1:500,000. Available at: https://pubs.usgs.gov/sim/3131/ (accessed February 24, 2022).

- GMAP 75661: Patton, W. W., F. H. Wilson, K. A. Labay, and N. Shew. 2009. Geologic map of the Yukon-Koyukuk basin, Alaska. U.S. Geological Survey, Reston, Virginia. Scientific Investigations Map 2909. Scale 1:500,000. Available at: https://pubs.usgs.gov/sim/2909/ (accessed February 24, 2022).
- GMAP 75963: Till, A. B., J. A. Dumoulin, M. B. Werdon, H. A. Bleick, K. A. Labay, H. Bleick, F. H. Wilson, and N. Shew. 2010. Digital data for the bedrock geologic map of the Seward Peninsula, Bendeleben 1x3 Sheet, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2009-1254. Scale 1:500,000. Available at: https://pubs.usgs.gov/of/2009/1254/ (accessed February 24, 2022).
- GMAP 75964: Till, A. B., J. A. Dumoulin, M. B. Werdon, H. A. Bleick, K. A. Labay, H. Bleick, F. H. Wilson, and N. Shew. 2010. Digital data for the bedrock geologic map of the Seward Peninsula, Kotzebue 1x3 Sheet, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2009-1254. Scale 1:500,000. Available at: https://pubs.usgs.gov/of/2009/1254/ (accessed February 24, 2022).
- GMAP 75965: Till, A. B., J. A. Dumoulin, M. B. Werdon, H. A. Bleick, K. A. Labay, H. Bleick, F. H. Wilson, and N. Shew. 2010. Digital data for the bedrock geologic map of the Seward Peninsula, Shishmaref 1x3 Sheet, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2009-1254. Scale 1:500,000. Available at: https://pubs.usgs.gov/of/2009/1254/ (accessed February 24, 2022).
- GMAP 75966: Till, A. B., J. A. Dumoulin, M. B. Werdon, H. A. Bleick, K. A. Labay, H. Bleick, F. H. Wilson, and N. Shew. 2010. Digital data for the bedrock geologic map of the Seward Peninsula, Teller 1x3 Sheet, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2009-1254. Scale 1:500,000. Available at: https://pubs.usgs.gov/of/2009/1254/ (accessed February 24, 2022).
- GMAP 76064: Wilson, F. H., C. P. Hults, C. G. Mull, and S. M. Karl. 2015. Geologic map of Alaska. U.S. Geological Survey, Reston, Virginia. Scientific Investigations Map 3340. Scale 1:1,584,000. Available at: https://pubs.er.usgs.gov/publication/sim3340 (accessed February 24, 2022).
- GMAP 76111: Grybeck, D. J. and J. A. Dumoulin. 2006. Alaska Resource Data File, Noatak Quadrangle, Alaska. U.S. Geological Survey, Reston, Virginia. Open-File Report 2006-1157. Scale 1:250,000. Available at: https://ardf.wr.usgs.gov/quadtable.php (accessed February 24, 2022).

Appendix B: Geologic Time Scale

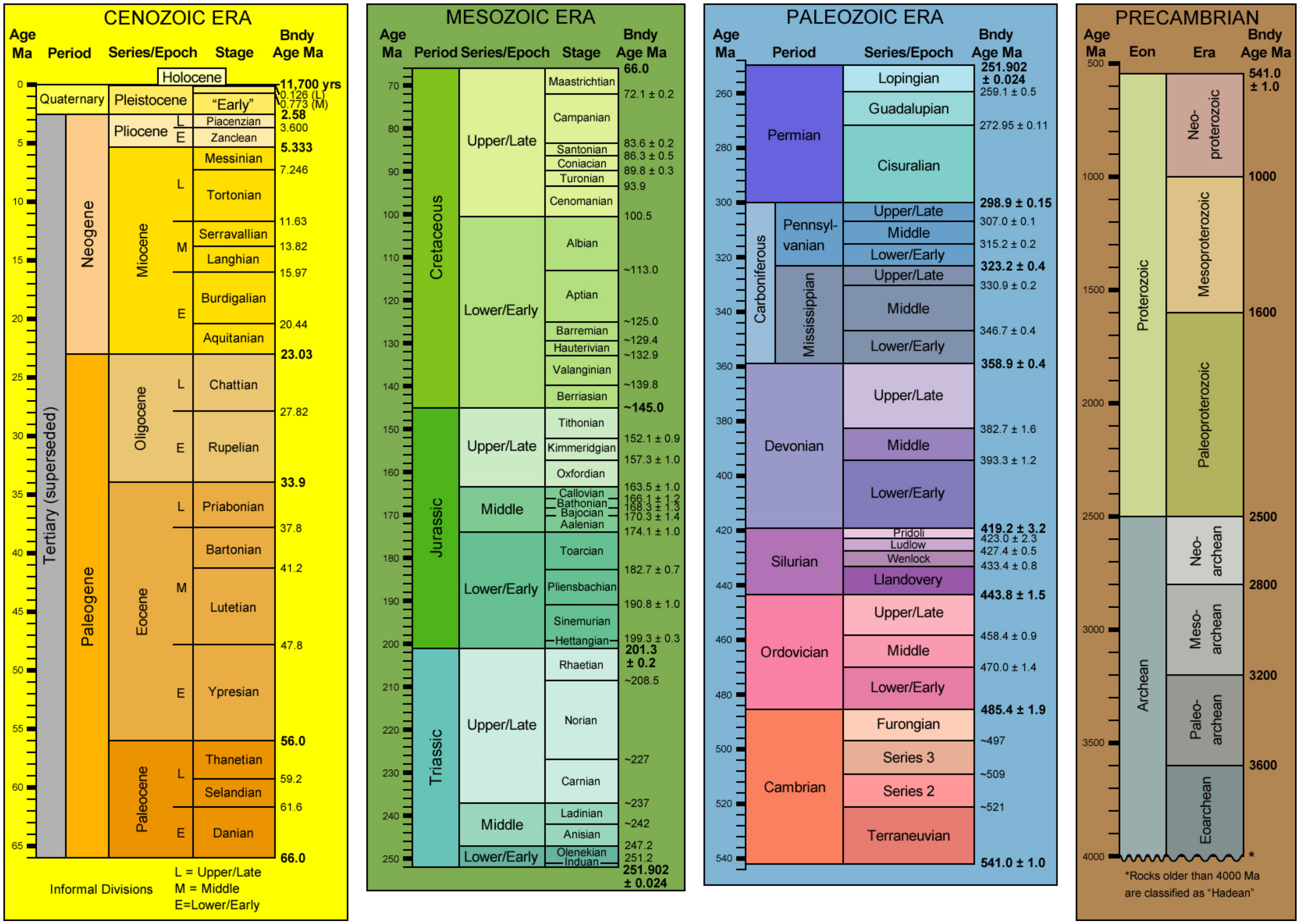


Figure B1. Geologic Time Scale. **Ma**=Millions of years old. **Bndy Age**=Boundary Age. Layout after 1999 Geological Society of America Time Scale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Dates after Gradstein et al. (2020).

NPS 953/180400, May 2022

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525