National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

National Park Service Geologic Type Section Inventory

Southwest Alaska Inventory & Monitoring Network

Natural Resource Report NPS/SWAN/NRR—2021/2296

ON THE COVER

View looking west toward Iliamna Volcano and Red Glacier, LACL. The composite type section of the Jurassic Red Glacier Formation of the Tuxedni Group is located on both sides of Red Glacier. NPS photo by Buck Mangipane.

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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.

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

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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 that 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, 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 2005). 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 which 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 was 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 (e.g., geology, hydrology, climate), biological resources (e.g., 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 such as inventory, monitoring, research, and 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. 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 Southwest Alaska Inventory & Monitoring Network (SWAN).

The goal of this project is to consolidate information pertaining to geologic stratotypes which occur within NPS-administered areas, in order that this information is available throughout the NPS to inform park managers and promote the preservation and protection of these important geologic references and geologic heritage resources. The review of stratotype occurrences for the SWAN shows there are currently no designated stratotypes for ALAG and KEFJ; ANIA has one type section and one reference section; KATM has four type sections, one type locality, and one reference section; and LACL has seven type sections (Table 1).

This report includes recommendations that address 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 SWAN stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Ketavik Formation	Parrish et al. 2010	Type section: on the southern shore of Naknek Lake, where exposures extend from approximately 0.7 km (0.4 mi) north to 5.2 km (3.2 mi) northwest of Brooks Camp; type section on east side of fault. Reference section: on the southern shore of Naknek Lake, where exposures extend from approximately 0.7 km (0.4 mi) north to 5.2 km (3.2 mi) northwest of Brooks Camp; reference section on west side of fault. Type locality: nears Brooks Camps, KATM.	Paleocene–Eocene
Kaguyak Formation (Kks)	Keller and Reiser 1959	Type section: Swikshak Bay along sea cliffs from Big River to Swikshak River [secs. 19 and 20, T. 18 S., R. 27 W., and secs. 13 and 14, T. 18 S., R. 28 W., Afognak C-6 Quadrangle (scale 1:63,360)], AK. Within KATM.	Late Cretaceous, early Maastrichtian
Pedmar Formation (Kp)	Detterman et al. 1996	Type section: in sea cliff, Katmai Bay, along north edge of section 26, Township 25 South, Range 34 West, Mount Katmai A-3 Quadrangle (scale 1:63,360), Alaska Peninsula, AK. Within KATM.	Early Cretaceous, Albian

Table 1 (continued). List of SWAN stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Katolinat Conglomerate Member, Naknek Formation (Jnk)	Detterman et al. 1996	Type section: exposures on unnamed mountain on northeast shore of Grosvenor Lake, in secs. 33 and 34, T. 17 S., R. 35 W., Mount Katmai C-4 Quadrangle (scale 1:63,360), Alaska Peninsula, AK. Within KATM.	Late Jurassic, late(?) Tithonian
Pomeroy Arkose Member, Naknek Formation (Jnp)	Detterman and Hartsock 1966	Type section (composite): north and south sides of Chinitna Bay, Seldovia D-8 Quadrangle, Iniskin Peninsula, AK. Within LACL.	Late Jurassic, early Kimmeridgian
Snug Harbor Siltstone Member, Naknek Formation (Jns)	Detterman et al. 1996	Reference section: along Northeast Creek (~1 km [0.6 mi] north of Northeast Creek Sandstone Member type section), on top of and extending down the southeast face of flat-topped ridge, in sec. 27, T. 37 S., R. 51 W., Sutwik Island D-5 Quadrangle (scale 1:63,360), Alaska Peninsula, AK. Within ANIA.	Late Jurassic, Kimmeridgian–late Oxfordian
Northeast Creek Sandstone Member, Naknek Formation (Jnn)	Detterman et al. 1996	Type section: on east-facing ridge and extending down to tributary of Northeast Creek, in sec. 34, T. 37 S., R. 51 W., Sutwik Island D-5 Quadrangle (scale 1:63,360), Alaska Peninsula, AK. Within ANIA.	Late Jurassic, Oxfordian
Chinitna Formation (Jct)	Martin and Katz 1912; Detterman and Reed 1980	Type section: exposures in the bluffs along the north shore of Chinitna Bay, AK. Within LACL.	Middle Jurassic, Callovian
Tuxedni Sandstone	Martin and Katz 1912	Type section: bluffs along the south shore of the western arm of Tuxedni Bay, Iliamna region, AK. Within LACL.	Middle Jurassic, Bajocian–Bathonian
Red Glacier Formation (Jtrg)	Detterman 1963; Detterman and Hartsock 1966	Type section (composite): along both sides of Red Glacier, AK. Within LACL. 1. Upper 1,009 m (3,310 ft) exposed along south side of Red Glacier, 7.2 km (4.5 mi) S. 62° E. of Iliamna Volcano; 2. Lower 375 m (1,230 ft) on north side of Red Glacier, 10.5 km (6.5 mi) N. 86° E. of Iliamna Volcano.	Middle Jurassic
Horn Mountain Tuff Member, Talkeetna Formation (Jtkh)	Detterman and Hartsock 1966	Type section: Horn Mountain, from the shore of Chinitna Bay to the peak of Horn Mountain and north along the ridge to the contact with Portage Creek Agglomerate Member, Iniskin–Tuxedni region, AK. Within LACL.	Early Jurassic
Portage Creek Agglomerate Member, Talkeetna Formation (Jtkp)	Detterman and Hartsock 1966	Type section: on south shore of Tuxedni Bay. Section starts about 3.9 km (2.4 mi) northwest of Fossil Point and continues along shoreline to contact with underlying Marsh Creek Member, Iniskin Peninsula, AK. Within LACL.	Early Jurassic

Table 1 (continued). List of SWAN stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Marsh Creek Breccia Member, Talkeetna Formation (Jtkm)	Detterman and Hartsock 1966	Type section: along south shore of Tuxedni Bay, starting 9.6 km (6 mi) northwest of Fossil Point and continuing 3.6 km (2.25 mi) to contact with quartz diorite pluton, Cook Inlet region, AK. Within LACL.	Early Jurassic

Acknowledgments

Many individuals were consulted in the preparation of this report on the geologic stratotypes for the national parks of the Southwest Alaska Inventory and Monitoring Network. 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 geologic stratotype inventory and other NPS projects. Randy, Nancy and David manage the National Geologic Map Database for the United States (NGMDB, https://ngmdb.usgs.gov/ngm-bin/ngm_compsearch.pl?glx=1) and the U.S. Geologic Names Lexicon ("GEOLEX", https://ngmdb.usgs.gov/Geolex/search), the national compilation of names and descriptions of geologic units for the United States, two critical sources of geologic information for science, industry, and the American public. We also extend our appreciation to Travis Hudson (USGS retired) and Frederic (Ric) Wilson (USGS) for their professional expertise and input in reviewing this report.

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. 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 Southwest Alaska Inventory and Monitoring Network and various network parks, including Amy Miller (SWAN Coordinator). Additional thanks to Robert Blodgett for his continued support for this and other important geology projects 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 Hal Pranger, Julia Brunner, Jason Kenworthy, and Jim Wood.

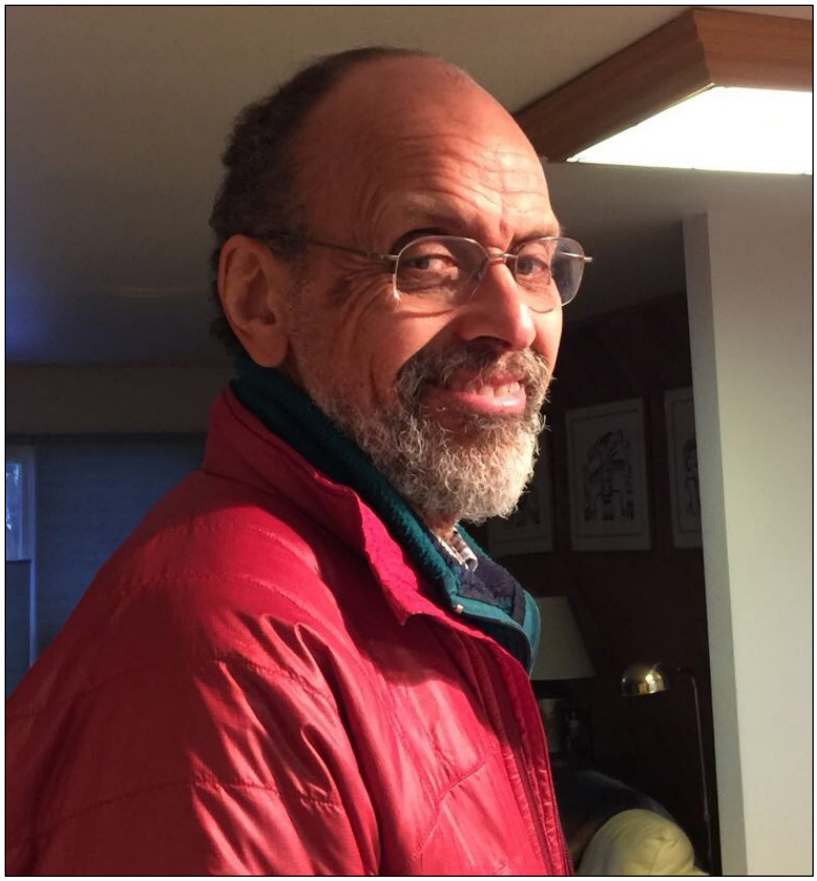
Dedication

This Southwest Alaska Inventory and Monitoring Network Geologic Type Section Inventory is dedicated to USGS geologist Frederic (Ric) Wilson.

Ric joined the Alaska Branch of the USGS in 1975 while a graduate student at the University of Alaska and moved to Menlo Park, California to become a potassium–argon geochronologist. After completing his Ph.D., Ric returned to Alaska in 1980 to build an argon extraction lab in Anchorage. Ric followed his dream to develop into a generalist; running projects in resource assessment, providing geochron support, and his favorite (geologic mapping and compilation). Back in the day, unable to use a Leroy lettering device for his first geologic map (they are extremely right-handed and Ric is left-handed), he worked to develop digital methods to overcome those challenges. Those tools ultimately led to the design of the database underlying the Alaska geologic maps that Ric has produced.

The thing Ric loves most about Alaskan geology is the variety, the history, and the complexity. He especially likes to try to envision what Alaska looked like at various times throughout geologic time. The geology of southwest Alaska, especially the Alaska Peninsula and Aleutian Islands, draws him in. Recently, Ric has been involved in an effort similar to the Alaska map in the Caribbean, but it is a poor trade to exchange glacial deposits for saprolite!

Ric's proudest accomplishment was the publication of the Geologic Map of Alaska (USGS SIM-3340) and its underlying digital database; the outcome of a long effort supported by numerous active and especially Emeritus USGS scientists. Ric is proud to have stood on the shoulders of giants, especially Robert Detterman and Florence Weber.



Ric Wilson

Introduction

The NPS Geologic Type Section Inventory Project ("Stratotype Inventory Project") is a continuation of and complements other 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 baseline geologic resource information and make it available to park managers, and advance science-informed management of natural resources in the national parks. The goals of the GRI team are to increase understanding and appreciation of the geologic features and processes in parks and to provide robust geologic information for use in park planning, decision making, public education, and resource stewardship.

Documentation of stratotypes (i.e., type sections/type localities/type areas) 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 2005). 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 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 type section inventory for the parks of the Southwest Alaska Inventory & Monitoring Network (SWAN) follows standard practices, methodologies, and organization of information introduced in the Greater Yellowstone I&M Network type section 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 have 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 occurred 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 commonly 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. 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;
- Understanding and interpretation of the geologic record depends upon 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 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 also prevents the protection of these localities from activities which 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, the hope is 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 SWAN I&M Network Parks

The Southwest Alaska Inventory and Monitoring Network (SWAN) includes five national park units located on the Alaska and Kenai peninsulas of southwestern Alaska. The five NPS units are Alagnak Wild River (ALAG), Aniakchak National Monument and Preserve (ANIA), Katmai National Park and Preserve (KATM), Kenai Fjords National Park (KEFJ), and Lake Clark National Park and Preserve (LACL) (Figure 1). Collectively, the SWAN park units encompass approximately 3.8 million hectares (9.4 million acres) and preserve exceptional geologic features, landforms, marine coastlines, aquatic systems, wilderness, flora, and fauna.

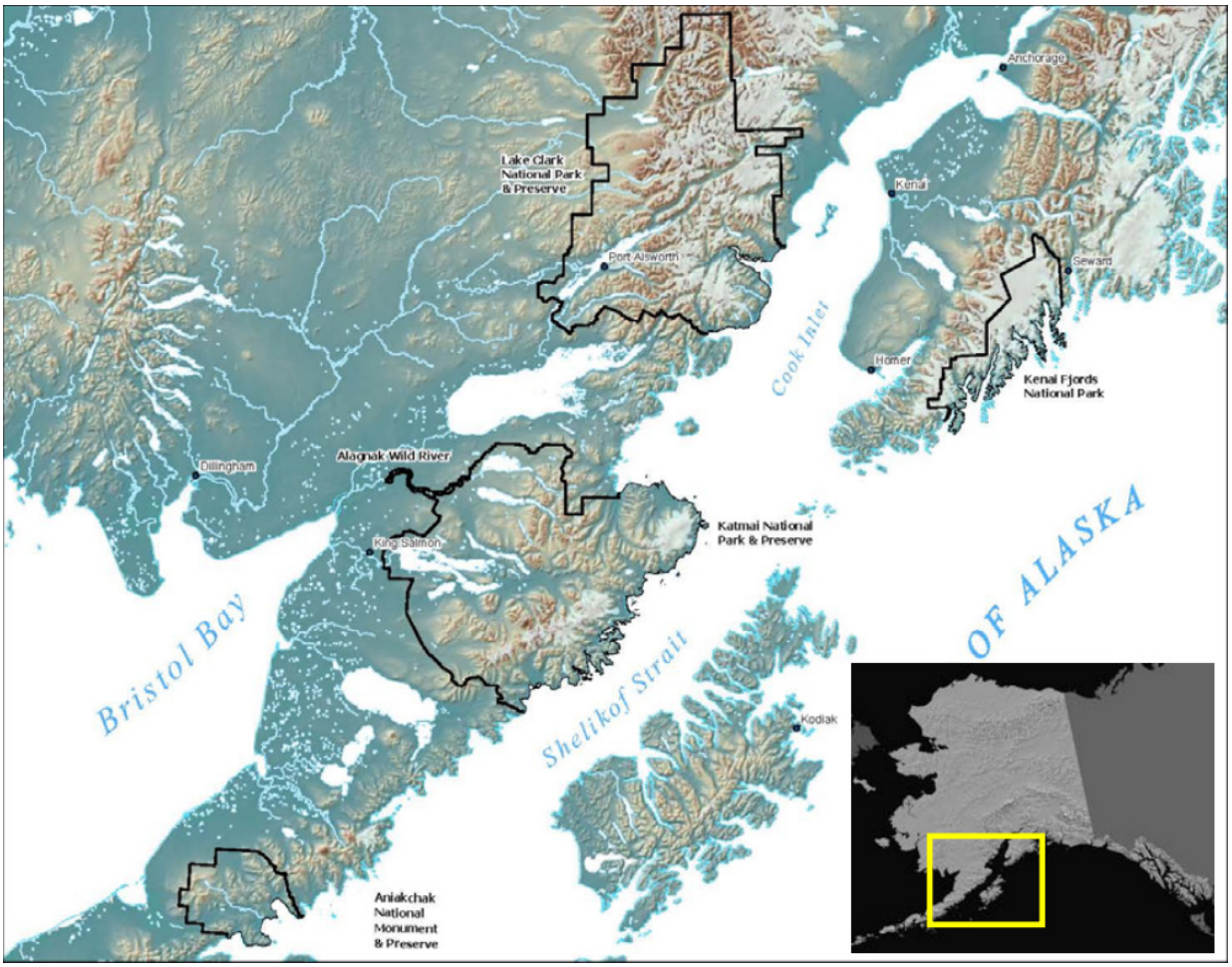


Figure 1. Map of Southwest Alaska I&M Network parks including: Alagnak Wild River (ALAG), Aniakchak National Monument and Preserve (ANIA), Katmai National Park and Preserve (KATM), Kenai Fjords National Park (KEFJ), and Lake Clark National Park and Preserve (LACL) (NPS).

The SWAN park units preserve a wide variety of geologic features and landscapes including mountains, volcanoes, and glaciers. ANIA preserves a large 3,600-year-old volcanic caldera along the volcanic arc of the Alaska Peninsula and Aleutian Islands. KATM preserves the Valley of Ten Thousand Smokes, Katmai caldera, and Novarupta which formed during the largest volcanic eruption

of the 20th century. KEFJ preserves the extensive Harding Ice Field. Geologic Resource Inventory reports for ALAG and KATM (Hults and Fierstein 2016), ANIA (Hults and Neal 2015), KEFJ (Lanik et al. 2018), and LACL (Lanik et al. in press) present detailed information on the geologic resources of these SWAN park units.

Precambrian

Precambrian rocks are not exposed in any of the parks in SWAN (see Appendix B for a geologic time scale).

Paleozoic

The only Paleozoic rocks documented in SWAN include low-grade metamorphic rocks of Paleozoic through Jurassic age that occur at ALAG and KATM.

Mesozoic

The Late Triassic-age Kamishak Formation and Cottonwood Bay Greenstone are exposed at or near KATM and LACL (Figure 2). Additionally, the Late Triassic Chilikadrotna Greenstone and the Tlikakila complex and other unnamed metamorphic rocks are present at LACL (Wilson et al. 2015).

Jurassic rocks are documented at ANIA, KATM, and LACL. The Early Jurassic Talkeetna Formation occurs at both KATM and LACL (Figure 2). The Middle Jurassic is represented at KATM by the Shelikof Formation, and a half-dozen Middle Jurassic formations within the Tuxedni Group are mapped at LACL (Wilson et al. 2015). The Late Jurassic Naknek Formation is mapped at ANIA, KATM, and LACL (Figure 2). Extensive Jurassic and Cretaceous plutonic rocks are mapped in LACL and KATM (Wilson et al. 2015).

Rocks of Early Cretaceous age are represented by the Staniukovich, Herendeen and Pedmar Formations at KATM, and igneous dikes at KEFJ span from the Early Cretaceous into the Cenozoic (Figure 2). Late Cretaceous units include the Hoodoo and Chignik Formations at ANIA, the Valdez Group at KEFJ, the Kuskokwim Group at LACL, and the Kaguyak Formation at KATM and LACL (Figure 2; Wilson et al. 2015).

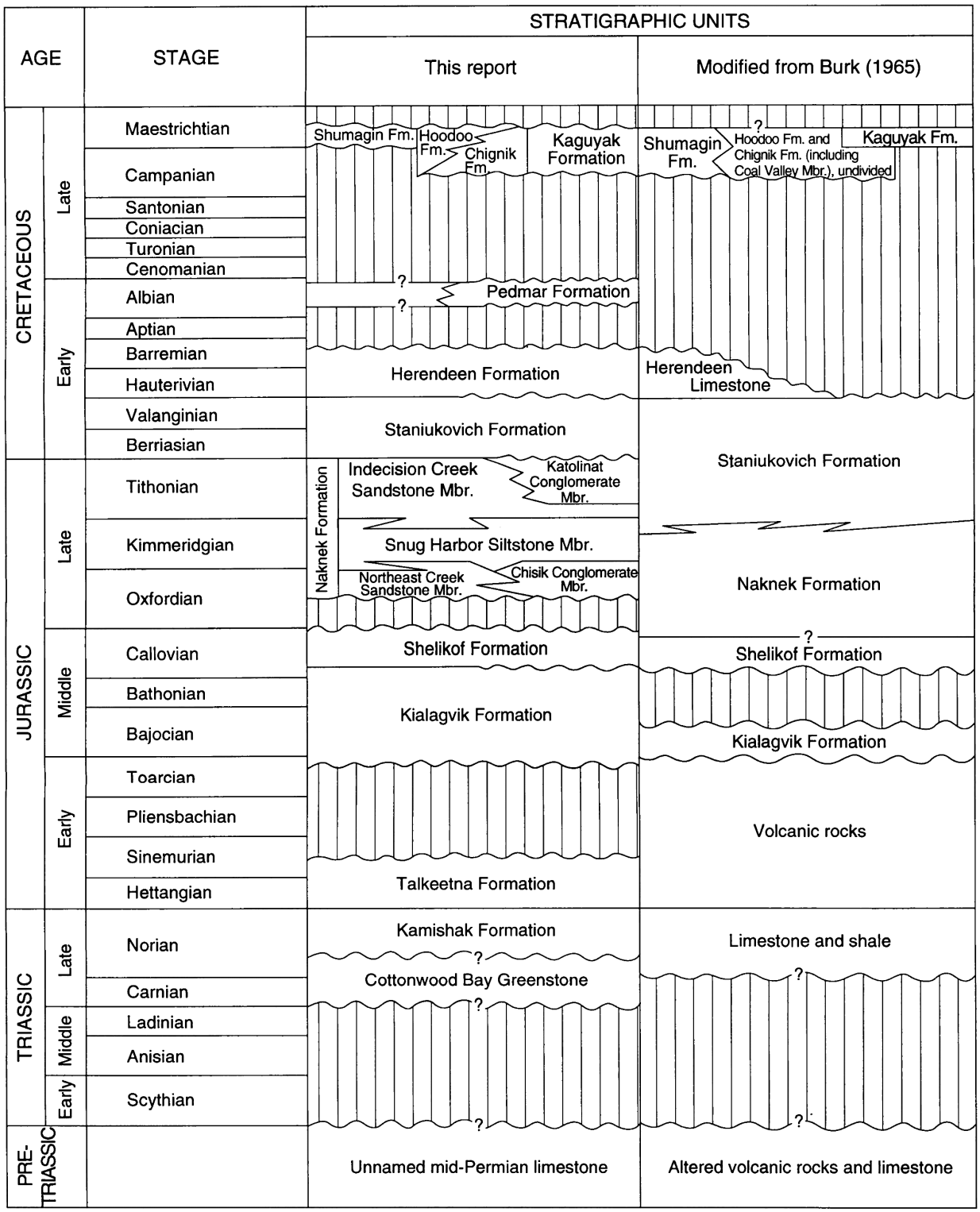


Figure 2. Correlation chart of Mesozoic stratigraphic units, Alaska Peninsula. Figure modified from Detterman et al. (1996: Figure 4).

Cenozoic

Igneous rocks are documented during the Cenozoic for all the SWAN parks. Paleocene and Eocene units include the Tolstoi Formation (ANIA), Copper Lake Formation (KATM), and West Foreland Formation (LACL) (Figure 3). Granitic rocks of the Harding Icefield region date to the Paleocene and Eocene. The Meshik Volcanics, which range in age from Middle Eocene to Early Oligocene, are documented in ANIA, KATM and LACL (Figure 3). The Hemlock Conglomerate is a Late Oligocene unit at KATM. The Tyonek Formation is a Late Oligocene–Middle Miocene unit mapped at LACL. The Gibraltar Lake Tuff at KATM is between Oligocene and Pliocene in age, though likely Pliocene. Quaternary surficial units occur in all of the SWAN park units (Wilson et al. 2015).

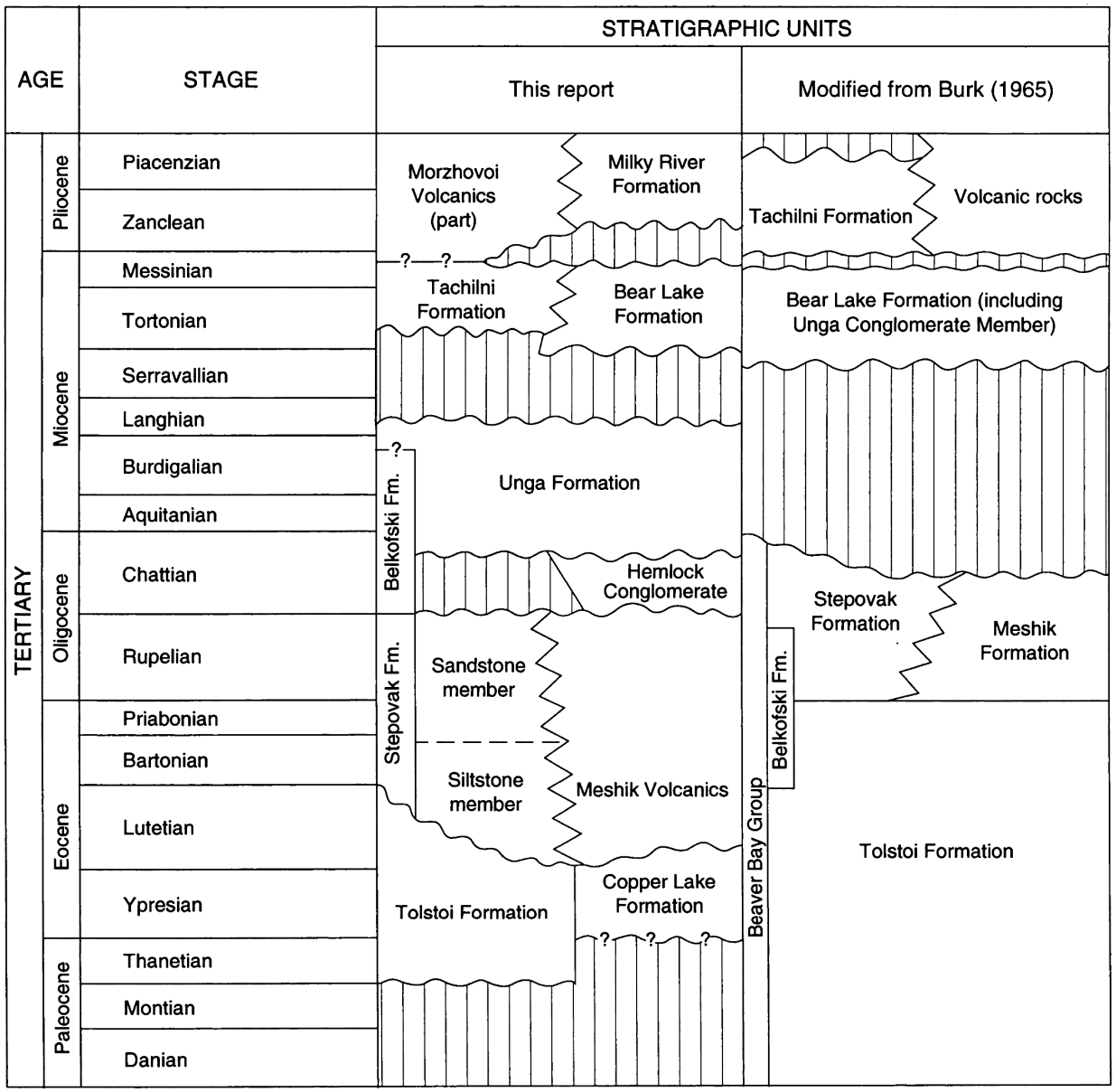


Figure 3. Correlation chart of Tertiary stratigraphic units, Alaska Peninsula. Figure modified from Detterman et al. (1996: Figure 12).

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 and the Colorado State University Department of Geosciences to produce GRI products.

GRI Products

The GRI team undertakes three 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, and (3) provide a GRI report. These products are designed and written for non-geoscientists.

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. Scoping sessions were held for all of the SWAN park units between February 14–18, 2005.

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 2020, GRI reports have been completed for ANIA, ALAG, KATM, and KEFJ; LACL is scheduled for publication in FY 2021. 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 SWAN parks follows the selected source maps and includes components such as: faults, mine area features, mine point features, geologic units (bedrock, surficial, glacial), geologic contacts, 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 the usage and societal value of geologic maps.

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. GRI has produced various maps for the SWAN parks.

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 a master geology document (PDF) for a specific park. The GRI team uses a unique "GMAP ID" value for each geologic source map, and all sources used to produce the GRI GIS datasets for the SWAN 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 ALAG, KATM, and LACL was compiled using data model version 2.3, which is available at https://www.nps.gov/articles/gri-geodatabase-model.htm; the ANIA and KEFJ data are based on older data models and need to be upgraded to the most recent version. The data model dictates the 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 ALAG, ANIA, KATM, KEFJ, or LACL from the unit list.

The following components are part of the data set:

- 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

Selected geologic data is draped over shaded relief images of the park and surrounding area to create a poster 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 in the GRI posters. 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 (1:250,000, 1:100,000, 1:63,360, and 1:24,000) and U.S. National Map Accuracy Standards (https://pubs.usgs.gov/fs/1999/0171/report.pdf), 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

We describe here the methods employed and definitions adopted during this inventory of geologic stratotypes located within the SWAN parks. This report is part of an inventory of geologic stratotypes throughout the parks of the National Park System. Therefore, the methods, definitions, and challenges identified here pertain not only to the park units of SWAN, but are for broader application throughout the park units of the National Park System.

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. For some park units specific information is not available which limits the final report. No fieldwork was done as part of this inventory, which is therefore dependent on existing information for 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 which transcend state boundaries. Geologic formations and other units which cross state boundaries may be referenced with different names in each of the states the units are mapped. An example would be the Triassic Chugwater Formation in Wyoming, which is equivalent to the Spearfish Formation in the Black Hills of South Dakota and Wyoming.

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

This inventory report is intended for a wide audience, including NPS staff who might 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 4).

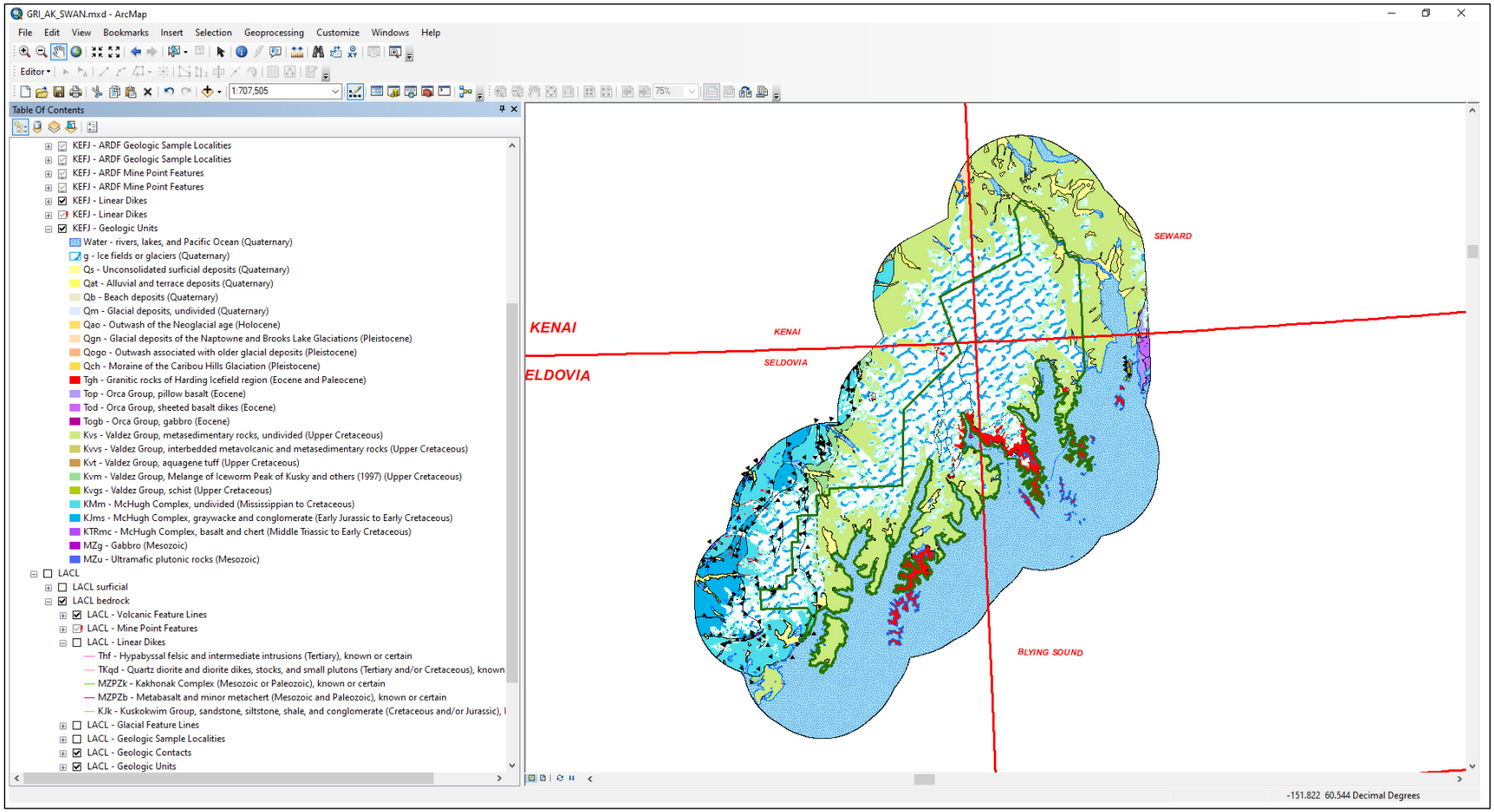


Figure 4. Screenshot of digital geologic map of Kenai Fjords National Park listing mapped units.

Each map unit name is then queried in the U.S. 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 5 below is taken from a search on the Kaguyak Formation.

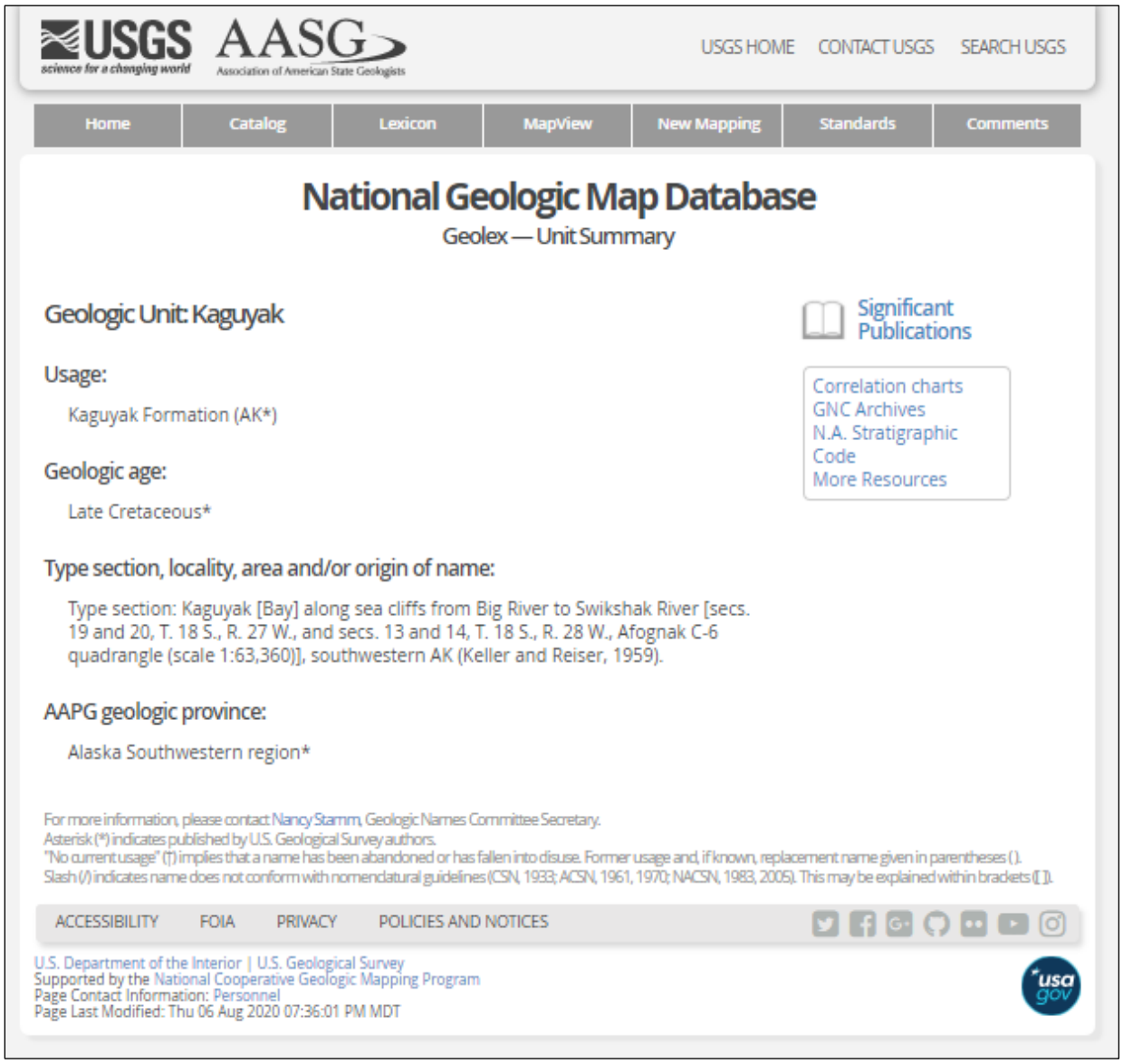
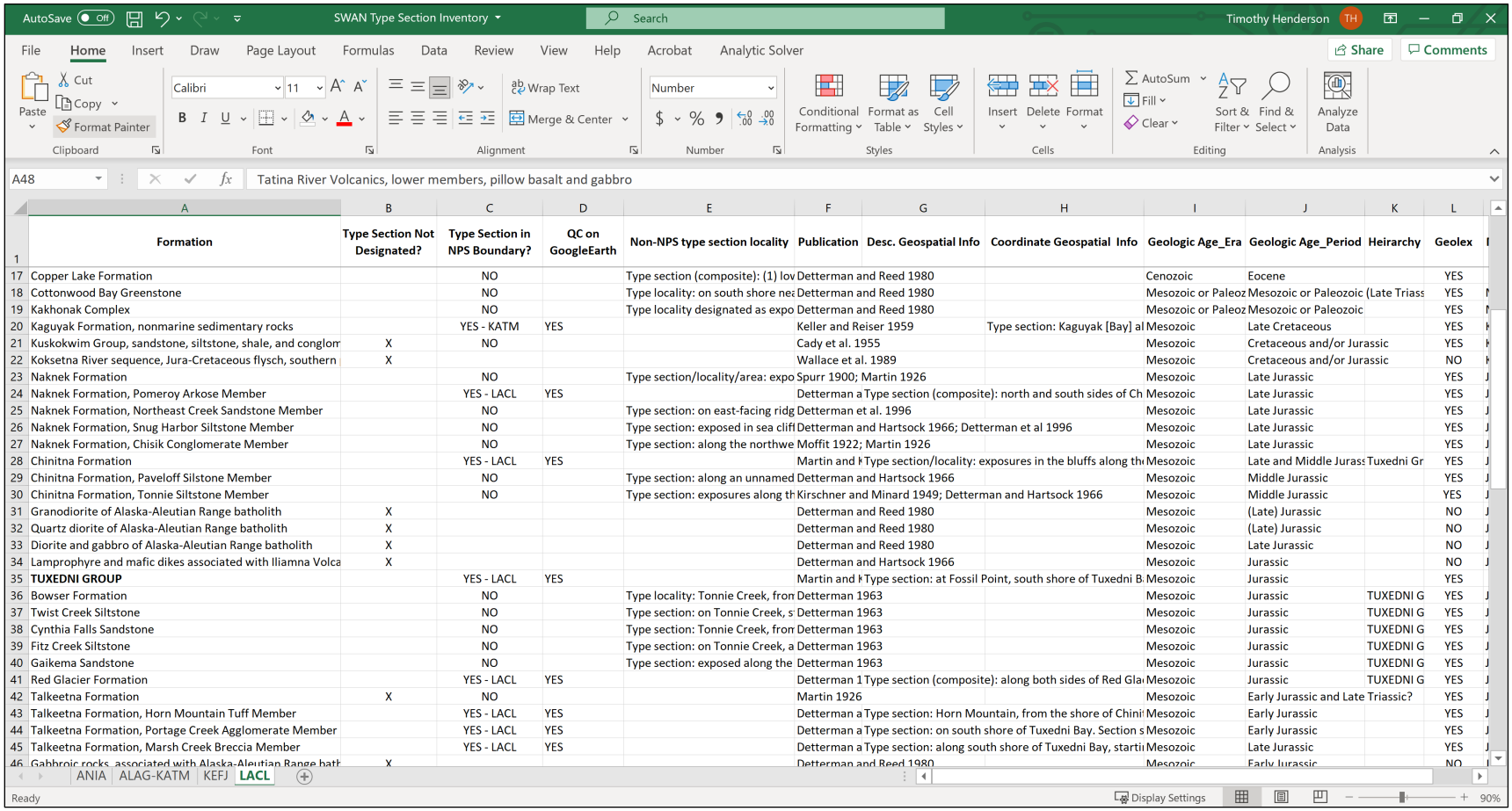


Figure 5. GEOLEX search result for the Kaguyak Formation.

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 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) is a stratotype officially designated; (2) is the stratotype on NPS land; (3) has it undergone a quality control check in Google Earth using a GRI digital geologic map overlay; (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) was the geologic unit found in GEOLEX; and (10) a generic notes field (Figure 6).



A48 | Tatina River Volcanics, lower members, pillow basalt and gabbro

	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
17	Copper Lake Formation		NO		Type section (composite): (1) lov	Detterman and Reed 1980			Cenozoic	Eocene		YES
18	Cottonwood Bay Greenstone		NO		Type locality: on south shore nea	Detterman and Reed 1980			Mesozoic or Paleoz	Mesozoic or Paleozoic (Late Triass		YES
19	Kakhonak Complex		NO		Type locality designated as expo	Detterman and Reed 1980			Mesozoic or Paleoz	Mesozoic or Paleozoic		YES
20	Kaguyak Formation, nonmarine sedimentary rocks		YES - KATM	YES		Keller and Reiser 1959		Type section: Kaguyak [Bay] al	Mesozoic	Late Cretaceous		YES
21	Kuskokwim Group, sandstone, siltstone, shale, and conglom	X	NO			Cady et al. 1955			Mesozoic	Cretaceous and/or Jurassic		YES
22	Koksetna River sequence, Jura-Cretaceous flysch, southern	X				Wallace et al. 1989			Mesozoic	Cretaceous and/or Jurassic		NO
23	Naknek Formation		NO		Type section/locality/area: expo	Spurr 1900; Martin 1926			Mesozoic	Late Jurassic		YES
24	Naknek Formation, Pomeroy Arkose Member		YES - LACL	YES		Detterman a	Type section (composite): north and south sides of Ch		Mesozoic	Late Jurassic		YES
25	Naknek Formation, Northeast Creek Sandstone Member		NO		Type section: on east-facing ridg	Detterman et al. 1996			Mesozoic	Late Jurassic		YES
26	Naknek Formation, Snug Harbor Siltstone Member		NO		Type section: exposed in sea cliff	Detterman and Hartsock 1966; Detterman et al 1996			Mesozoic	Late Jurassic		YES
27	Naknek Formation, Chisik Conglomerate Member		NO		Type section: along the northwe	Moffit 1922; Martin 1926			Mesozoic	Late Jurassic		YES
28	Chinitna Formation		YES - LACL	YES		Martin and k	Type section/locality: exposures in the bluffs along th		Mesozoic	Late and Middle Jurass	Tuxedni Gr	YES
29	Chinitna Formation, Paveloff Silstone Member		NO		Type section: along an unnamed	Detterman and Hartsock 1966			Mesozoic	Middle Jurassic		YES
30	Chinitna Formation, Tonnie Siltstone Member		NO		Type section: exposures along th	Kirschner and Minard 1949; Detterman and Hartsock 1966			Mesozoic	Middle Jurassic		YES
31	Granodiorite of Alaska-Aleutian Range batholith	X				Detterman and Reed 1980			Mesozoic	(Late) Jurassic		NO
32	Quartz diorite of Alaska-Aleutian Range batholith	X				Detterman and Reed 1980			Mesozoic	(Late) Jurassic		NO
33	Diorite and gabbro of Alaska-Aleutian Range batholith	X				Detterman and Reed 1980			Mesozoic	Late Jurassic		NO
34	Lamprophyre and mafic dikes associated with Iliamna Volca	X				Detterman and Hartsock 1966			Mesozoic	Jurassic		NO
35	**TUXEDNI GROUP**		YES - LACL	YES		Martin and k	Type section: at Fossil Point, south shore of Tuxedni B		Mesozoic	Jurassic		YES
36	Bowser Formation		NO		Type locality: Tonnie Creek, fron	Detterman 1963			Mesozoic	Jurassic	TUXEDNI G	YES
37	Twist Creek Siltstone		NO		Type section: on Tonnie Creek, s	Detterman 1963			Mesozoic	Jurassic	TUXEDNI G	YES
38	Cynthia Falls Sandstone		NO		Type section: Tonnie Creek, fron	Detterman 1963			Mesozoic	Jurassic	TUXEDNI G	YES
39	Fitz Creek Siltstone		NO		Type section: on Tonnie Creek, a	Detterman 1963			Mesozoic	Jurassic	TUXEDNI G	YES
40	Gaikema Sandstone		NO		Type section: exposed along the	Detterman 1963			Mesozoic	Jurassic	TUXEDNI G	YES
41	Red Glacier Formation		YES - LACL	YES		Detterman 1	Type section (composite): along both sides of Red Gla		Mesozoic	Jurassic	TUXEDNI G	YES
42	Talkeetna Formation	X	NO			Martin 1926			Mesozoic	Early Jurassic and Late Triassic?		YES
43	Talkeetna Formation, Horn Mountain Tuff Member		YES - LACL	YES		Detterman a	Type section: Horn Mountain, from the shore of Chini		Mesozoic	Early Jurassic		YES
44	Talkeetna Formation, Portage Creek Agglomerate Member		YES - LACL	YES		Detterman a	Type section: on south shore of Tuxedni Bay. Section s		Mesozoic	Early Jurassic		YES
45	Talkeetna Formation, Marsh Creek Breccia Member		YES - LACL	YES		Detterman a	Type section: along south shore of Tuxedni Bay, startii		Mesozoic	Late Jurassic		YES
46	Gabbroic rocks, associated with Alaska-Aleutian Range bath	X				Detterman and Reed 1980			Mesozoic	Early Jurassic		NO

ANIA | ALAG-KATM | KEFJ | LACL

Figure 6. Stratotype inventory spreadsheet of the SWAN 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 adopted for this inventory. This code describes explicit practices for classifying and naming all formally defined geologic units. An important designation for a geologic unit is known as a ***stratotype***–the standard (original or subsequently designated) basis for definition or recognition of a geologic unit or boundary (North American Commission on Stratigraphic Nomenclature 2005). There are several variations of stratotypes in the literature and this report, and they are defined as following:

(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 2005). Once a unit stratotype is assigned, it is never changed (unless the unit is abandoned). 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 2005).

(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 2005). 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 2005).

(4) **Lithodeme**: the term "lithodeme" is defined as a mappable unit of plutonic (igneous rock that solidified at great depth), highly metamorphosed, or pervasively deformed rock and is a term equivalent in rank to "formation" among stratified rocks (North American Commission on Stratigraphic Nomenclature 2005). The formal name of a lithodeme consists of a geographic name followed by a descriptive term that denotes the average modal composition or lithology of the rock (example: Cathedral Peak Granodiorite). Lithodemes are commonly assigned type localities, type areas, and reference localities.

Alagnak Wild River (ALAG)

Alagnak Wild River (ALAG) is west of the Aleutian Range in the Bristol Bay and Lake and Peninsula Boroughs, Alaska (Figure 7). Established on December 2, 1980, ALAG encompasses ~12,409 hectares (30,741 acres) and protects 110 km (67 mi) of the Alagnak River, its scenic landscape, natural features, cultural heritage, and recreational activities (Anderson 2017). The headwaters of the Alagnak River are in neighboring Katmai National Park and Preserve, where the river flows northwest from Kukaklek Lake to its confluence with the Kvichak River. The river system is home to a diverse array of wildlife, including an important sockeye (red) salmon fishery, and is a critical natural resource for southwest Alaska (Hults and Fierstein 2016).

The geology along the Alagnak River reflects an active landscape shaped by the dynamic forces of volcanism, glaciation, wind and river erosion, and active tectonics. Geologic units along the Alagnak River Valley predominantly consist of Pleistocene glacial drift and outwash deposits of the Mak Hill Glaciation and Brooks Lake Glaciation (Figure 8). The oldest units within the park unit are found along the northeastern boundary and are the metamorphic rocks of the Late Jurassic and older Kakhonak Complex. As the Alagnak River flows northwest, exposed units along the river include the Eocene–Oligocene Meshik Volcanics, Pleistocene glacial deposits, and Quaternary alluvium (unconsolidated clay, silt, sand, and gravel), alluvial terrace deposits, solifluction deposits ("soil flow"), abandoned channel deposits, and eolian deposits.

There are no designated stratotypes identified within the boundaries of ALAG. There is one identified stratotype located within 48 km (30 mi) of ALAG boundaries, for the Jurassic Naknek Formation (type section).

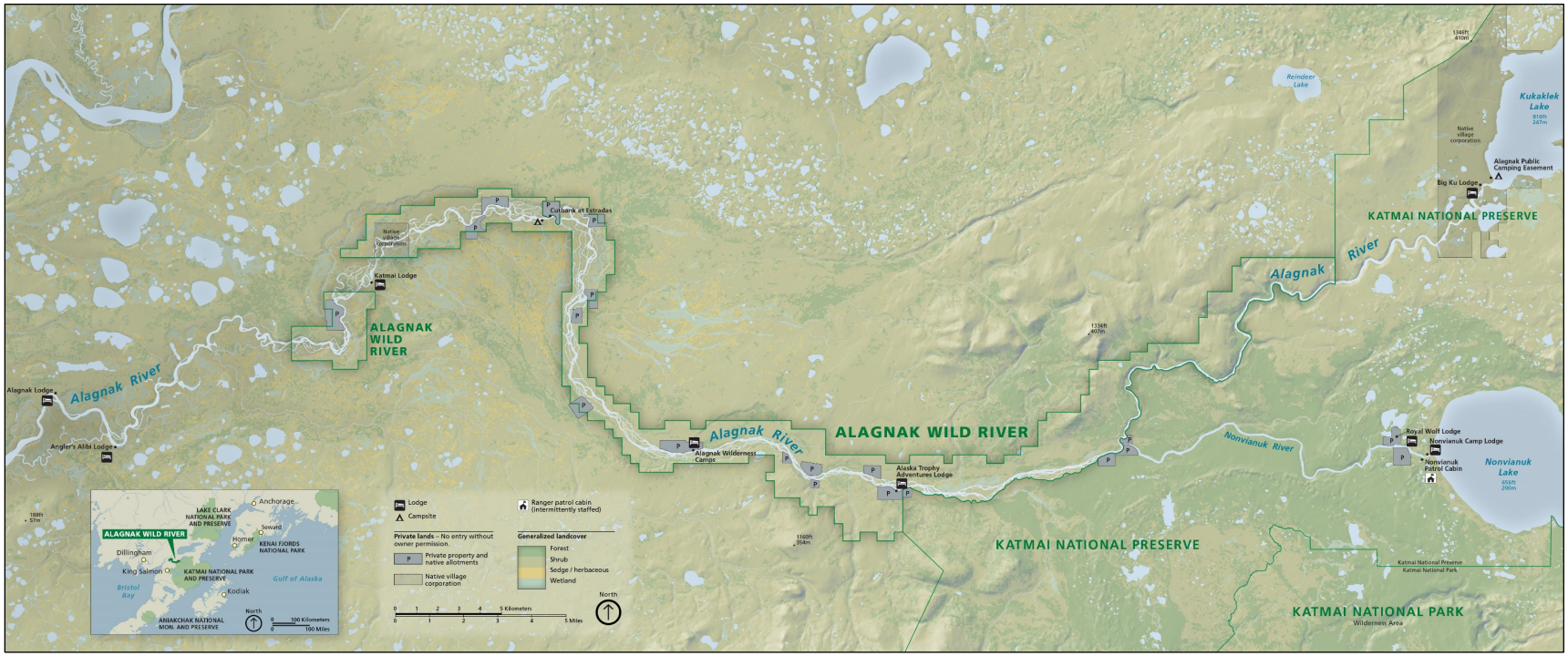


Figure 7. Park map of ALAG, Alaska (NPS).

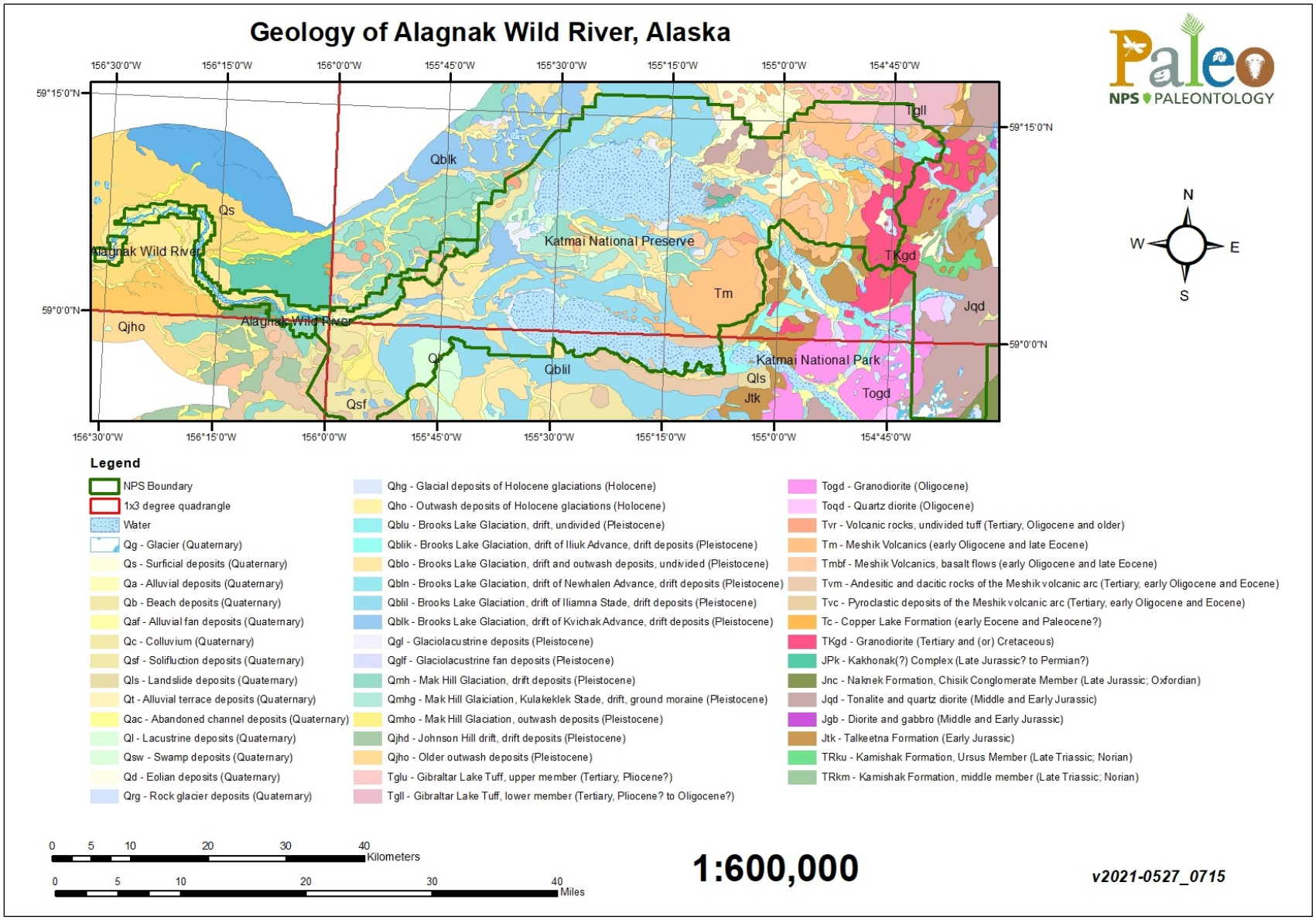


Figure 8. Geologic map of ALAG, Alaska.

Aniakchak National Monument and Preserve (ANIA)

Aniakchak National Monument and Preserve (ANIA) is located on the Alaska Peninsula in the Lake and Peninsula Borough, Alaska (Figure 9). Originally proclaimed as Aniakchak National Monument on December 1, 1978, the monument was expanded to include the national preserve on December 2, 1980. ANIA includes approximately 244,226 hectares (603,497 acres) of volcanic landscapes, glaciated mountains, and coastal landforms associated with the Aleutian Range (Anderson 2017). The park unit namesake, Aniakchak Caldera, is a product of a historically active volcano and represents one of the best exposed calderas on earth (Hults and Neal 2015). Aniakchak Volcano last erupted in 1931 through Vent Mountain; the caldera contains lava flows, cinder cones, explosion pits, and Surprise Lake, the source of the Aniakchak River, whose headwaters cascade through The Gates, a 457 m (1,500 ft) high breach in the crater wall.

The geology of ANIA consists of sedimentary and igneous rocks that range in age from Late Jurassic to recent volcanic deposits associated with Aniakchak Caldera (Figure 10). Quaternary volcanic deposits associated with Aniakchak Volcano blanket a large portion of northwestern ANIA and predominantly consist of pyroclastic deposits (rocks composed of fragments produced and ejected by explosive volcanic eruptions) and debris flows. These volcanic deposits have been sculpted by glaciers and erosion to form amazing landforms (Hults and Neal 2015). The oldest geologic units exposed in ANIA are primarily located in the northeastern area of the monument just north of Amber Bay and are of the Late Jurassic Naknek Formation. The Naknek Formation and younger sedimentary bedrock units of ANIA include marine and non-marine sedimentary rocks that contain abundant invertebrate fossils, plant fossils, and locally, dinosaur tracks (Hults and Neal 2015).

ANIA contains two identified stratotypes that define the Jurassic Snug Harbor Siltstone and Northeast Creek Sandstone Members of the Naknek Formation (Table 2; Figure 11). In addition to the designated stratotypes located within ANIA, stratotypes located within 48 km (30 mi) of park boundaries include the Jurassic Indecision Creek Sandstone Member of the Naknek Formation (type section) and Cretaceous Chignik Formation (type area and reference section).

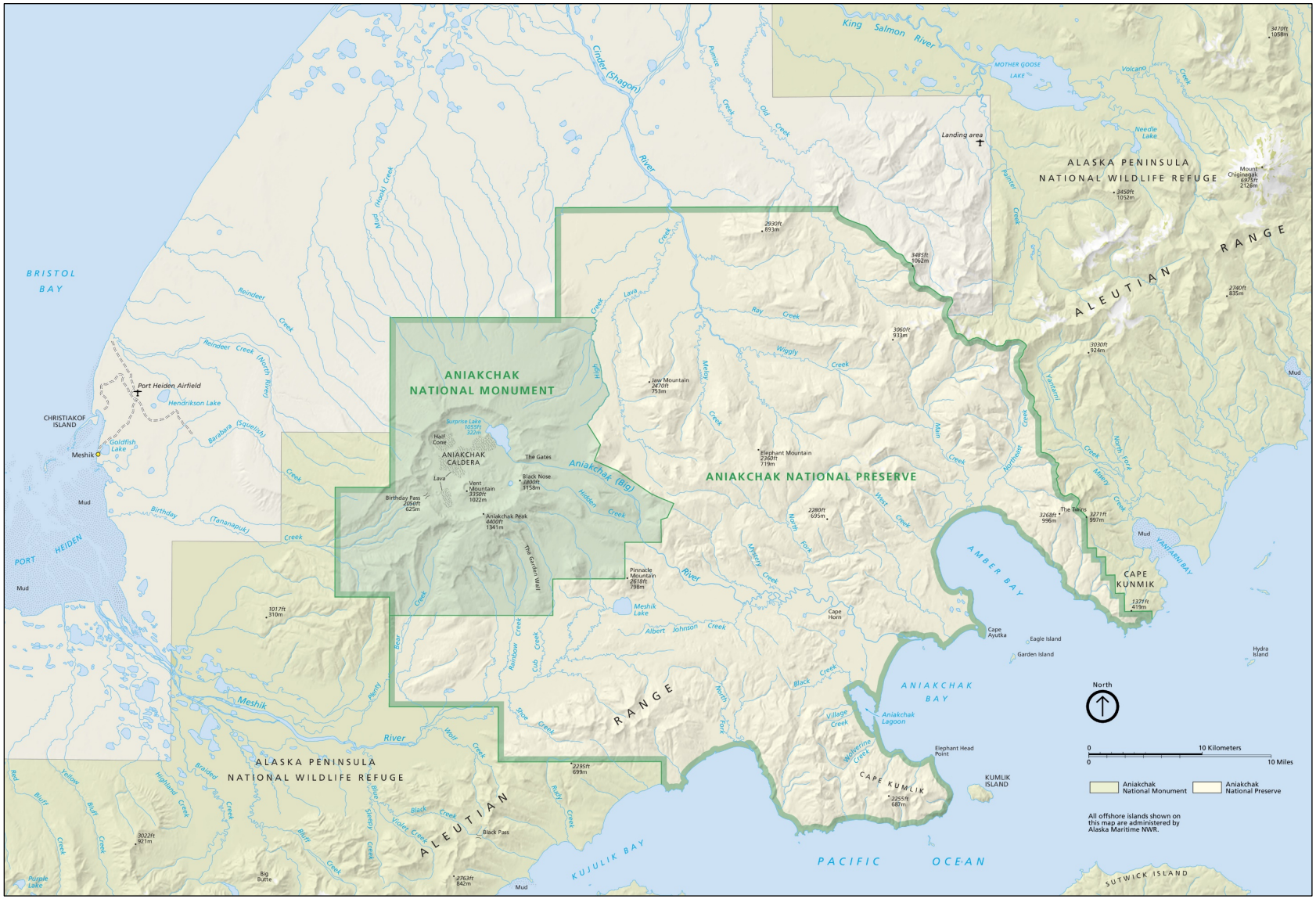


Figure 9. Park map of ANIA, Alaska (NPS).

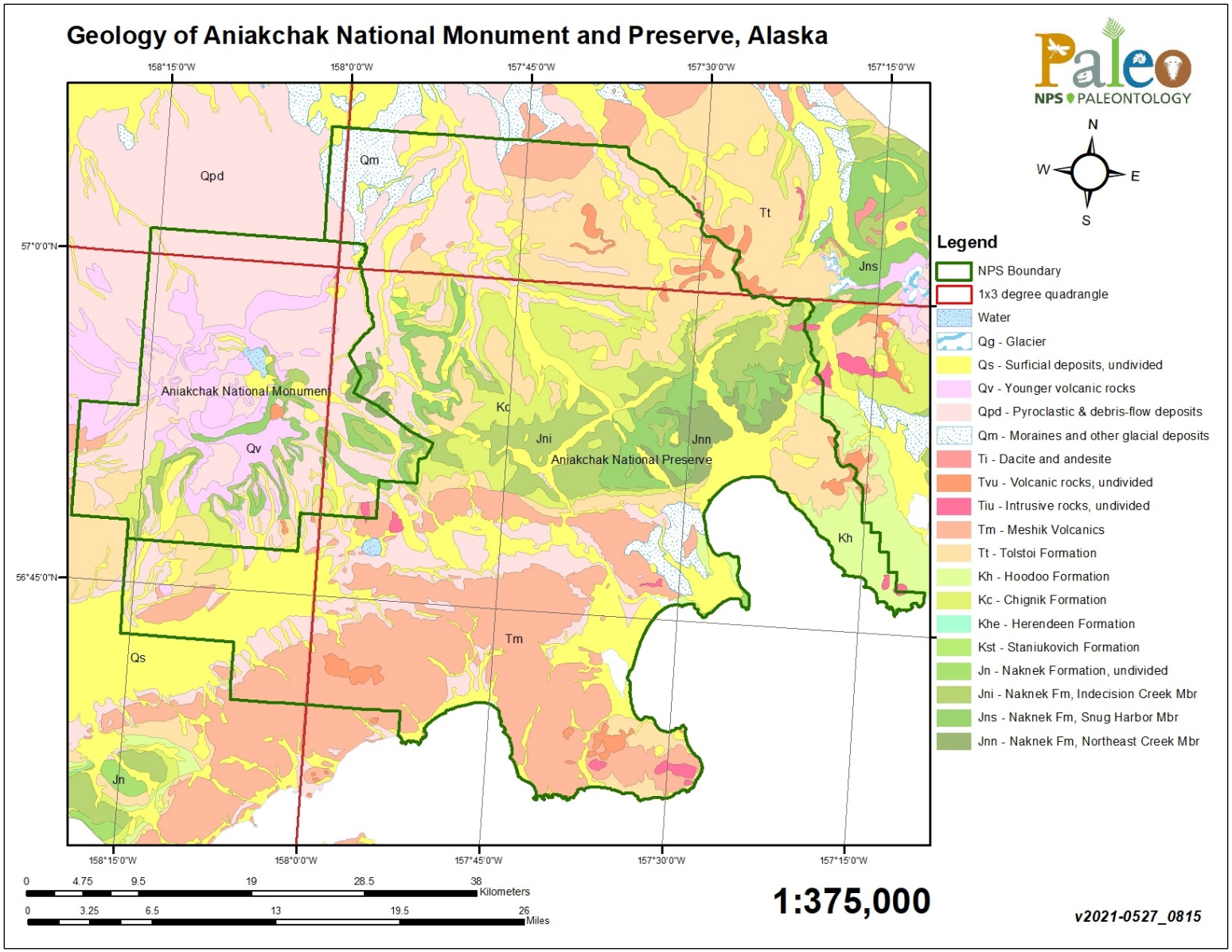


Figure 10. Geologic map of ANIA, Alaska.

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

Unit Name (map symbol)	Reference	Stratotype Location	Age
Snug Harbor Siltstone Member, Naknek Formation (Jns)	Detterman et al. 1996	Reference section: along Northeast Creek (~1 km [0.6 mi] north of Northeast Creek Sandstone Member type section), on top of and extending down the southeast face of flat-topped ridge, in sec. 27, T. 37 S., R. 51 W., Sutwik Island D-5 Quadrangle (scale 1:63,360), Alaska Peninsula, AK.	Late Jurassic, Kimmeridgian –late Oxfordian
Northeast Creek Sandstone Member, Naknek Formation (Jnn)	Detterman et al. 1996	Type section: on east-facing ridge and extending down to tributary of Northeast Creek, in sec. 34, T. 37 S., R. 51 W., Sutwik Island D-5 Quadrangle (scale 1:63,360), Alaska Peninsula, AK.	Late Jurassic, Oxfordian

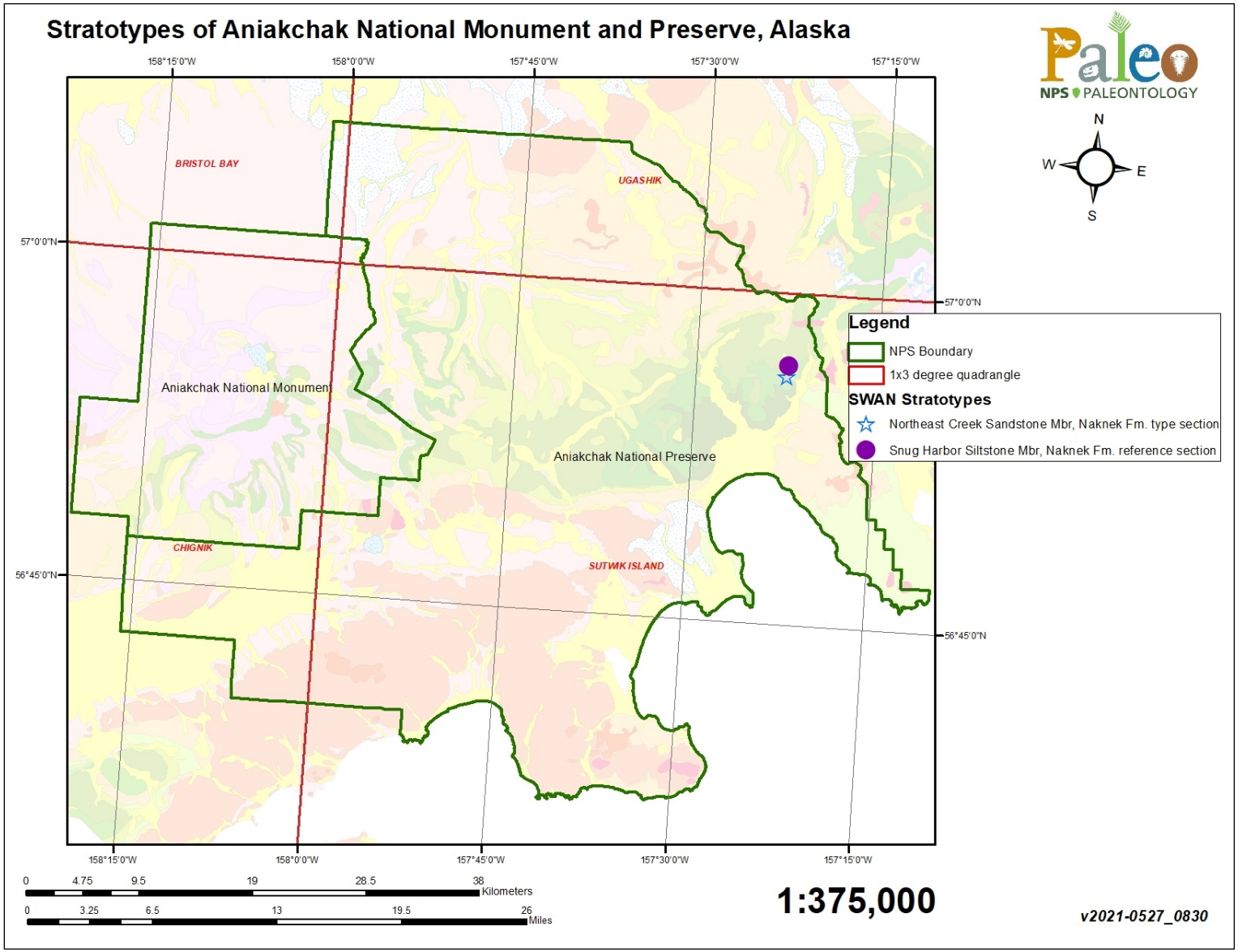


Figure 11. Modified geologic map of ANIA showing stratotype locations. The transparency of the geologic units layer has been increased.

The Late Jurassic (Oxfordian) Northeast Creek Sandstone Member of the Naknek Formation was named by Detterman et al. (1996) after exposures along Northeast Creek in the Sutwik Island D-5 Quadrangle, Alaska. Detterman et al. (1996) designated the type section on an east-facing ridge in sec. 34, T. 37 S., R. 51 W., where the section begins at the top of the ridge and extends down to a tributary of Northeast Creek (Table 2; Figure 11). The type section measures about 625 m (2,050 ft) thick and predominantly consists of yellowish- to brownish-gray, fine- to medium-grained, cross-bedded, laminated sandstone with intervals of locally bioturbated siltstone (Detterman et al. 1996). At the type section, the member conformably underlies the Snug Harbor Siltstone Member and the basal contact of the Northeast Creek Sandstone is not exposed at the type section.

The Late Jurassic (Kimmeridgian to late Oxfordian) Snug Harbor Siltstone Member of the Naknek Formation was proposed by Detterman and Hartsock (1966) for excellent exposures in the sea cliffs at Snug Harbor on the southwest end of Chisik Island, southwestern Alaska. A reference section of the member is designated on Northeast Creek, within ANIA, approximately 1 km (0.6 mi) north of the Northeast Creek Sandstone Member type section in the Sutwik D-5 Quadrangle (Table 2; Figure 11; Detterman et al. 1996). The reference section extends down the southeast face of a flat-topped ridge in sec. 27, T. 37 S, R. 51 W. and measures 637 m (2,090 ft) thick. The reference section predominantly consists of dark-gray, thin-bedded siltstone and yellowish-brown, thin- to medium-bedded, fine- to medium-grained sandstone. It conformably overlies the Northeast Creek Sandstone Member (Detterman et al. 1996).

Katmai National Park and Preserve (KATM)

Katmai National Park and Preserve (KATM) is located on the Alaska Peninsula within the active Aleutian volcanic arc in the Bristol Bay, Kenai Peninsula, Kodiak Island, and Lake and Peninsula Boroughs, Alaska (Figure 12). Originally established as Katmai National Monument on September 24, 1918, the park unit was re-designated as a national park and preserve on December 2, 1980 (Anderson 2017). KATM encompasses approximately 1,656,405 hectares (4,093,067 acres) of diverse landscape that contains lakes, forests, mountains, and marshlands that host a rich biological community. The park and preserve protect the remnants of the massive 1912 eruption that formed the Novarupta volcanic vent, the small Katmai Caldera, and the Valley of Ten Thousand Smokes (Hults and Fierstein 2016). Preservation of the volcanic features provides a valuable data-store for scientific analysis of the eruption and its ecological impact, response, and recovery (Hults and Fierstein 2016).

The geology of KATM reflects one of the most geologically active areas in North America and has been influenced by the dynamic forces of plate tectonics, volcanism, glaciation, rivers, waves, and wind. The Bruin Bay Fault bisects the park unit along a NE–SW trend juxtaposing two distinctly different bedrock assemblages (Figures 13 and 14). Northwest of the fault, geologic units consist of Mesozoic rocks including the Kakhonak Complex, Cottonwood Bay Greenstone, Kamishak Formation, Talkeetna Formation, and intrusive igneous rocks. Younger units of the northwestern region include Cenozoic volcanic and intrusive rocks, and Quaternary glacial deposits and alluvium. Southeast of the fault, the geology is composed of gently folded, Mesozoic marine sedimentary rocks of the Shelikof, Naknek, Staniukovich, Herendeen, Pedmar, and Kaguyak Formations (Hults and Fierstein 2016). Cenozoic units of southeastern KATM include the Copper Lake Formation, Hemlock Conglomerate, Cenozoic intrusive and volcanic rocks, Quaternary glacial deposits and other unconsolidated deposits, and younger volcanic deposits associated with the historic 1912 eruption.

KATM contains six identified stratotypes that represent the Upper Jurassic Katolinat Conglomerate Member of the Naknek Formation, the Lower Cretaceous Pedmar Formation, the Upper Cretaceous Kaguyak Formation, and the Paleocene–Eocene Ketavik Formation (Table 3; Figure 15). In addition to the designated stratotypes located within KATM, stratotypes located within 48 km (30 mi) of park boundaries include the Triassic Kamishak Formation (reference section), Bruin Limestone Member of the Kamishak Formation (type locality), Triassic–Jurassic Kakhonak Complex (type locality), Middle Jurassic Shelikof Formation (type section), Upper Jurassic Naknek Formation (type section), Paleocene–Eocene Copper Lake Formation (upper, middle, and lower members–type sections), Pliocene Gibraltar Lake Tuff (type locality), and the Pliocene Intricate Basalt (type locality).

Figure 12. Park map of KATM, Alaska (NPS). ALAG is shown to the northwest of KATM.

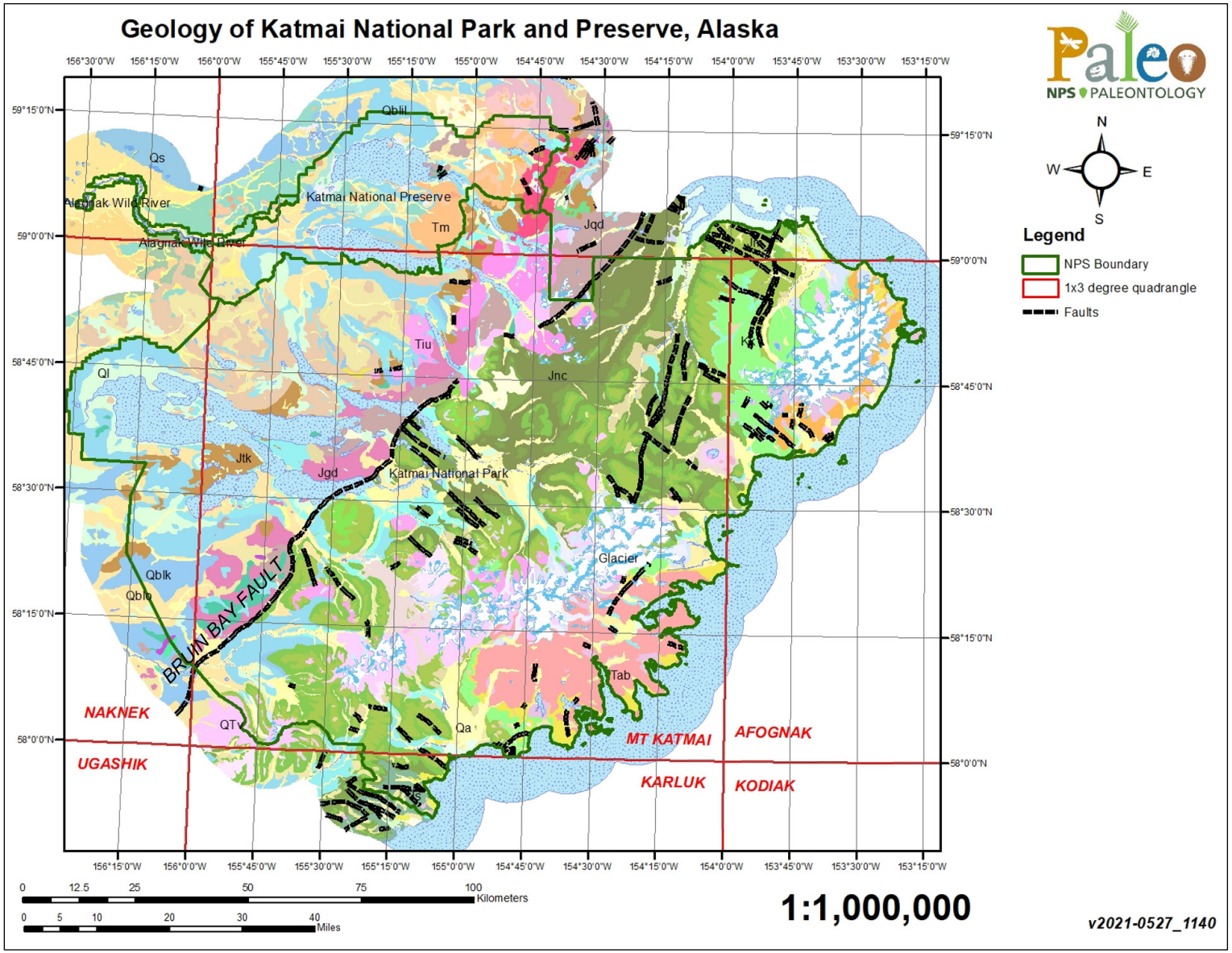


Figure 13. Geologic map of KATM and ALAG, Alaska. See Figure 14 for legend.

Figure 14. Geologic map legend of KATM and ALAG, Alaska.

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

Unit Name (map symbol)	Reference	Stratotype Location	Age
Ketavik Formation	Parrish et al. 2010	Type section: on the southern shore of Naknek Lake, where exposures extend from approximately 0.7 km (0.4 mi) north to 5.2 km (3.2 mi) northwest of Brooks Camp; type section on east side of fault. Reference section: on the southern shore of Naknek Lake, where exposures extend from approximately 0.7 km (0.4 mi) north to 5.2 km (3.2 mi) northwest of Brooks Camp; reference section on west side of fault. Type locality: nears Brooks Camps, KATM.	Paleocene–Eocene
Kaguyak Formation (Kks)	Keller and Reiser 1959	Type section: Swikshak Bay along sea cliffs from Big River to Swikshak River [secs. 19 and 20, T. 18 S., R. 27 W., and secs. 13 and 14, T. 18 S., R. 28 W., Afognak C-6 Quadrangle (scale 1:63,360)], AK	Late Cretaceous, early Maastrichtian
Pedmar Formation (Kp)	Detterman et al. 1996	Type section: in sea cliff, Katmai Bay, along north edge of sec. 26, T. 25 S., R. 34 W., Mount Katmai A-3 Quadrangle (scale 1:63,360), Alaska Peninsula, AK.	Early Cretaceous, Albian
Katolinat Conglomerate Member, Naknek Formation (Jnk)	Detterman et al. 1996	Type section: exposures on unnamed mountain on northeast shore of Grosvenor Lake, in secs. 33 and 34, T. 17 S., R. 35 W., Mount Katmai C-4 Quadrangle (scale 1:63,360), Alaska Peninsula, AK	Late Jurassic, late(?) Tithonian

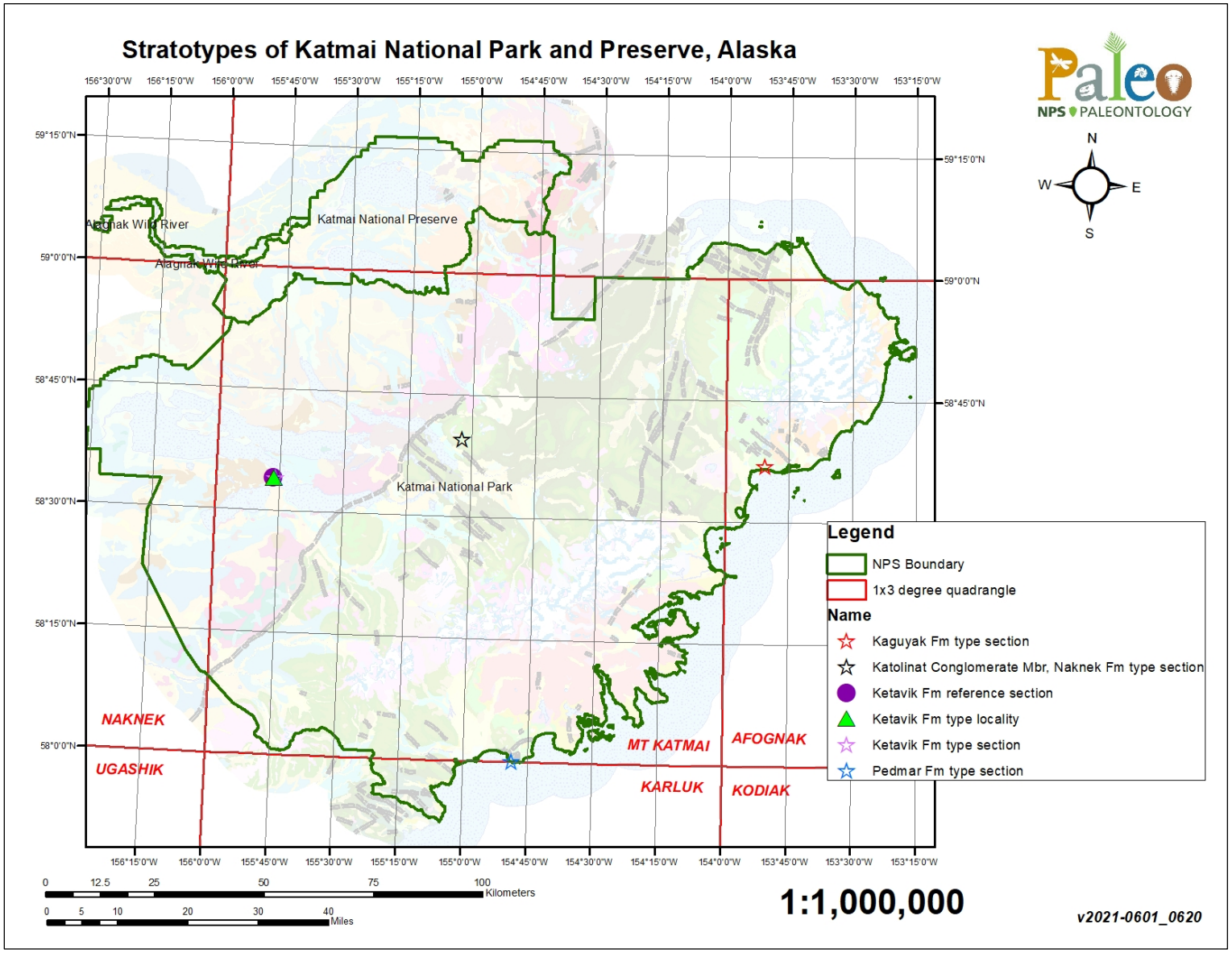


Figure 15. Modified geologic map of KATM showing stratotype locations. The transparency of the geologic units layer has been increased.

The Katolinat Conglomerate Member of the Naknek Formation, of Late Jurassic (late[?] Tithonian) age, was named by Detterman et al. (1996) after Mount Katolinat on the south shore of the Iliuk Arm of Naknek Lake in the Mount Katmai B-5 Quadrangle, Alaska. Detterman et al. (1996) designated the type section on an unnamed mountain along the northeast shore of Lake Grosvenor, in secs. 33 and 34, T. 17 S., R. 35 W., in the Mount Katmai C-4 Quadrangle (Table 3; Figure 15). The type section measures about 455 m (1,490 ft) thick and consists of massive, pebble–boulder conglomerate, thin- to medium-bedded conglomeratic sandstone, and thin- to medium-bedded, medium- to coarse-grained, cross-bedded sandstone (Detterman et al. 1996). The Katolinat Conglomerate Member conformably overlies the Indecision Creek Sandstone Member and locally unconformably underlies the Herendeen Formation (Detterman et al. 1996).

The Early Cretaceous (Albian) Pedmar Formation was proposed by Detterman et al. (1996) for a thin sequence of strata in sea cliffs along Katmai Bay in the region of Mount Pedmar within KATM. The type section of the formation is located in the sea cliff along the north edge of sec. 24, T. 25 S., R. 34 W. in the Mount Katmai A-3 Quadrangle (Table 3; Figure 15; Detterman et al. 1996). The type section is 82 m (270 ft) thick and consists of olive-gray, medium- to thick-bedded, fine- to medium-grained, cross-bedded sandstone and thin-bedded siltstone with abundant carbonaceous debris (Detterman et al. 1996). The type section is in fault contact with the Naknek Formation at its base and unconformably underlies the Kaguyak Formation.

The Late Cretaceous (early Maastrichtian) Kaguyak Formation was named by Keller and Reiser (1959) for exposures in the vicinity of Kaguyak, southwestern Alaska. Keller and Reiser (1959) designated the type section of the formation as the sea cliffs along Swikshak Bay from the mouth of the Big River to the Swikshak River (Table 3; Figures 15 and 16). The type section is about 1,117 m (3,665 ft) thick and includes three informal members: 1) a lower fossiliferous siltstone member; 2) a middle massive, locally cross-bedded sandstone and interbedded sandstone and siltstone member; and 3) an upper thin-bedded sandstone and siltstone member (Keller and Reiser 1959). The Kaguyak Formation type section unconformably overlies the Naknek Formation and has no observable upper contact (Keller and Reiser 1959). Detterman et al. (1996) remeasured the type section of the Kaguyak, except for a non-contiguous section measured by Keller and Reiser (1959). Detterman et al. (1996) report that “neither the upper nor the lower contact of the Kaguyak Formation is exposed at the type section, but both are exposed nearby.”

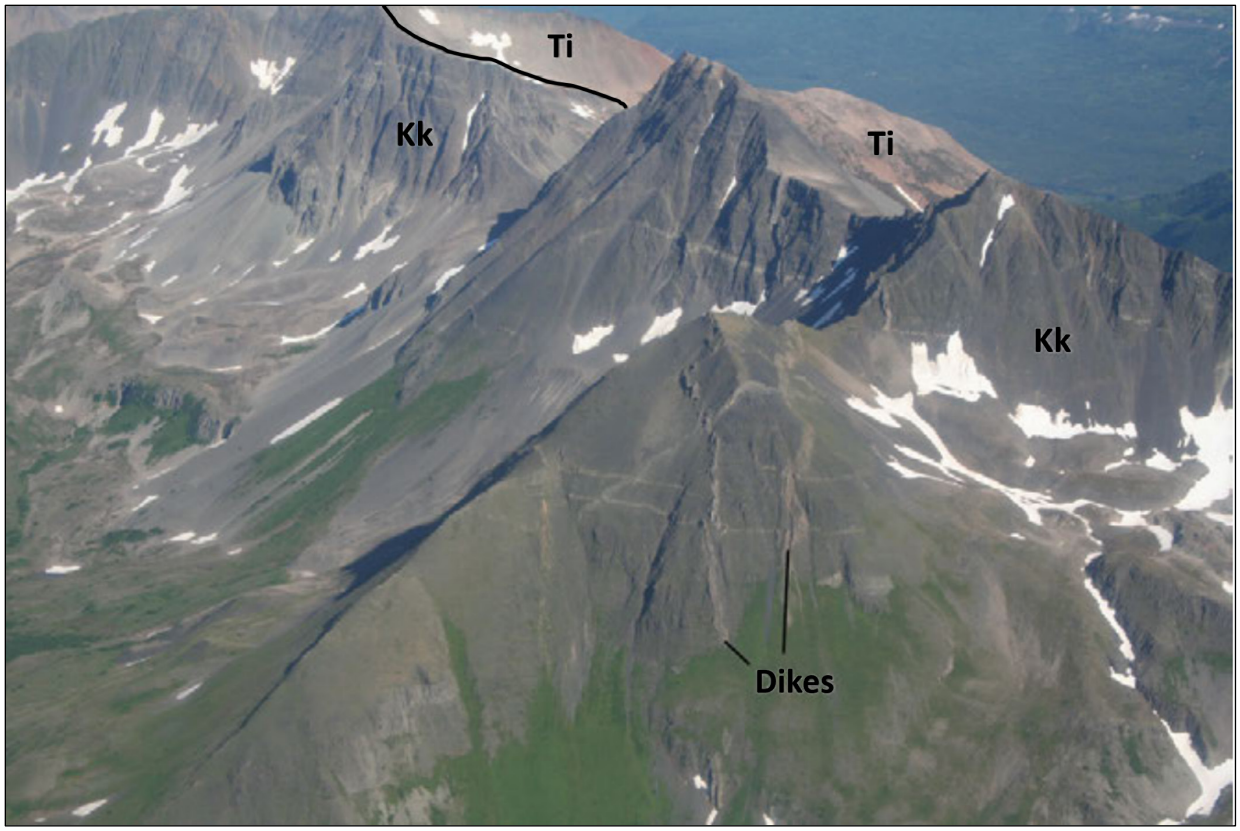


Figure 16. Type section cliff exposure of the Kaguyak Formation (Kk) between Big River and Swikshak River along Swikshak Bay, KATM. The dark gray, fine-grained sedimentary rocks of the Kaguyak Formation measure about 1,387 m (4,550 ft) and were intruded by lighter gray dikes that are probably associated with nearby, larger Tertiary intrusive bodies (Ti). NPS photograph by Chuck Lindsay.

The Paleocene–Eocene Ketavik Formation was proposed by Parrish et al. (2010) and named after Ketavik Falls (previously known as Brooks Falls) along the Brooks River between Naknek Lake and Lake Brooks, KATM. Parrish et al. (2010) designated the type section and reference section on the southern shore of Naknek Lake, where exposures extend from approximately 0.7 km (0.4 mi) north to 5.2 km (3.2 mi) northwest of Brooks Camp (Table 3; Figure 15; Parrish et al. 2010). The two sections are in fault contact with one another; the type section is located east of the fault and the reference section to the west of the fault. A more generalized type locality is designated near Brooks Camps, KATM (Table 3; Figure 15; Parrish et al. 2010). The type and reference sections measure 48.4 m (159 ft) and 18.7 m (61.4 ft), respectively, and consist of interbedded quartz feldspathic and quartz lithic sandstone and conglomerate with rare, thin interbeds of silty sandstone or mudstone (Parrish et al. 2010). Sedimentary structures within sandstone intervals include trough cross-bedding and ripples (Parrish et al. 2010). The contacts of the Ketavik Formation and adjacent rocks were not directly observed, but the unit appears to share an erosional unconformity with the Talkeetna Formation (Parrish et al. 2010).

Kenai Fjords National Park (KEFJ)

Kenai Fjords National Park (KEFJ) is located on the southeastern side of the Kenai Peninsula approximately 100 km (62 mi) south of Anchorage in the Kenai Peninsula Borough, Alaska (Figure 17). Originally proclaimed a national monument on December 1, 1978, the park unit was re-designated as a national park on December 2, 1980 (Anderson 2017). The park encompasses nearly 271,132 hectares (669,984 acres) of rugged glacial landscape that is home to a diverse biological community that includes bears, moose, seals, sea lions, sea otters, and seabirds. The park includes the 2,072 km^2 (800 mi^2) Harding Icefield, coastal fjords, coastal islands, ecosystems they host, and the outflowing glaciers that feed into them (Lanik et al. 2018).

The geology of KEFJ reflects a geologically active landscape that has been heavily influenced by plate tectonic processes and glaciation. Distinctive landforms in KEFJ reflect the powerful erosive forces of ice and include steep-sided fjords, rocky cliffs, recently deglaciated mountainsides, active glaciers, and the Harding Icefield (Lanik et al. 2018). The bedrock geology of the park is part of the Chugach–Prince William accretionary complex emplaced against the continental margin during Late Cretaceous and Tertiary subduction. Rocks of the accretionary complex range in age from possibly latest Jurassic to potentially as young as Eocene (~150–33 million years ago), and include marine sedimentary rocks scraped off the subducting oceanic plate, as well as sedimentary debris shed from the overriding landmass (Figure 18; Lanik et al. 2018). Geologic units of the park include rocks of the Cretaceous McHugh Complex, Late Cretaceous Valdez Group, Paleocene to Eocene Orca Group, Pleistocene and Holocene glacial deposits, and Quaternary beach and alluvium deposits.

There are no designated stratotypes identified within the boundaries of KEFJ. There is one identified stratotype located within 48 km (30 mi) of KEFJ boundaries, for the Miocene–Pliocene Kenai Group (type locality).

Figure 17. Park map of KEFJ, Alaska (NPS).

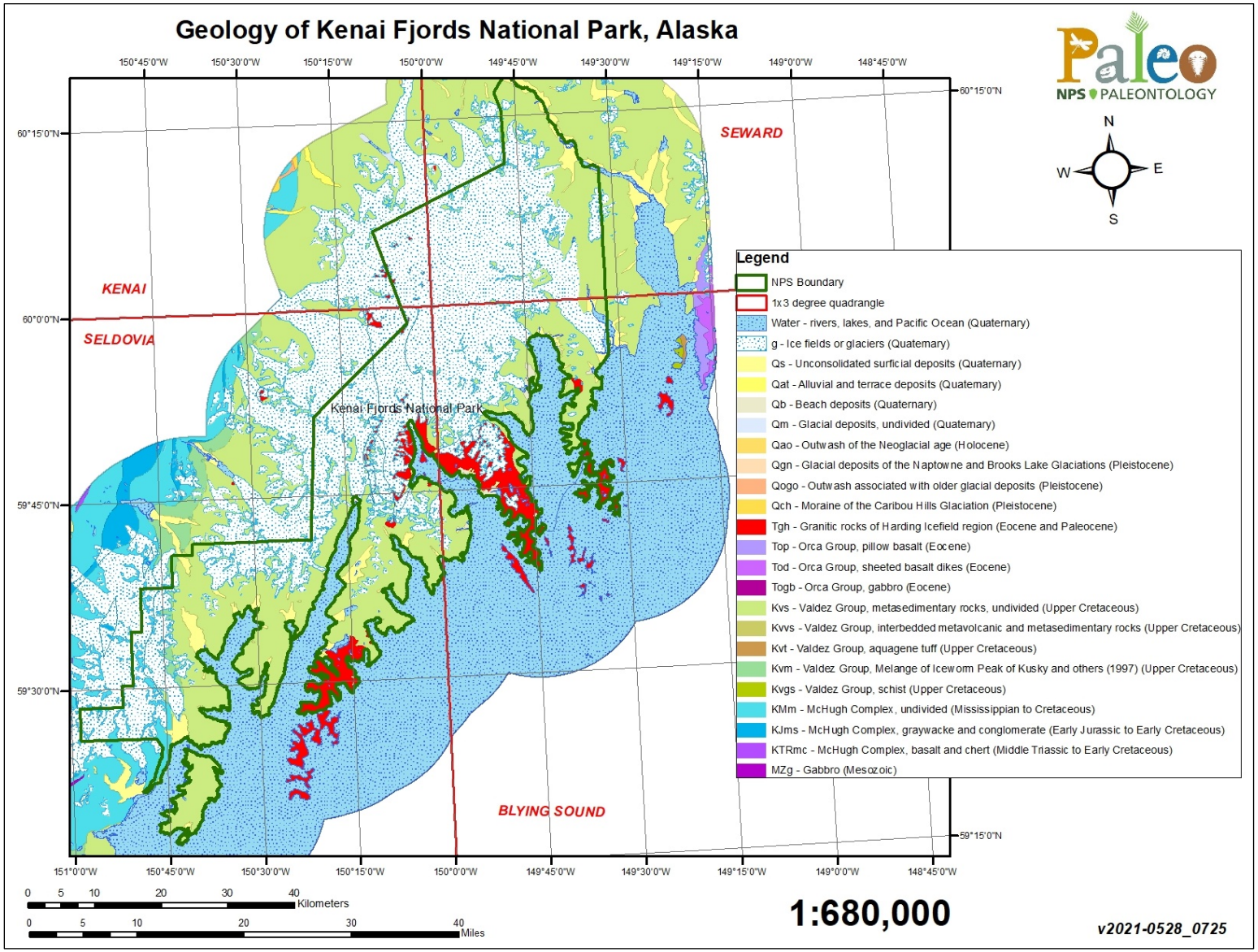


Figure 18. Geologic map of KEFJ, Alaska.

Lake Clark National Park and Preserve (LACL)

Lake Clark National Park and Preserve (LACL) is on a geologically northern extension of the Alaska Peninsula rock units where the Aleutian Range transitions to the Alaska Range approximately 130 km (81 mi) southwest of Anchorage in the Bethel, Kenai Peninsula, Lake and Peninsula, and Matanuska–Susitna Boroughs, Alaska (Figure 19). Originally established as Lake Clark National Monument on December 1, 1978, the park unit was upgraded to a national park and preserve on December 2, 1980. Lake Clark National Park and Preserve encompasses ~1,630,936 hectares (4,030,130 acres) of geologically diverse landscape that includes jagged peaks, granite spires, two active volcanoes, and a score of glacially carved lakes (Anderson 2017). The park unit namesake, Lake Clark, is over 64 km (40 mi) long, covers an area of 332 km^2 (128 mi^2), and supports a diverse ecosystem. The lakes, rivers, and streams of LACL are part of the spawning grounds for one of the world's largest salmon runs of Bristol Bay, and the park is home to the only known salmon-dependent wolf pack.

Situated in one of the most geologically active regions of North America, the geology of LACL reflects the dynamic processes associated with plate tectonics, volcanism, and glaciation. There are several faults in LACL, the longest of which is the 225 km (140 mi)-long Lake Clark Fault situated beneath Lake Clark and Lake Clark Pass. The bedrock geology in the park and preserve predominantly consists of Mesozoic rocks that have been uplifted in the Jurassic and subsequently eroded by glaciers (Figures 20 and 21). Numerous Quaternary-age, unconsolidated deposits in LACL include Wisconsin-age glacial deposits of the Brooks Lake Glaciation, deltaic and estuarine deposits, as well as younger volcanic rocks. Although the active Redoubt and Iliamna volcanoes are geologically young (forming ~880,000 years ago), older igneous rocks provide evidence of volcanic activity as far back as 190 million years ago. The park and preserve contains a rich assemblage of marine invertebrate fossils from Jurassic units, including bivalves, ammonites, and belemnites.

LACL contains seven identified stratotypes that represent Mesozoic strata (Table 4; Figure 22). In addition to the designated stratotypes located within LACL, stratotypes located within 48 km (30 mi) of park boundaries include the Triassic Chilikadrotna Greenstone (type locality), Cottonwood Bay Greenstone (type locality), and Ursus Member of the Kamishak Formation (type section); the Triassic–Jurassic Kakhonak Complex (type locality); the Middle Jurassic Paveloff Siltstone Member of the Chinitna Formation (type section), Tonnie Siltstone Member of the Chinitna Formation (type section), and the following formations of the Tuxedni Group: Bowser Formation (type section), Twist Creek Siltstone (type section), Cynthia Falls Sandstone (type section), Fitz Creek Siltstone (type section), and Gaikema Sandstone (type section); three members of the Upper Jurassic Naknek Formation: Pomeroy Arkose Member (part of composite type section), Snug Harbor Siltstone Member (type section), and Chisik Conglomerate Member (type section); the Paleocene–Eocene West Foreland Formation (subsurface type section) and Copper Lake Formation (upper, middle, and lower members–type sections); the Miocene Chuitna Member of the Tyonek Formation (subsurface type section); and the Pliocene Intricate Basalt (type locality).

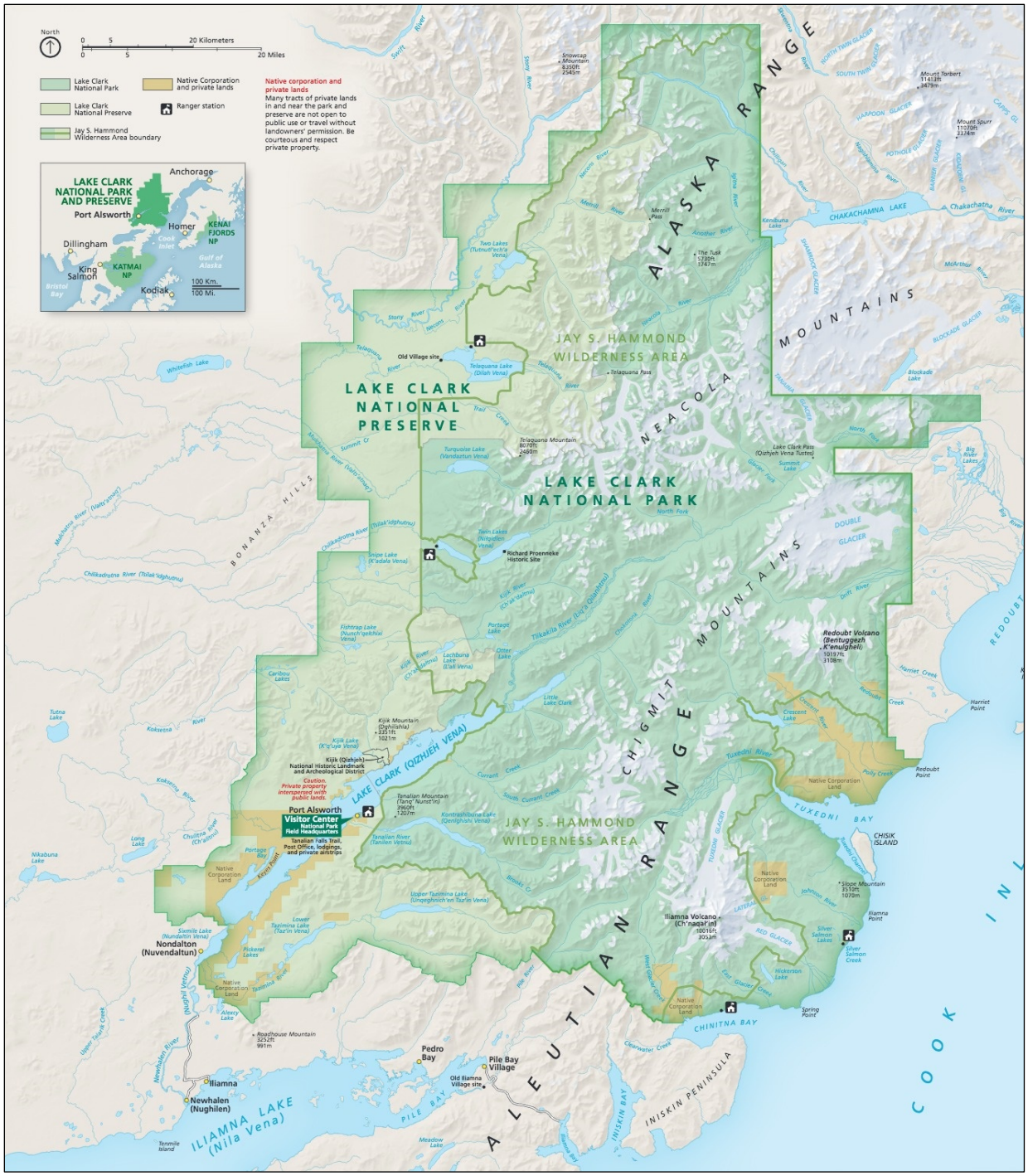


Figure 19. Park map of LACL, Alaska (NPS).

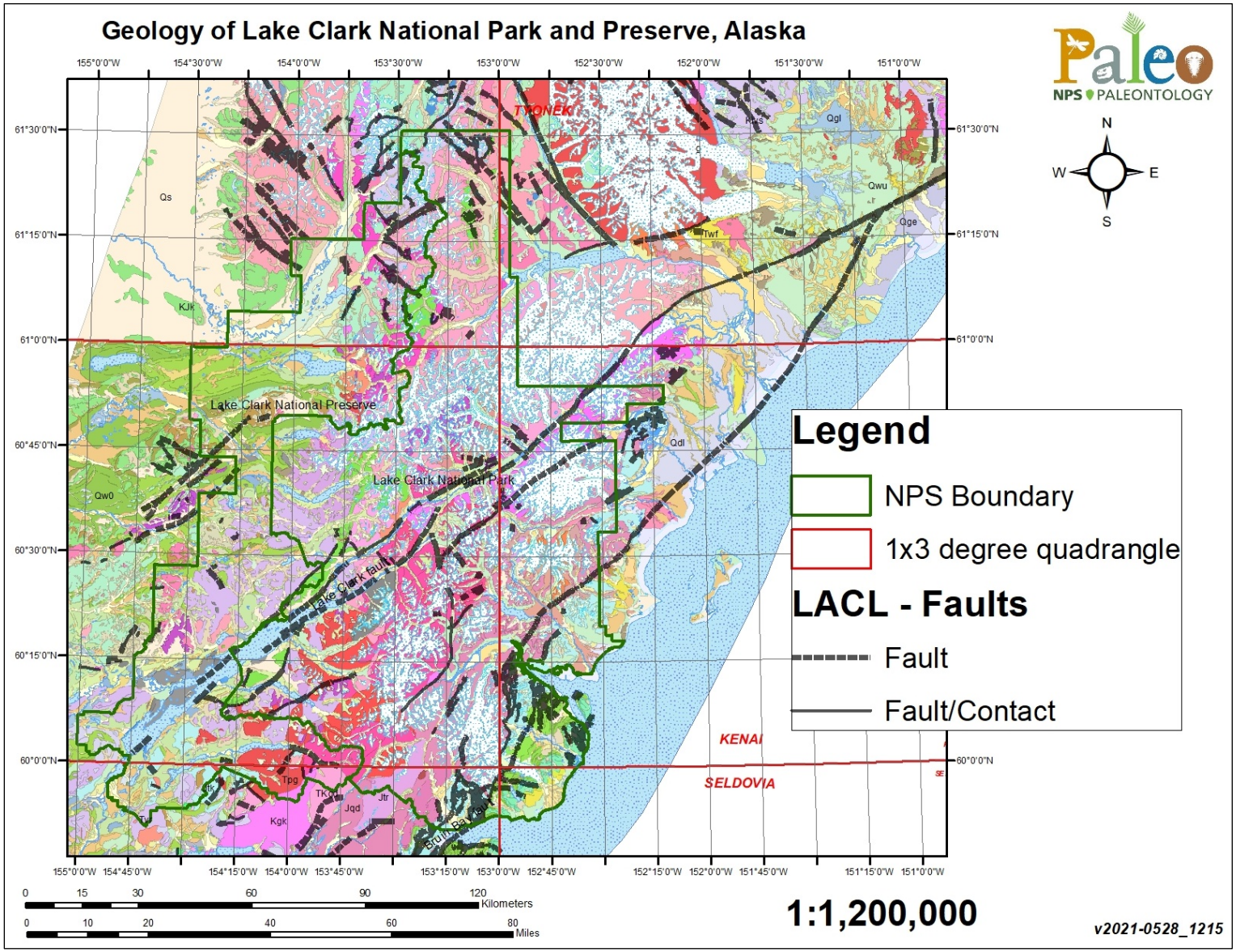


Figure 20. Geologic map of LACL, Alaska. See Figure 21 for legend.

Figure 21. Geologic map legend of LACL, Alaska.

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

Unit Name (map symbol)	Reference	Stratotype Location	Age
Pomeroy Arkose Member, Naknek Formation (Jnp)	Detterman and Hartsock 1966	Type section (composite): north and south sides of Chinitna Bay, Seldovia D-8 Quadrangle, Iniskin Peninsula, AK.	Late Jurassic, early Kimmeridgian
Chinitna Formation (Jct)	Martin and Katz 1912; Detterman and Reed 1980	Type section: exposures in the bluffs along the north shore of Chinitna Bay, AK.	Middle Jurassic, Callovian
Tuxedni Sandstone	Martin and Katz 1912	Type section: bluffs along the south shore of the western arm of Tuxedni Bay, Iliamna region, AK.	Middle Jurassic, Bajocian–Bathonian
Red Glacier Formation (Jtrg)	Detterman 1963; Detterman and Hartsock 1966	Type section (composite): along both sides of Red Glacier, AK 1. Upper 1,009 m (3,310 ft) exposed along south side of Red Glacier, 7.2 km (4.5 mi) S. 62° E. of Iliamna Volcano; 2. Lower 375 m (1,230 ft) on north side of Red Glacier, 10.5 km (6.5 mi) N. 86° E. of Iliamna Volcano.	Middle Jurassic
Horn Mountain Tuff Member, Talkeetna Formation (Jtkh)	Detterman and Hartsock 1966	Type section: Horn Mountain, from the shore of Chinitna Bay to the peak of Horn Mountain and north along the ridge to the contact with Portage Creek Agglomerate Member, Iniskin–Tuxedni region, AK.	Early Jurassic
Portage Creek Agglomerate Member, Talkeetna Formation (Jtkp)	Detterman and Hartsock 1966	Type section: on south shore of Tuxedni Bay. Section starts about 3.9 km (2.4 mi) northwest of Fossil Point and continues along shoreline to contact with underlying Marsh Creek Member, Iniskin Peninsula, AK.	Early Jurassic
Marsh Creek Breccia Member, Talkeetna Formation (Jtkm)	Detterman and Hartsock 1966	Type section: along south shore of Tuxedni Bay, starting 9.6 km (6 mi) northwest of Fossil Point and continuing 3.6 km (2.25 mi) to contact with quartz diorite pluton, Cook Inlet region, AK.	Early Jurassic

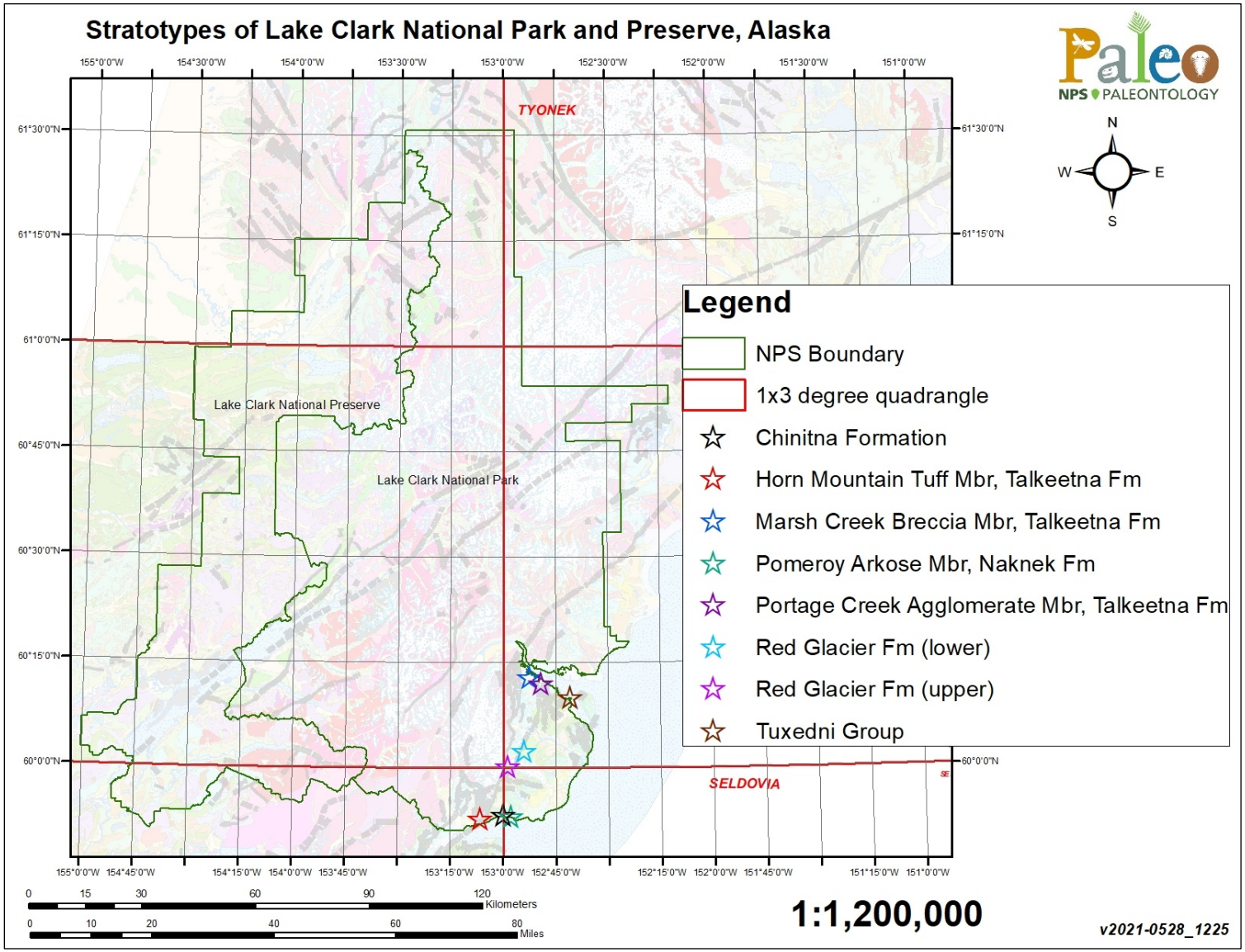


Figure 22. Modified geologic map of LACL showing stratotype locations. The transparency of the geologic units layer has been increased.

The Early Jurassic (likely Sinemurian age) Marsh Creek Breccia Member of the Talkeetna Formation is the basal member of the formation and was named after exposures near Marsh Creek in the Iniskin–Tuxedni region, southwestern Alaska (Detterman and Hartsock 1966). The type section of the member is along the south shore of Tuxedni Bay, starting 10 km (6 mi) northwest of Fossil Point and continues along the shoreline ~3.62 km (~2.25 mi) to the contact with a quartz diorite pluton (Table 4; Figures 22 and 23; Detterman and Hartsock 1966). The type section measures 1,021 m (3,350 ft) thick and consists of massive, dark-green to green tuff breccia interbedded with andesitic to dacitic lava flows (Detterman and Hartsock 1966). Stratigraphically, the Marsh Creek Breccia Member is in fault contact with the overlying Portage Creek Agglomerate Member and overlies unnamed metamorphic rocks (Detterman and Hartsock 1966). These might be mapped as the Kamishak Formation and Cottonwood Bay Greenstone today.

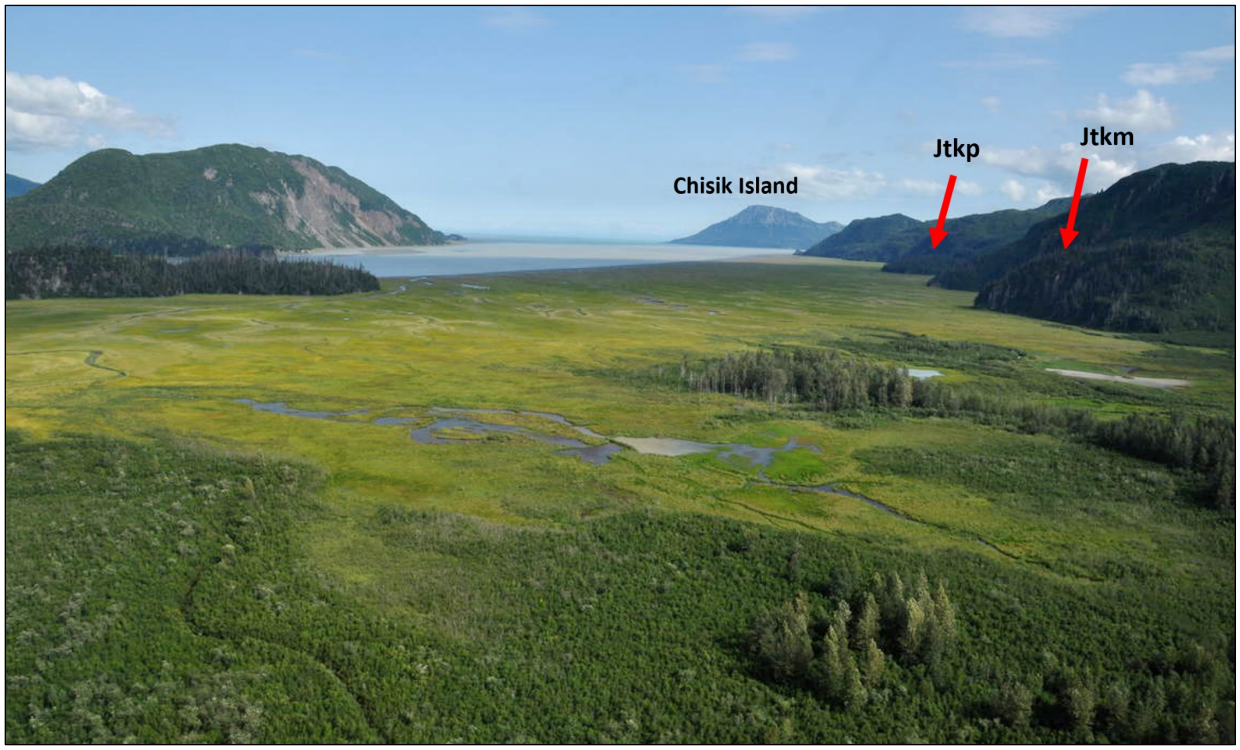


Figure 23. Aerial view looking east across tidal flats in Tuxedni Bay, LACL. The type sections of the Portage Creek Agglomerate Member (Jtkp) and Marsh Creek Breccia Member (Jtkm) of the Talkeetna Formation are situated in the bluffs along the southern coast of the bay (red arrows). Chisik Island is located in the background to the center-right of the figure. Figure modified after USGS photo by Chris Zimmerman.

The Early Jurassic Portage Creek Agglomerate Member of the Talkeetna Formation was named by Detterman and Hartsock (1966) after exposures near Portage Creek on Iniskin Peninsula, southwestern Alaska. The type section of the member is located along the south shore of Tuxedni Bay, starting about 3.9 km (2.4 mi) northwest of Fossil Point and continuing along the shoreline to the basal fault contact with the Marsh Creek Breccia Member (Table 4; Figures 22 and 23; Detterman and Hartsock 1966). The type section is about 686 m (2,250 ft) thick; however, the

estimated thickness of the unit is between 686 and 869 m (2,250 to 2,850 ft; Detterman and Hartsock 1966). The Portage Creek Agglomerate is composed of fragmental volcanic ejecta that are mostly rounded, volcanic bomb-type detritus, and massive, reddish-pink beds of agglomerate, lapilli tuff, and argillite (Detterman and Hartsock 1966). At the type section, the Portage Creek Agglomerate Member is fault-bounded and overlies the Marsh Creek Breccia Member and underlies the Horn Mountain Tuff Member.

The Early Jurassic Horn Mountain Tuff Member of the Talkeetna Formation was named by Detterman and Hartsock (1966) after its type section exposure in Horn Mountain, LACL (Table 4; Figures 22 and 24). The type section is about 549 m (1,800 ft) thick; however, the top of the section is fault-bounded. Detterman and Hartsock (1966) suggest that about 244 m (800 ft) of additional section is present north of the type section. The Horn Mountain Tuff predominantly consists of thin-bedded to massive, vari-colored tuff, tuffaceous feldspathic sandstone, porphyritic andesite lava flows, and minor volcanic breccia, agglomerate, greenstone, and argillite (Detterman and Hartsock 1966). The Horn Mountain Tuff Member overlies the Portage Creek Agglomerate Member and its upper contact is either an angular unconformity or a fault contact with the overlying Red Glacier Formation.

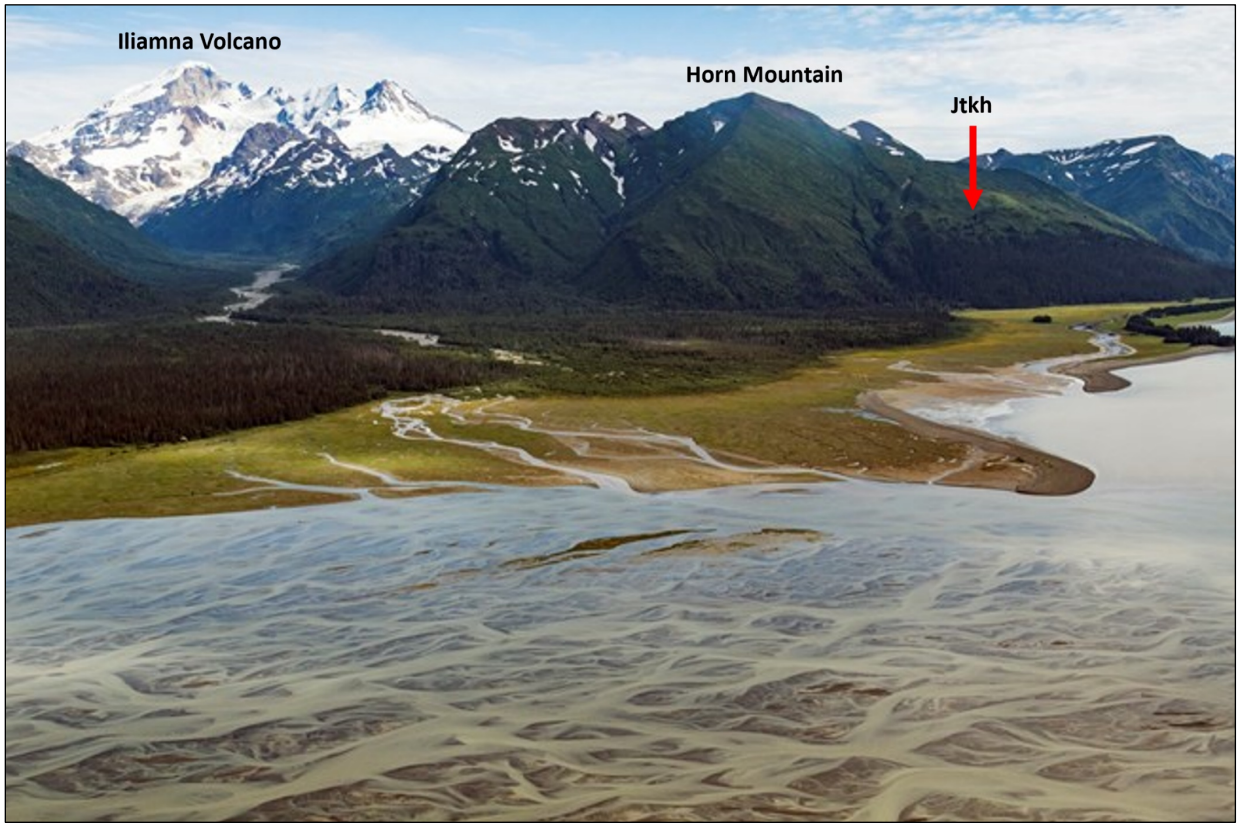


Figure 24. View looking north across Chinitna Bay at the mouth of Middle Glacier Creek, LACL. The type section of Horn Mountain Tuff Member of the Talkeetna Formation (Jtkh) is located in Horn Mountain (red arrow). Iliamna Volcano rises high in the background. Figure modified after NPS photo by T. Vaughn.

The Jurassic Tuxedni Group, first proposed as the Tuxedni Sandstone by Martin and Katz (1912), was raised to group status by Detterman (1963). The historical type section of the Tuxedni Sandstone is designated in the bluffs along the south shore of Tuxedni Bay in the Iliamna region, southwestern Alaska (Table 4; Figure 22 and 25; Martin and Katz 1912). The type section measures 344 m (1,128 ft) thick and consists of gray to black shale, shaly sandstone, and sandstone with minor beds of limestone and conglomerate (Martin and Katz 1912). The Tuxedni Group is divided into six formations, of which the lowermost Red Glacier Formation type section lies within LACL. Stratigraphically, the Tuxedni Group unconformably underlies the Chinitna Formation and is in fault contact with the underlying Talkeetna Formation (Detterman and Reed 1980).

Figure 25. Fossil Point, prominent northeast promontory along the south shore of Tuxedni Bay, LACL. Bluff exposures northwest of Fossil Point (right) along the southern shore of the western arm of Tuxedni Bay represent the type locality exposures for the Jurassic Tuxedni Sandstone. NPS photo by Jeff Shearer.

The Middle Jurassic (Bajocian) Red Glacier Formation of the Tuxedni Group was named by Detterman (1963) after exposures along Red Glacier on the flank of Iliamna Volcano in the Cook Inlet region, Alaska. Detterman (1963) designated a composite type section along both sides of Red Glacier: 1) the upper section exposed south of Red Glacier, 7.2 km (4.5 mi) S. 62° E. of Iliamna Volcano; and 2) the lower section exposed north of Red Glacier, 10.5 km (6.5 mi) N. 86° E. of Iliamna Volcano (Table 4; Figures 22 and 26). The composite type section has a total thickness of 1,384 m (4,540 ft) and consists of arkosic to feldspathic arenite, arenaceous siltstone interbedded with graywacke, black fissile shale, and minor interbeds of limestone and conglomerate (Detterman 1963; Detterman and Reed 1980). The Red Glacier Formation unconformably overlies the Talkeetna Formation and conformably underlies the Gaikema Sandstone (Detterman 1963).

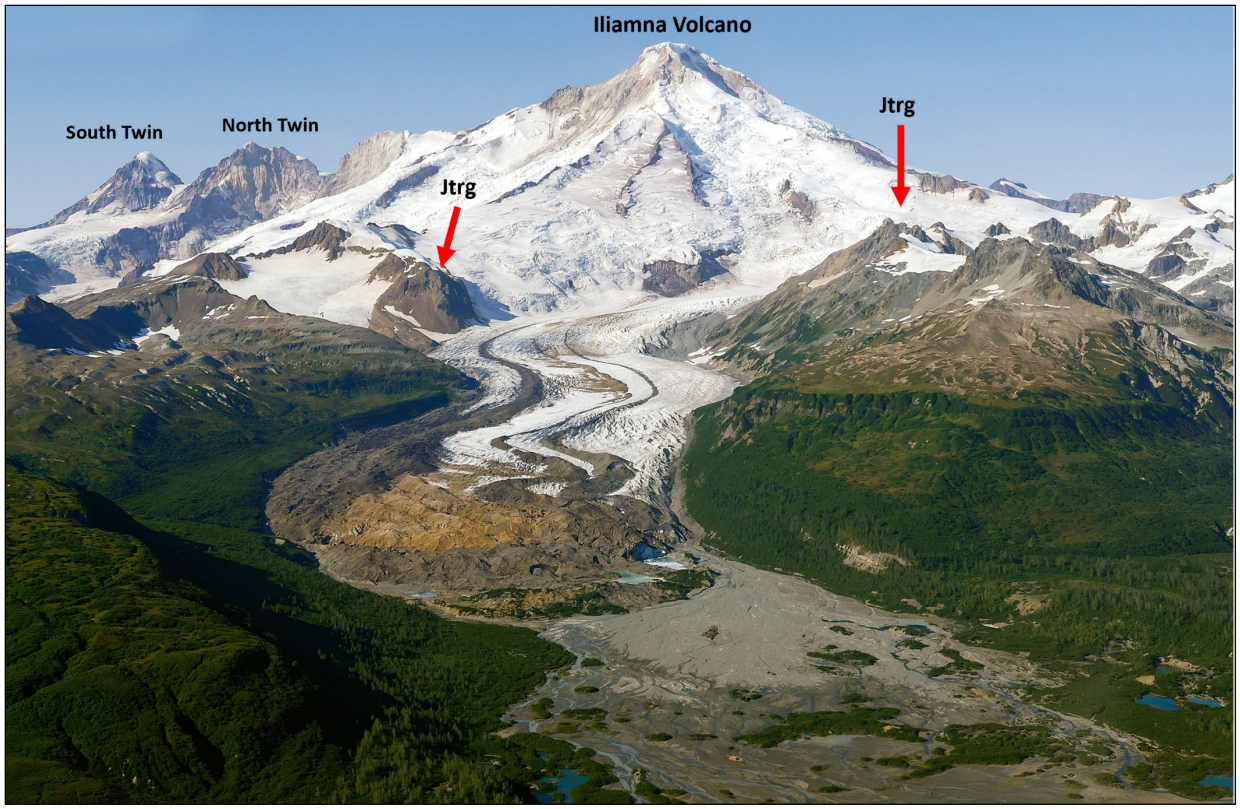


Figure 26. Westward view of Iliamna Volcano and Red Glacier, LACL. The composite type section of the Red Glacier Formation (Jtrg) is exposed on both sides of Red Glacier (red arrows). Figure modified from NPS photo by Buck Mangipane.

The Middle Jurassic (Callovian) Chinitna Formation was originally referred to as the Chinitna Shale by Martin and Katz (1912) and named after exposures along the shores of Chinitna Bay, southwestern Alaska. The type section of the formation is located along the north shore of Chinitna Bay and measures about 706 m (2,315 ft) thick (Table 4; Figure 22; Martin and Katz 1912; Detterman and Reed 1980). Lithologically, the type section consists of dark argillaceous shale and sandstone with minor thin beds and lenses of limestone (Martin and Katz 1912). The Chinitna Formation stratigraphically occurs between the overlying Naknek Formation and underlying Bowser Formation of the Tuxedni Group. Type sections for the Paveloff Siltstone and Tonnie Siltstone Members of the Chinitna Formation lie just outside the park.

The Late Jurassic (early Kimmeridgian) Pomeroy Arkose Member of the Naknek Formation was first proposed by Kirschner and Minard (1948) for exposures on the Iniskin Peninsula, Alaska. The formation was redescribed and redefined by Detterman and Hartsock (1966), who designated a composite type section on the north and south sides of Chinitna Bay with a combined thickness of 732 m (2,400 ft) (Table 4; Figure 22). At the type section the member consists of gray, thin-bedded to massive, coarse-grained, cross-bedded arkose sandstone and siltstone (Detterman and Hartsock 1966). Stratigraphically, the Pomeroy Arkose Member conformably overlies the Snug Harbor Siltstone Member and unconformably underlies Tertiary-age deposits (Detterman and Hartsock 1966).

Recommendations

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) The NPS Geologic Resources Division should schedule a briefing for SWAN staff and respective network parks to provide an overview of SWAN stratotypes and their significance.

3) The Eocene-Oligocene Meshik Volcanics was originally named the Meshik Formation by Knappen (1929) for its typical development along the valley of Meshik River and Meshik Lake in the Aniakchak region, ANIA. However, no formal stratotype designation for the unit has been assigned. Additional publications by Detterman et al. (1981, 1996) describe a thick succession of volcanic and volcanic sedimentary rock that contain megaflora fossils in the mountains south of Meshik River. It is recommended that a type section for the Meshik Volcanics be designated in order to: A) provide a standard reference for scientific research; B) educate park staff and visitors about the geoheritage significance of these units; and C) help safeguard these exposures.

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 infrastructure 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.

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.

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.

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 (rockfalls, 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/petrologic samples collected from type sections within respective 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.

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).

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Appendix A: Source Information for GRI Maps of SWAN Parks

ALAG–KATM

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ANIA

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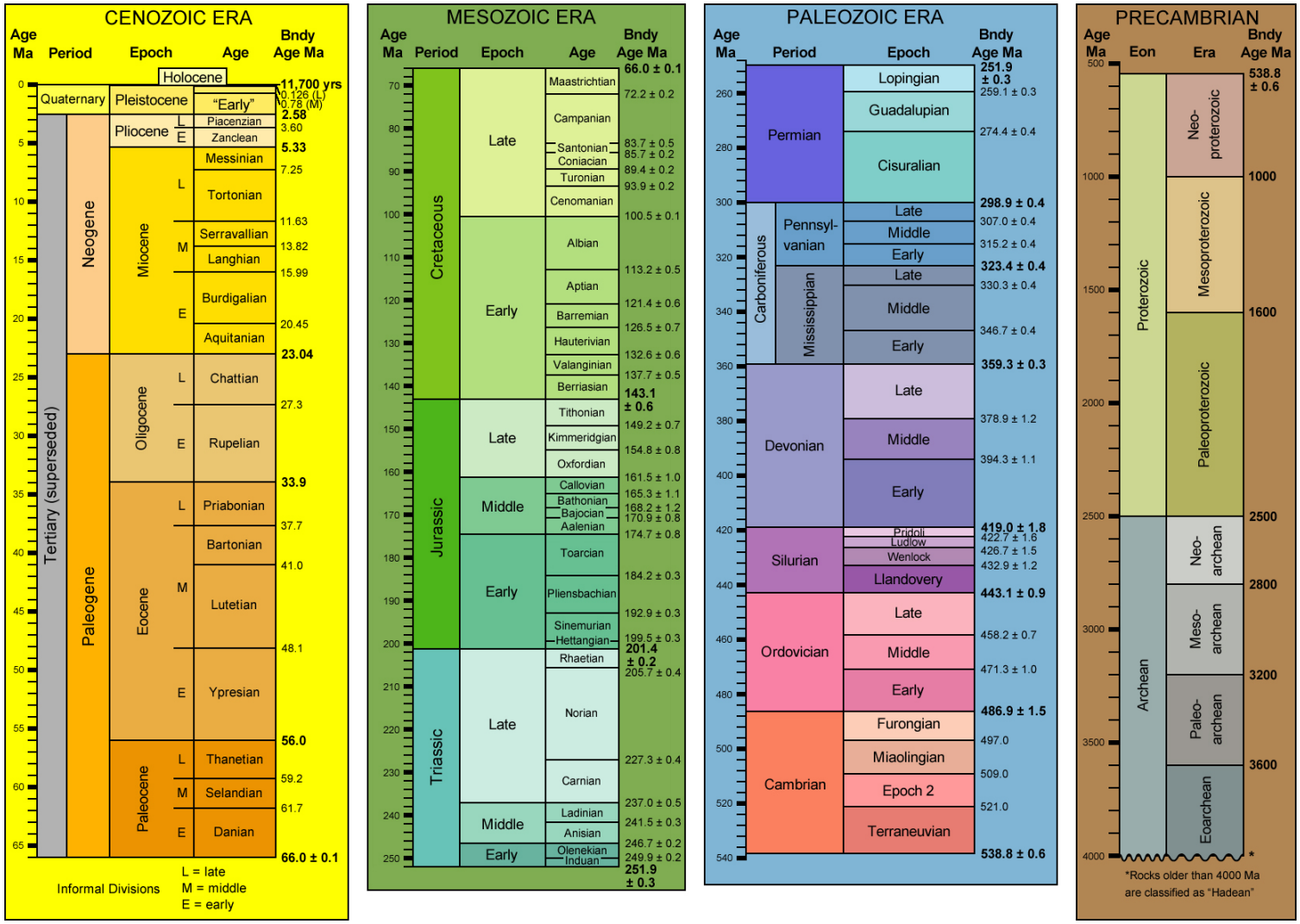
Appendix B: Geologic Time Scale



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).

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