National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Klondike Gold Rush National Historical Park

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2022/2426

ON THE COVER
Photograph of the Chilkoot Trail between Sheep Camp and the Scales. A glacier can be seen at the highest elevations on the right side of the valley and the upper Taiya River is flowing through the valley bottom. The rocks visible in the valley walls are igneous rocks of the Coast plutonic complex, which underlies most of the park and surrounding area. National Park Service photograph by K. Unertl.

THIS PAGE
Photograph of wharf pilings at the historic townsite of Dyea. Some of the infrastructure that remains at Dyea, such as these pilings, demonstrate natural changes that have occurred since the town was abandoned following the gold rush. Glacial isostatic rebound, or the uplift of land formerly overlain by heavy glacial ice, is causing southeast Alaska to rise rapidly. This uplift is outpacing global sea level rise, resulting in local sea level fall. National Park Service photograph.

Klondike Gold Rush National Historical Park

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2022/2426

Amanda Lanik

Geologist
University of Alaska Museum of the North
National Park Service Geologic Resources Inventory
Alaska Regional Office
240 W 5th Ave
Anchorage, AK 99501

July 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.

This report is available from the Geologic Resources Inventory publications site and the Natural Resource Report publication series site. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov

Please cite this publication as:

Lanik, A. 2022. Klondike Gold Rush National Historical Park: Geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2022/2426. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/2293931.

NPS 461/182811, July 2022

Contents

Figures

Tables

Executive Summary

Comprehensive park management needed to fulfill the National Park Service (NPS) mission requires an accurate inventory of the geologic features of a park unit, but park managers may not have the needed technical information or geologic expertise to complete such an undertaking; therefore, the Geologic Resources Inventory (GRI) provides information and resources to help park managers make decisions for visitor safety, planning and protection of infrastructure, and preservation of natural and cultural resources. Information in the GRI report may also be useful for interpretive activities.

Klondike Gold Rush National Historical Park, hereafter also referred to as the "park," is a NPS unit in southeast Alaska that was created to preserve the historic structures and trails associated with the Klondike Gold Rush of 1897–1898. The Klondike Gold Rush lasted only three years but brought thousands of people to the boomtowns of Skagway and Dyea on their way to the goldfields in what is now Yukon, Canada. The park includes three units that preserve the Skagway historic district, Chilkoot Trail, and upper portions of the historic White Pass Trail. Today Skagway is a popular stop for cruise ships, and because of this tourism, the park is the most visited park in Alaska. Popular visitor activities include visiting the park museum and historic structures in downtown Skagway, exploring the abandoned townsite of Dyea, and hiking along the Chilkoot Trail.

Southeast Alaska, also known as the "Alaska Panhandle," is composed of a series of fjords (steep-sided, narrow inlets carved by glaciers) and islands bordered by the Coast Mountains to the east and the Gulf of Alaska to the west. This region's steep topography was carved out during the last ice age by glaciers that extended far onto the continental shelf. When climate warmed around 12,000 years ago, the glaciers retreated and sea level rose, flooding the deepest valleys and leaving the tops of mountains as islands. Glaciers are still found in southeast Alaska, with more heavily glaciated regions including the Juneau Icefield to the southeast of the park and Glacier Bay to the southwest. The park is situated at the head of Taiya Inlet, which sits at the northernmost end of the Lynn Canal–Chatham Strait corridor. The park encompasses two major rivers (Taiya and Skagway Rivers) that flow from glacier-free mountain passes to Taiya Inlet. Chilkoot Pass and White Pass provide some of the only glacier-free access through the Coast Mountains in this part of southeast Alaska, which is what drew so many people here during the gold rush.

The bedrock, geologic structures, and topography of southeast Alaska are all tied to the active tectonic margin trending along the outer coast of the Alexander Archipelago. In this part of Alaska, the North American and Pacific tectonic plates have been colliding and grinding against each other for millions of years. The bedrock that underlies the park formed during a magmatic event during the Cretaceous Period (145.0 million–66.0 million years ago) and early Tertiary (a widely used but no longer formally recognized term for the geologic period from 66.0 million–2.6 million years ago), when a crustal block called the Wrangellia composite terrane collided with and slid along the western margin of North America. Evidence of this long history of deformation is also found in rocks throughout the region in the form of faults. Most modern slip is being accommodated by the Queen Charlotte–Fairweather fault system to the west of the park, but the bedrock in and around the park is cut by splays of the likely inactive Chatham Strait fault and most of the major valleys in the region are fault controlled.

Geology is a complex science with many specialized terms. This report provides definitions of geologic terms at first mention, typically in parentheses following the term. Geologic map units in the GRI GIS data are referenced in this report using map unit symbols, and the GRI poster, which displays the GRI GIS data, is referenced throughout the report as a primary figure.

This report contains the following chapters:

Introduction to the Geologic Resources Inventory—This chapter provides background information about the GRI, highlights the GRI process and products, and recognizes GRI collaborators. The GRI team produced four main products for the park: (1) a scoping meeting and summary; (2) a bedrock geology map in GIS format; (3) a poster displaying the GRI GIS data; and (4) a GRI report (this document). GRI products are available on the GRI publications website http://go.nps.gov/gripubs and through the NPS Integrated Resource Management Applications (IRMA) portal https://irma.nps.gov/. Additional information regarding the GRI, including contact information, is available at http://go.nps.gov/gri.

Geologic Heritage—This chapter highlights the significant geologic features, landforms, landscapes, and stories of the park preserved for their heritage values. The story of the 1897–1898 Klondike Gold Rush is at the heart of the park's mission. This chapter discusses how geologic processes formed the landscape that lured stampeders to the Chilkoot and White Pass Trails during the gold rush, and how the region's geologic features and hazards made traversing these trails an arduous and sometimes dangerous task.

Geologic History—This chapter describes the geologic events that formed the present landscape. The geologic events are discussed in chronological order, starting in the Eocene Epoch (56.0 million–33.9 million years ago) with the formation of the park's granitic bedrock and ending with modern active geologic processes, such as glacier retreat, erosion, and sea level change.

Geologic Features and Processes—This chapter describes the geologic features and processes of significance for the park. The features and processes discussed are fluvial features; coastal features; glacier features, history, and modern change; active margin tectonics and faults; and bedrock geology.

Geologic Resource Management Issues—This chapter discusses management issues related to the park's geologic resources. Issues discussed are geohazards (earthquakes, tsunamis, landslides and snow avalanches, and floods), erosion of Dyea, uplift and sea level change, and abandoned mineral lands.

Guidance for Resource Management—This chapter provides resource managers information about finding and receiving management assistance with geologic resources. It also contains lists of park-specific resource management documents, NPS resource management documents, and geologic resource laws, regulations, and policies.

Literature Cited—This chapter is a bibliography of references cited in this GRI report. Many of the cited references are available online, as indicated by an Internet address included as part of the reference citation. Park staff may contact the GRI team for more information about literature cited in this report.

Introduction to the Geologic Resources Inventory

The Geologic Resources Inventory (GRI), which is administered by the Geologic Resources Division (GRD) of the National Park Service (NPS) Natural Resource Stewardship and Science Directorate, provides geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the National Park System. The GRI is funded by the NPS Inventory and Monitoring Program.

GRI Products

The GRI team—which is a collaboration among the NPS Geologic Resources Division; Colorado State University, Department of Geosciences; and University of Alaska Museum of the North—completed the following tasks as part of the GRI process for Klondike Gold Rush National Historical Park (referred to as the "park" throughout this report): (1) conducted a scoping meeting and provided a scoping summary (KellerLynn 2009), (2) provided geologic map data in a geographic information system (GIS) format, (3) created a poster to display the GRI GIS data, and (4) provided a GRI report (this document).

GRI products are available on the GRI publications website http://go.nps.gov/gripubs and through the NPS Integrated Resource Management Applications (IRMA) portal https://irma.nps.gov/. Enter "GRI" as the search text and select a park from the unit list. Additional information regarding the GRI, including contact information, is available at http://go.nps.gov/gri.

Information provided in GRI products is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based upon the information provided in GRI products. Inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features in the GRI GIS data or on the poster.

Scoping Meeting

On 16 and 17 June 2009, the NPS held a scoping meeting at the park in Skagway, Alaska. The scoping meeting brought together park staff and geologic experts, who reviewed and assessed available geologic maps, developed a geologic mapping plan, and discussed geologic features, processes, and resource management issues to be included in the final GRI report. A scoping summary (KellerLynn 2009) summarizes the findings of that meeting.

GRI GIS Data

Following the scoping meeting, the GRI team compiled a geologic map in GIS format of the park. These data are the principal deliverable of the GRI. The GRI team did not conduct original geologic mapping but compiled existing geologic information (i.e., paper maps and/or digital data) into the GRI GIS data (Figure 1). Scoping participants and the GRI team identified the best available source maps based on coverage (area mapped), map scale, date of mapping, and compatibility of the mapping with the current geologic interpretation of the park. The data was compiled by the GRI team in 2021 and may be updated if new, more accurate geologic maps become available or if software advances require an update to the digital format.

The GRI GIS data for the park was compiled from the following source maps:

- Wilson, F. H., C. P. Hults, C. G. Mull, and S. M. Karl. 2015. Geologic map of Alaska (scale 1:1,584,000). Scientific Investigations Map 3340. US Geological Survey, Anchorage, Alaska.
- Crafford, T. C. 2001. Alaska resource data file, Skagway quadrangle (scale 1:250,000). Open-File Report 01-193. US Geological Survey, Anchorage, Alaska.

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

GRI Poster

A poster of the GRI GIS data draped over a shaded relief image of the park and surrounding area is the primary figure referenced throughout this GRI report. Relevant map units are listed at the beginning of each section. Map units are also cited within the text. The poster is not a substitute for the GIS data but is supplied as a helpful tool for office and field use, and for users without access to ArcGIS. In addition to the geologic feature classes from the GRI GIS data (Table 1), the poster also includes geographic information and

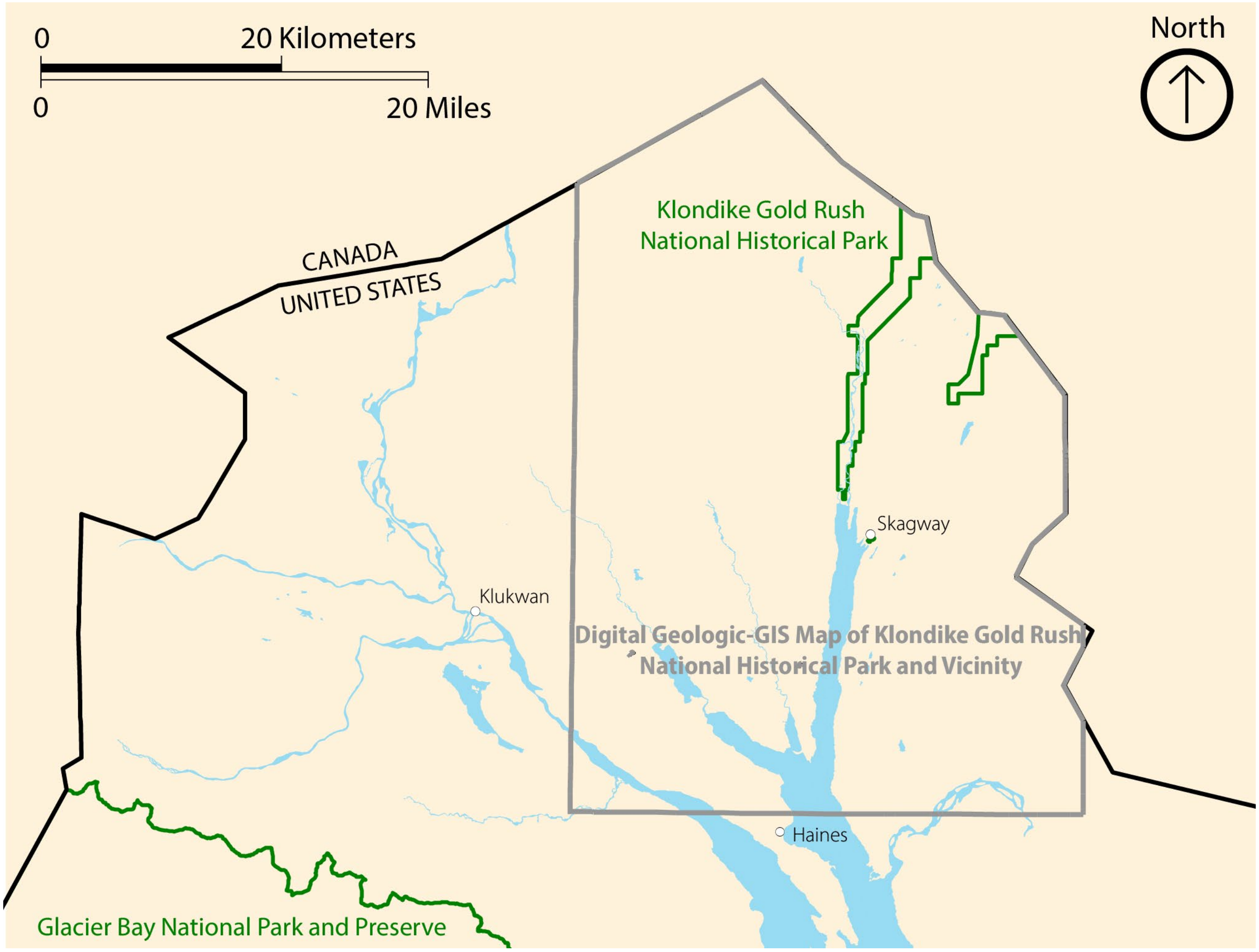


Figure 1. Index map for the GRI GIS data.
The map displays the extent (outlined in gray) of the GRI GIS data. The boundary for Klondike Gold Rush National Historical Park is outlined in green, as is the nearby boundary of Glacier Bay National Park and Preserve. Index map by Ron Karpilo (Colorado State University).

Table 1. GRI GIS data layers for Klondike Gold Rush National Historical Park.

Data Layer	On Poster?	Google Earth Layer?
Geologic Sample Localities	Yes	No
Faults	Yes	Yes
Geologic Contacts	Yes	Yes
Geologic Units	Yes	Yes

selected park features. 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 the GRI team for assistance.

GRI Report

On 2 September 2020, the GRI team hosted a follow-up conference call for park staff. The call provided an opportunity to get back in touch with park staff, introduce new (since the 2009 scoping meeting) staff to the GRI process, and update the list of geologic features, processes, and resource management issues for inclusion in the final GRI report.

The GRI report is a culmination of the GRI process. It synthesizes discussions from the scoping meeting in 2009, the follow-up conference call in 2020, and additional geologic research. The selection of geologic features and processes highlighted in this report was guided by the GRI GIS data. Information from the park's foundation statement (NPS 2009) and natural resource condition assessment (Bernatz et al. 2010) was also included as applicable to the park's geologic resources and resource management. See the "Literature Cited" chapter of this report for a complete list of sources.

The GRI report links the GRI GIS data to the geologic features and processes discussed in the report using map unit symbols; for example, the porphyritic granodiorite phase of Coast plutonic complex of Brew and Morrell (1979b) has the map symbol **Tcpp**. The capital letter indicates age, and the following lowercase letters symbolize the unit name. "**T**" represents Tertiary (a widely used but no longer formally recognized term for the geologic period from 66.0 million–2.6 million years ago), "**cp**" represents Coast plutonic complex, and the second "p" represents porphyritic granodiorite phase. A geologic time scale is provided as a table in this report.

Acknowledgements

I am very appreciative to those who took the time to share their expertise with me and provide feedback that greatly increased the quality of this report. I would like to thank my reviewers Paul Burger (NPS Alaska Regional Office, hydrologist), Jeffrey Coe (US Geological Survey, research geologist), and Elaine Furbish (Klondike Gold Rush National Historical Park, biologist). An additional thank you goes to Elaine Furbish for sharing an abundance of references that made the research for this report significantly easier. Thank you to Rebecca Port (NPS Geologic Resources Division, GRI reports lead) and Chad Hults (NPS Alaska Regional Office, regional geologist) for providing consistent guidance, encouragement, and feedback throughout the writing process. Additional thanks go to Sarah Venator (NPS Alaska Regional Office, geologist) and Kyle Hinds (NPS Geologic Resources Division, Abandoned Mineral Lands [AML] mining engineer) for reviewing the "Abandoned Mineral Lands" section; Rebecca Beavers (NPS Geologic Resources Division, coastal geology and adaptation coordinator) for reviewing the coastal sections; Jack Wood (NPS Geologic Resource Division, geologist) for reviewing the "Geohazards" section and providing general feedback; Tim Connors (NPS Geologic Resource Division, geologist) for reviewing the geologic heritage ("geoheritage") discussion; Jonathan Flood (Klondike Gold Rush National Historical Park, archaeology program manager) for reviewing the cultural and historical information; and Jamey Jones (US Geological Survey, research geologist) for providing feedback on the discussion of the Coast plutonic complex.

The GRI team thanks the participants of the 2009 scoping meeting and 2020 follow-up conference call for their assistance in this inventory. The lists of participants (below) reflect the names and affiliations of these participants at the time of the meeting and call. Because the GRI team does not conduct original geologic mapping, we are particularly thankful for the US Geological Survey for maps of the area. This report and accompanying GIS data could not have been completed without them. Thanks to Trista Thornberry-Ehrlich (Colorado State University, research associate) for producing some of the figures in this report.

Scoping Participants

Susan Boudreau (Klondike Gold Rush National Historical Park)
Dave Brew (US Geological Survey)
Tim Connors (NPS Geologic Resources Division)
Bruce Giffen (NPS Alaska Regional Office)
Deanna Greco (NPS Geologic Resources Division)
Bruce Heise (NPS Geologic Resources Division)
Ron Karpilo (Colorado State University)
Katie KellerLynn (Colorado State University)
Dan Lawson (Cold Regions Research and Engineering Laboratory)
Brendan Moynahan (NPS Southeast Alaska Network)
Hal Pranger (NPS Geologic Resources Division)
Dave Schirokauer (Klondike Gold Rush National Historical Park)
Theresa Thibault (Klondike Gold Rush National Historical Park)
Ric Wilson (US Geological Survey)

Conference Call Participants

Chad Hults (NPS Alaska Regional Office)
Elaine Furbish (Klondike Gold Rush National Historical Park)

Report Review

Paul Burger (NPS Alaska Regional Office)
Jeff Coe (US Geological Survey)
Elaine Furbish (Klondike Gold Rush National Historical Park)

Report Editing

Katie KellerLynn (Colorado State University)

Report Formatting and Distribution

Rebecca Port (NPS Geologic Resources Division)

Source Maps

US Geological Survey

GRI GIS Data Production

Ron Karpilo (Colorado State University)
James Chappell (Colorado State University)
Stephanie O'Meara (Colorado State University)

GRI Poster Design

Thom Curdts (Colorado State University)
Lucas Chappell (Colorado State University)
Dalton Meyer (Colorado State University)

Geologic Heritage of Klondike Gold Rush National Historical Park

Geologic heritage, also referred to as "geoheritage," encompasses the significant geologic features, landforms, landscapes, and stories characteristic of the United States that are preserved for the full range of values that society places on them, including scientific, aesthetic, cultural, ecosystem, educational, recreational, and tourism. This chapter highlights those features of the park valued for their geologic heritage qualities. It also draws connections between geologic resources and other park resources and stories.

Park Background and Establishment

The Klondike Gold Rush was sparked by the discovery of gold in 1896 in the Klondike region of what is now Yukon, Canada. The brief but intense mining boom that followed caught the attention of the world and transformed the demographics, culture, and environment of the region. Between 1897 and 1898, tens of thousands of hopeful gold seekers ("stampeders") were drawn to the boomtowns of Skagway and Dyea on their way to the goldfields. Skagway and Dyea were the last towns before stampeders faced the challenge of crossing the Coast Mountains into Canada. The would-be miners could either choose to follow the Chilkoot Trail out of Dyea or the White Pass Trail out of Skagway. Either way, the journey over the mountains was arduous. Stampeders were required to bring a year's worth of supplies into Canada. These supplies could weigh close to a ton and had to be transported by multiple trips through the mountain passes (Figure 2). Once the stampeders finally reached the goldfields, many found that the best claims had already been staked and returned home empty handed.

The Klondike Gold Rush ended as quickly as it began. Following the gold rush, population and commerce declined in both Skagway and Dyea. Dyea was largely abandoned by 1900. Although Skagway has persisted, its population never again reached the levels seen during the gold rush. Today, Skagway is a popular stop for cruise ships, and tourism constitutes a large part of its economy.

Klondike Gold Rush National Historical Park was created on 30 June 1976 to preserve the historic structures and trails associated with the Klondike Gold Rush of 1897–1898 (US 94th Congress 1976). The park encompasses 53 km^2 (20 mi^2) of land across three units: the Skagway Unit, the White Pass Unit, and the Chilkoot Unit (Figure 3; see poster; NPS 2009). The Skagway Unit is in downtown Skagway and includes historic structures of the Skagway historic district. The White Pass Unit is northwest of Skagway, preserving the upper portions of the historic White Pass Trail. The Chilkoot Unit, which is the largest of the three park units, follows the historic Chilkoot Trail, stretching from the townsite of Dyea at the head of Taiya Inlet to Chilkoot Pass at the Canadian border. Across the border in British Columbia, Parks Canada preserves the Chilkoot Trail National Historic Site.

Figure 2. Photograph of stampeders. Stampeders hike up from the Scales tent city to the Chilkoot Pass on the Chilkoot Trail in 1897. Public domain photograph from the Klondike Gold Rush National Historical Park Museum Collection.

The park is within a mountainous coastal environment where elevation rises quickly from sea level to more than 1,500 m (5,000 ft) above sea level. The park is situated at the head of a steep-sided fjord called Taiya Inlet (Figure 3; Figure 4). Taiya Inlet is at the northern end of the Lynn Canal–Chatham Strait corridor, one of the largest of the many fjords that divide southeast Alaska into a series of islands known as the Alexander Archipelago (Martin and Williams 1924). The park encompasses two river valleys that cut a path through the Coast Mountains. The Taiya and Skagway Rivers flow from glacier free mountain passes to the Taiya Inlet. These river valleys are conduits between coastal and mountainous environments that support diverse populations of wildlife. Ecologists postulate that the area is a biodiversity hot spot (Pojar and MacKinnon 1994). The environment is unusually dry for southeast Alaska, which contributes to the region's unusual combination of plants and animals.

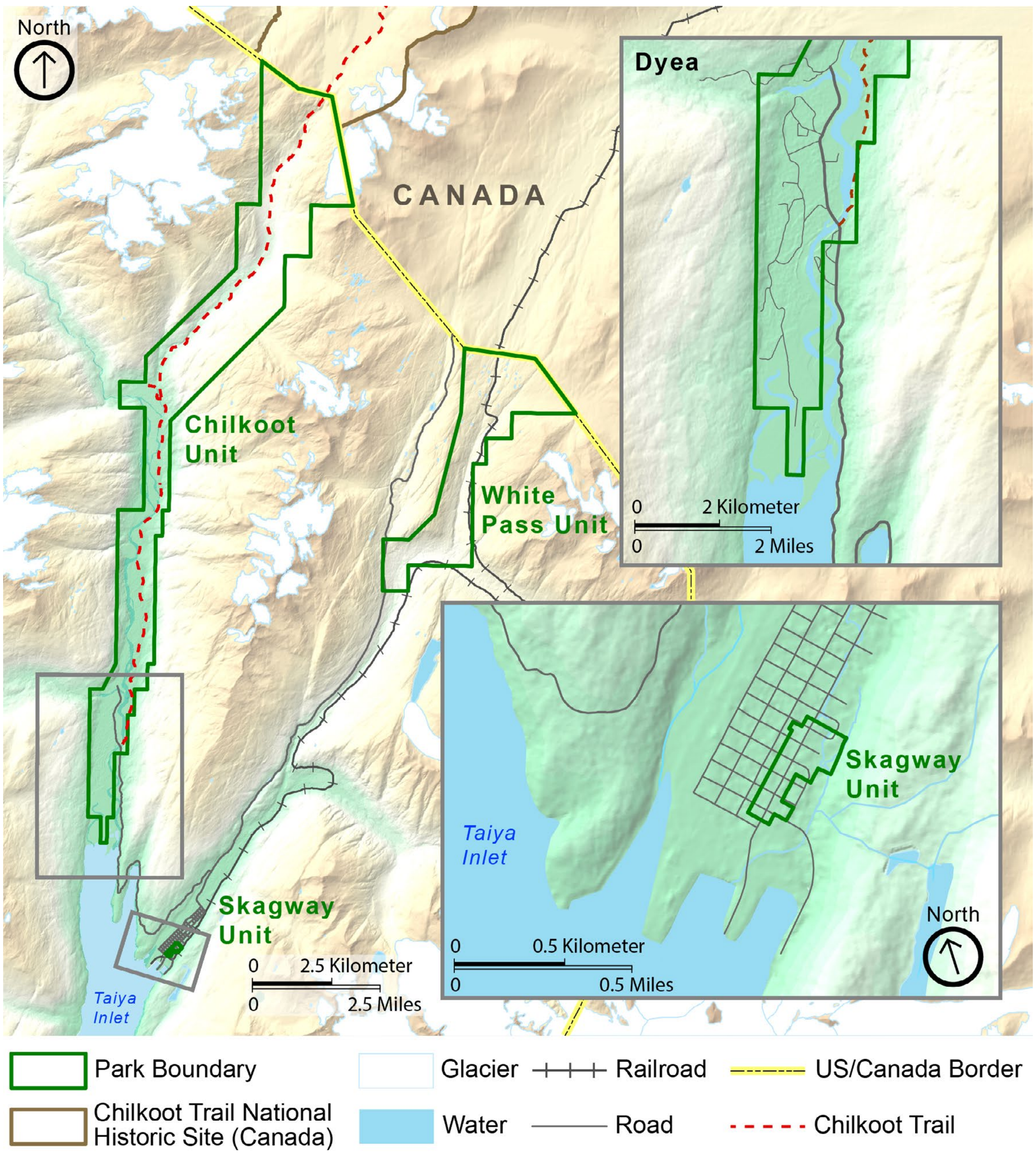


Figure 3. Map of Klondike Gold Rush Historical Park.
Klondike Gold Rush Historical Park consists of three units. The Skagway Unit is in downtown Skagway and the White Pass Unit is northeast of Skagway. The Chilkoot Unit follows the path of the historic Chilkoot Trail, stretching from the townsite of Dyea to the Chilkoot Pass at the Canadian border. Across the border in Canada, the Chilkoot Trail National Historic Site protects the continuation of the Chilkoot Trail.

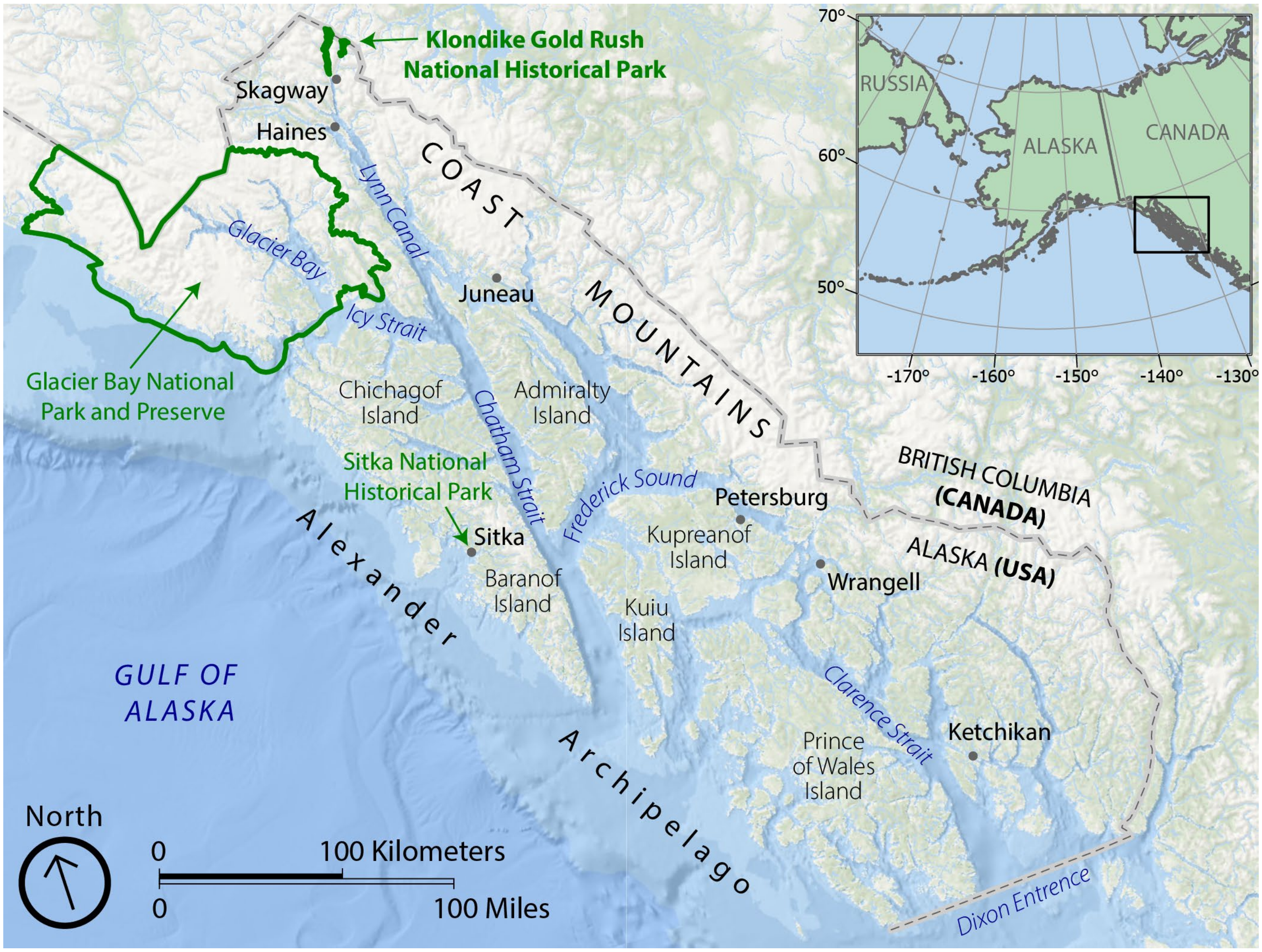


Figure 4. Map of southeast Alaska.
Southeast Alaska, also known as the Alaska Panhandle, is composed of a series of fjords and islands (known as the Alexander Archipelago) bordered by the Coast Mountains to the east and the Gulf of Alaska to the west. Klondike Gold Rush National Historical Park is situated at the head of Taiya Inlet, which forms the northernmost end of the Lynn Canal–Chatham Strait corridor. Two other NPS units are located in southeast Alaska: Glacier Bay National Park and Preserve and Sitka National Historical Park.

The park is the most visited National Park System unit in Alaska. Although visitation was down in 2020 due to impacts from the COVID-19 pandemic, in 2019 the park received more than 1 million visitors (Ziesler 2020). Most visitors travel to the park by cruise ship. In the Skagway Unit, visitors can explore the Skagway historic district, NPS visitor center, and park museum. The Chilkoot Unit contains the historic ghost town of Dyea, and visitors can hike and camp along the Chilkoot Trail. The White Pass Unit is the least developed part of the park. Most of the original White Pass Trail has been disturbed throughout the years by construction and natural processes, but parts of it can be seen from the Klondike Highway and still-operational White Pass and Yukon Route railroad.

Geologic Heritage and Connections to Park Resources

The significant geologic features, landforms, and landscape characteristics that formed the backdrop for the Klondike Gold Rush are part of the park's geologic heritage. Geologic heritage (or "geoheritage") is the nexus of geology and human experience; it encompasses the features, sites, and stories preserved for the full range of values that society places on them. These values include scientific, aesthetic, cultural, ecosystem, educational, recreational, and economic. The park was created to preserve the historical objects and physical landscape that tell the story of the Klondike Gold Rush (NPS 2009). From the ice-free mountain passes that provided access to the goldfields, to the rugged landscape that made traversing these passes so treacherous, the geology played an important role in the story at the heart of the park's mission.

The Coast Mountains were a formidable barrier between the towns of Skagway and Dyea and the interior goldfields. These mountains are the result of tectonic stress associated with the major tectonic boundary between the Pacific and North American plates that runs offshore of southeast Alaska. The plates are converging and sliding past each other, causing the land to slowly rise. During the last ice age and even older glacial periods, glaciers carved the mountains into the sharp peaks and U-shaped valleys that characterize the region today.

Geologic processes were also responsible for creating the paths through the Coast Mountains utilized by stampeders during the gold rush and the Tlingit before them. Tectonic activity has caused the bedrock in the region to fracture, producing major faults such as the Chatham Strait fault (see poster). At the head of Taiya Inlet, strands of the Chatham Strait fault extend onshore. Preferential glacial and fluvial erosion along these fault strands produced the Taiya and Skagway River valleys. Centuries before the Klondike Gold Rush, trails were established through the Taiya and Skagway valleys by the Tlingit, who managed trade between the coast and interior. The trails follow the path of the rivers to the Chilkoot and White Passes, which offer some of the only glacier-free access through the Coast Mountains. During the Klondike Gold Rush, stampeders used these routes to access the alluring riches to the north.

Although the Chilkoot and White Pass Trails offered passage through the mountains, traversing these trails was still a formidable task due in large part to the rugged landscape and active geologic hazards. Glacially carved valleys, such as the Taiya and Skagway River valleys, typically have a U-shaped profile with steep flanking ridges and peaks. The portion of the Chilkoot Trail on the south side of the pass was known as the "Golden Staircase" and was too steep for pack animal use (see Figure 2). Later, three aerial tramways were constructed over Chilkoot Pass to move supplies and gear over the steep terrain more easily. While the White Pass Trail did not have the same extreme steepness, the terrain was still rugged and more than 3,000 pack animals died on the trail, earning a part of the trail the name "Dead Horse Gulch." In addition to the terrain being harsh overall, the stampeders also had to contend with discrete geologic hazards ("geohazards"), such as floods and avalanches. As a severe example, the Palm Sunday Avalanche occurred along the Chilkoot Trail on 3 April 1898. It was the deadliest event of the Klondike Gold Rush, causing the death of more than 65 people.

Geoheritage sites are conserved so that their lessons and beauty will remain as a legacy for future generations. Such areas generally have great potential for scientific studies, use as outdoor classrooms, and enhancing public understanding and enjoyment. Geoheritage sites are fundamental to understanding dynamic earth systems, the succession and diversity of life, climatic changes over time, evolution of landforms, and the origin of mineral deposits. Currently, the United States does not have a comprehensive national registry that includes all geoheritage sites in the country, but the Chilkoot Trail and Dyea National Historic Landmark is listed by the NPS as examples of geoheritage sites on public lands. For more information on Geologic Heritage, see the "Additional References, Resources, and Websites" section of the "Guidance for Resource Management" chapter.

Geologic History

This chapter briefly describes the geologic events that formed the present landscape of the park. The "Geologic Features and Processes" chapter provides additional details about these events. Events are discussed in order of geologic age (oldest to youngest) and tell a story that began more than 50 million years ago in the Eocene Epoch. A geologic time scale (Table 2) shows the eons, eras, periods, and epochs that geologists have established to understand Earth's more than 4-billion-year history. These divisions are one of the primary ways that geologic time is discussed in this chapter and throughout the report.

Table 2. Geologic time scale.

The geologic time scale puts the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. GRI map abbreviations for each time division and map unit symbols are in parentheses. The Paleogene and Neogene Periods are also collectively referred to as the Tertiary, a widely used but no longer formally recognized term for the geologic period from 66.0 million–2.6 million years ago. Ages are millions of years ago (MYA) and follow the International Commission on Stratigraphy (ICS 2022).

Eon	Era	Period	Epoch	MYA
Phanerozoic	Cenozoic	Quaternary (Q)	Holocene (H)	0.0117 (11,700 years) –today
Phanerozoic	Cenozoic	Quaternary (Q)	Pleistocene (PE)	2.6–0.0117
Phanerozoic	Cenozoic	Neogene (N)	Pliocene (PL)	5.3–2.6
Phanerozoic	Cenozoic	Neogene (N)	Miocene (MI)	23.0–5.3
Phanerozoic	Cenozoic	Paleogene (PG)	Oligocene (OL)	33.9–23.0
Phanerozoic	Cenozoic	Paleogene (PG)	Eocene (E)	56.0–33.9
Phanerozoic	Cenozoic	Paleogene (PG)	Paleocene (EP)	66.0–56.0
Phanerozoic	Mesozoic	Cretaceous (K)	Upper, Lower	145.0–66.0
Phanerozoic	Mesozoic	Jurassic (J)	Upper, Middle, Lower	201.3–145.0
Phanerozoic	Mesozoic	Triassic (TR)	Upper, Middle, Lower	251.9–201.3
Phanerozoic	Paleozoic	Permian (P)	Lopingian, Guadalupian, Cisuralian	298.9–251.9
Phanerozoic	Paleozoic	Pennsylvanian (PN)	Upper, Middle, Lower	323.2–298.9
Phanerozoic	Paleozoic	Mississippian (M)	Upper, Middle, Lower	358.9–323.2
Phanerozoic	Paleozoic	Devonian (D)	Upper, Middle, Lower	419.2–358.9
Phanerozoic	Paleozoic	Silurian (S)	Pridoli, Ludlow, Wenlock, Llandovery	443.8–419.2
Phanerozoic	Paleozoic	Ordovician (O)	Upper, Middle, Lower	485.4–443.8
Phanerozoic	Paleozoic	Cambrian (C)	Furongian, Miaolingian, Series 2, Terreneuvian	538.8–485.4
Proterozoic	Neoproterozoic (Z)	Ediacaran, Cryogenian, Tonian	n/a	1,000–538.8
Proterozoic	Mesoproterozoic (Y)	Stenian, Ectasian, Calymmian	n/a	1,600–1,000
Proterozoic	Paleoproterozoic (X)	Statherian, Orosirian, Rhyacian, Siderian	n/a	2,500–1,600
Archean	Neo-, Meso-, Paleo-, Eo-archean	n/a	n/a	4,000–2,500
Hadean	n/a	n/a	n/a	~4,600–4,000

Eocene Epoch

The bedrock of the park formed during the Eocene Epoch (see Table 2), when magma intruded the margin of North America. The magma cooled slowly underground, creating bodies of granodiorite (**Tcpp** and **Tcp**) that underlie the entire park and surrounding area (see poster). Additionally, heat from the magma metamorphosed Proterozoic (commonly referred to as "Precambrian") rocks that existed in southeast Alaska prior to this event. These metamorphic rocks can be found locally within the granodiorite.

Post-Oligocene Epochs

Sometime after the Oligocene Epoch, tectonic pressure caused rocks to break and slide along the Chatham Strait fault. The Chatham Strait fault is one of the major geologic structures in southeast Alaska, extending about 400 km (250 mi) through the Lynn Canal and Chatham Strait. At its northern end, the Chatham Strait fault splits into several strands. One of these strands, called the Taiya Inlet fault, runs through the park. Although seismic hazard analyses (Wesson et al. 2007) note the Chatham Strait fault as potentially active, recent research suggests that it hasn't ruptured in the last 13,000 years (Brothers et al. 2018; Choi et al. 2021). Starting in the mid-Miocene Epoch (about 14 million years ago), geologic processes accelerated uplift of the Coast Mountains (Parrish 1983; Rohr and Currie 1997).

Pleistocene Epoch

Glaciers covered most of southeast Alaska during multiple cycles of glaciation during the Pleistocene Epoch. Intense erosion and isostatic rebound (rise of land after glaciers retreat) associated with glaciations within the last 2.5 million years gave rise to the modern topography of the Coast Mountains (Farley et al. 2001). During the most recent glacial period, sea level was lower, and glaciers flowed onto the continental shelf. These glaciers carved out the deep fjords, steep slopes, and sharp peaks that characterize southeast Alaska today.

Holocene Epoch

Glaciers have primarily been retreating since the beginning of the Holocene Epoch. As glaciers retreated, sea level rose and flooded the deep valleys that were carved during the Pleistocene Epoch, which led to the complex coastline in southeast Alaska characterized by islands and fjords. Additionally, subaerial, up-valley retreat of glaciers left U-shaped valleys free of ice and available for the development of rivers such as the park's Taiya and Skagway Rivers. Although glaciers primarily retreated during the Holocene Epoch, minor readvances took place. The most recent of the Holocene glacial advances is known as the Little Ice Age (1540s–1710s and 1810s–1880s; Barclay et al. 2009). By the 1900s, glaciers in the region were retreating again and have continued to retreat to the present day.

Active geologic processes are still shaping the park's landscape in many ways. Erosion along the rivers cause the channels to shift, and eroded sediment is transported from high elevations to the head of Taiya Inlet. This sediment is building the Taiya and Skagway deltas. The post–Little Ice Age loss of glaciers in the region, particularly the weight of that ice, is causing the land beneath the park to rebound upwards. Along the coast, this uplift is causing the sea level to decrease relative to the land. The many active geologic processes in the park can sometimes cause geohazards—including earthquakes, tsunamis, landslides, and floods—that may affect the park and surrounding area.

Geologic Features and Processes

The geologic features and processes highlighted in this chapter are significant to the park's landscape and history. At the beginning of each of the following sections, map units corresponding to the poster are listed; these indicate which map units are discussed in each section. Map units are referenced directly in the text as well. Some sections may not be directly related to a map unit on the poster, in which case no unit is listed at the start of the section. The map units can also be viewed in the GRI GIS data.

The selection of the features and processes was based on input from scoping and conference call participants, analysis of the GRI GIS data, and research of the scientific literature and NPS reports. Based on these information sources, the following geologic features and processes are discussed in this chapter:

- Fluvial Features
- Coastal Features
- Glacier Features, History, and Modern Change
- Active Margin Tectonics and Faults
- Bedrock Geology

Fluvial Features

Map unit: **Qs**

The park encompasses two major rivers at the head of Taiya Inlet: the Taiya River and the Skagway River. These rivers follow two splays of the Taiya Inlet fault that diverge near the head of Taiya Inlet (see the "Active Margin Tectonics and Faults" section of this report for more information). Preferential glacial erosion of fault-weakened bedrock formed the valleys that these major rivers now occupy. The Chilkoot Unit of the park is entirely within the Taiya River watershed, and the White Pass Unit is within the Skagway River watershed (see Figure 3; Hood et al. 2006). The park's Skagway Unit, which is largely within the smaller watershed of the locally named Pullen Creek, is entirely contained within the town of Skagway (Hood et al. 2006). In the GRI GIS data and on the poster, the fluvial deposits along the Taiya and Skagway Rivers are included in unconsolidated surficial deposits, undivided (**Qs**).

The Taiya River watershed drains a 481 km^2 (186 mi^2) area and contains four subbasins (Figure 5): upper Taiya River, Nourse River, West Creek, and lower Taiya River. The main stem of the Taiya River flows through a 1-km- (0.6-mi-) wide U-shaped valley, starting at the glacier-free Chilkoot Pass and ending about 14 km (8.7 mi) downstream at the mouth of the river. The valley bottom contains distinct surfaces that include the active main stem, abandoned main stem, alluvial fans, and emergent tidal areas (Curran 2020). Presently, the main stem is mostly a single channel, but before 1894, the active channel migrated and was sometimes braided within multiple wider unvegetated corridors (Curran 2020). The progressive narrowing and stabilizing of the main channel may be due to a reduction in glacial lake outburst flood (release of meltwater from a moraine- or ice-dammed lake) sediment input (Curran 2020). The mouth of the river is characterized by a prograding (seaward advance) delta formed by the deposition of sediment as the river enters the inlet and loses energy (see the "Coastal Features" section of this report for more information). In addition to the valley occupied by the main stem of the river, the basin includes two other prominent valleys occupied by gravel-bedded streams (Curran 2020); Nourse River and West Creek flow from the northwest into the main stem of the Taiya River and both are fed by a series of tributary glaciers and streams (Figure 5).

The Skagway River watershed drains an area of approximately 375 km^2 (145 mi^2) and includes the major tributaries of the East Fork and White Pass Fork (Figure 5; Hood et al. 2006). The White Pass Fork flows through the White Pass Unit of the park. Several glaciers provide water and sediment to the watershed, including Laughton Glacier, South Glacier, and Denver Glacier. The mouth of the Skagway River is located at the head of Taiya Inlet at the municipality of Skagway. Within Skagway, the river has been channelized to control channel migration and flooding and reduce erosion along the banks (US Army Corps of Engineers 2008). Flood control dikes have been built on both sides of the Skagway River through the town to about 1.5 miles upstream (US Army Corps of Engineers 2008).

The locally named Pullen Creek is within a small watershed entirely contained within the town of Skagway. The main stem of the creek is approximately 2.4 km (1.5 mi) long. The watershed includes two spring-fed tributaries from three headwater locations (Hood et al. 2006). Pullen Creek has been moved and channelized several times through engineering efforts, receives most of its runoff from impervious surfaces, and has 31 culverts along its length (ADEC 2010). The Dewey lakes hydropower plant augments flow in the lower reach of Pullen Creek (Hood et al. 2006). Above

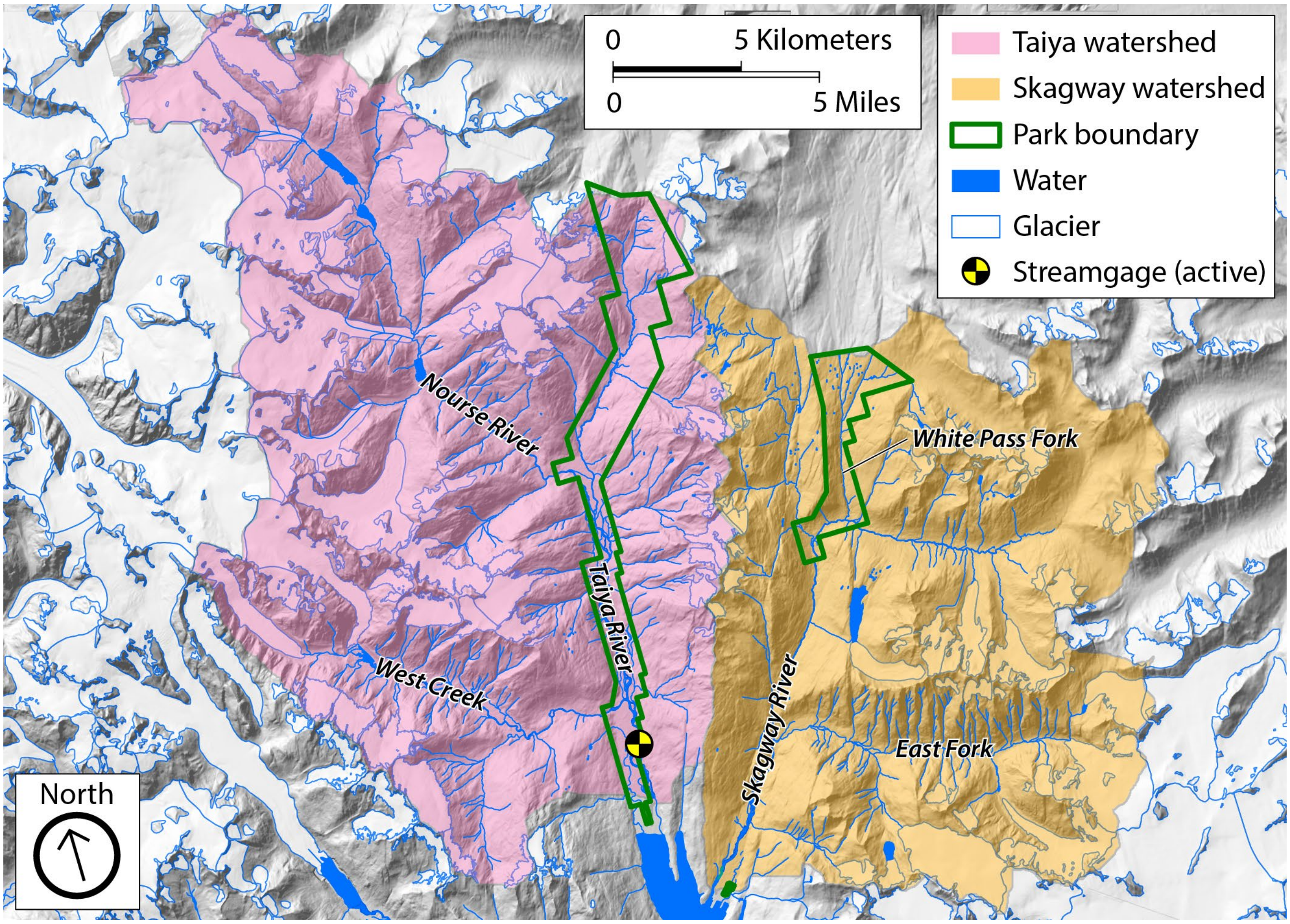


Figure 5. Watershed map of the Klondike Gold Rush National Historical Park area. The extents of the Taiya River watershed (in pink) and the Skagway River watershed (in yellow) are shown, as well as the major rivers within these watersheds, glaciers surrounding these watersheds, the location of the active streamgage on the Taiya River, and the park boundaries. The Chilkoot Unit is within the Taiya River watershed and encompasses most of the Taiya River. The White Pass Unit is within the Skagway River watershed and contains the White Pass Fork (stream) and part of the Skagway River. Both the Taiya and Skagway Rivers drain into Taiya Inlet. The watershed outlines are from Bernatz et al. (2010). The streamgage and stream/river locations are from the National Hydrography Dataset (US Geological Survey 2016) and the glacier outlines are from the Randolph Glacier Inventory (RGI Consortium 2017).

the hydropower plant, the bed of Pullen Creek is predominantly silt and sand, whereas below the plant the streambed is mainly composed of larger gravels and cobbles (Hood et al. 2006). In 1990, Pullen Creek was added to Alaska's section 303(d) list of impaired water bodies (ADEC 2010). The impairment is due to elevated levels of heavy metals (zinc, copper, lead, and cadmium) in sediments in and around Pullen Creek (STC 2006, ADEC 2010). The contamination is the result of historical transport and transfer of mining ore through the Nahku ore storage and transfer facility in Skagway harbor (ADEC 2010). Because no active sources are known to contribute to the sediment contamination, a 2010 Alaska Department of Environmental Conservation report recommended natural attenuation as the best course of action to achieve levels of pollutants within applicable water quality standards (ADEC 2010). Other suggested restoration actions include minimizing the erosion of contaminated soils adjacent to the stream and continued monitoring to track the natural recovery over time (STC 2006; ADEC 2010).

Three streams within the park (Skagway River, West Creek, and Taiya River) have been monitored by USGS streamgages. One of the gages is currently active (Figure 5; Taiya River, https://waterdata.usgs.gov/nwis/uv/?site_no=15056210, accessed 3 May 2022). Discharge on the

Skagway River was measured between 1964 and 1986, on West Creek between 1962 and 1977, and on the Taiya River between 1970 and 1977 and 2004–present. During the monitoring periods, the Skagway River had a mean annual discharge of 15.9 m^3/s (562 ft^3/s), West Creek had a mean annual discharge of 9.49 m^3/s (335 ft^3/s), and the Taiya River had a mean annual discharge of 34.6 m^3/s (1,222 ft^3/s; Hood and Berner 2009; Curran et al. 2016). All three streams exhibited seasonal flow patterns typical of glacierized basins in Alaska. Highest flow occurs in the summer because of inputs from melting glaciers and icefields (Hood and Berner. 2009; Curran et al. 2016). Peak discharge for West Creek and the Taiya River occurs most commonly in August and September but has occurred as early as June and as late as November (Curran 2020). Analysis of the Taiya River streamflow data for the periods 1970–1977 and 2004–2017 showed a shift toward an earlier spring snowmelt pulse; in the 1970s, the average date of the spring snowmelt pulse was 1 June while the average date in the 2000s was 18 May (Bernatz et al. 2010; Curran 2020).

Floods in the Skagway River and Taiya River watersheds have been triggered by high rainfall events and glacial lake outburst events. Notable floods include a 1967 rainfall-generated flood that affected both watersheds, glacier lake outburst floods from the Nourse River valley before and during the 1897–1898 Klondike Gold Rush, and a 2002 glacial lake outburst flood from West Creek (Curran 2020). See the "Geohazards" section of this report for more details.

Coastal Features

Map units: **Qs**

Southeast Alaska is composed of many islands and branching fjords that were carved out by glaciers during the last ice age. The park is located at the head of Taiya Inlet, which is the northernmost extension of the Lynn Canal. The Lynn Canal transitions into the Chatham Strait to the south, and both follow the trace of the Chatham Strait fault. Together the Lynn Canal and Chatham Strait form the longest and straightest of the many fjords in southeast Alaska (Martin and Williams 1924). The Lynn Canal is a classic U-shaped fjord, with steep sides and a relatively flat bottom. Rivers and streams feeding into the Lynn Canal input freshwater and sediment into the system, creating estuaries and steep deltas.

Prominent deltas lie at the head of Taiya Inlet, where the Taiya and Skagway Rivers enter the ocean and deposit sediment. The Skagway delta is at the northeastern corner of the inlet and is associated with the municipality of Skagway, whereas the Taiya delta is at the northwestern corner of the inlet and associated with the historic townsite of Dyea. The Chilkoot Unit of the park encompasses 3.2 km (2.0 mi) of coastline along the Taiya delta (Hood et al. 2006). Although the Skagway Unit of the park does not contain coastline, it is within the coastal municipality of Skagway and is about 0.25 km (0.16 mi) from the boat harbor. In the GRI GIS data and on the poster, the deltas at the mouth of the Taiya and Skagway Rivers are included in unconsolidated surficial deposits, undivided (**Qs**).

The Taiya delta is a broad tidal river delta that is gradually extending into the Taiya Inlet through the buildup of sediment from the Taiya River. The main channel from the Taiya River forms a broad braided channel on the east side of the estuary. A slow-moving slough locally called Nelson Creek flows along the western boundary of the estuary (Hood et al. 2006). Yehle and Lemke (1972) proposed that the Taiya delta is probably composed of more silt and fine sand than the Skagway delta, based on the sandy nature of the downstream banks of the Taiya River. As the delta continues to extend into the head of Taiya Inlet, subaqueous slides undoubtably occur along the steep delta front (Yehle and Lemke 1972).

The Skagway delta is formed by the deposition of sediment carried by the Skagway River. It contains a high percentage of sand and gravel, whereas the distal part of the delta is mainly unconsolidated mud (Synolakis et al. 2002). The Skagway delta ranges from 3 to 15 m (10 to 50 ft) thick, and is underlain by older deltaic deposits, glacial deposits, and bedrock (Yehle and Lemke 1972). Like the Taiya delta, the Skagway delta is an active geologic feature that is extending into Taiya Inlet because of the addition of sediment at the delta front and slow emergence of the land throughout the region (Yehle and Lemke 1972). However, much of the surface of the delta has been modified by human activities and is covered by artificial fill. The Skagway River channel has altered the flow of the river and longshore currents (currents that flow parallel to the shore) in the harbor area (Yehle and Lemke 1972).

Glacier Features, History, and Modern Change

Map units: **g**

Glaciers are perennial masses of ice that flow from high elevations, where more snow falls than melts (accumulation zone), to lower elevations, where more melting occurs (ablation zone). Globally, glaciers vary in size, ranging from small cirque glaciers to medium-sized mountain glaciers to huge continental glaciers that covered large portions of North America during the Pleistocene (2.6 million years ago–11,700 years ago; see Table 2). Modern glacier coverage in the park is restricted to one unnamed glacier partially within the boundary in the northernmost part of the Chilkoot Trail corridor (see poster; Figure 6; Figure 7). The glacier straddles the US–Canada border on the ridge just southeast of Chilkoot Pass. The glacier is relatively small, covering approximately 1.4 km^2 (0.5 mi^2) as of 2011 (Loso et al. 2014).

Although the park itself contains only one small glacier, the surrounding mountains are home to many glaciers that feed the area's streams and rivers. Broadly speaking, the park is situated between the more heavily glaciated regions of the Juneau Icefield to the southeast and Glacier Bay to the southwest. Several small- and medium-sized cirque and mountain glaciers exist in the area directly west of the park (Figure 7; see poster). The abundance of glaciers increases farther southeast of the park, ultimately coalescing into the continuous expanse of the Juneau Icefield. The fact that the Taiya and Skagway River valleys contain relatively little glacial ice compared to the surrounding area is why routes through these valleys were established by the Tlingit and have been used for centuries to traverse the mountains, including by stampeders during the gold rush.

Glaciers in southeast Alaska went through a series of advances and retreats throughout the Pleistocene Epoch that correspond to global "glacial" and "interglacial" periods. Glacial periods occur when large, continental ice sheets dominate the Northern Hemisphere. Interglacial periods are when these large ice sheets are absent. During the most recent glacial period, glaciers in southeast Alaska were much more extensive than today, flowing onto the continental shelf and carving the deep fjords and islands of the Alexander Archipelago (see Figure 4; Kaufman and Manley 2004). As Earth transitioned into an interglacial period at the end of the Pleistocene Epoch, these glaciers retreated and sea level rose, leaving behind the present-day coastline characterized by steep slopes, sharp peaks, islands, and fjords.

While glaciers have generally been receding since the end of the last glacial period, minor readvances have occurred during the Holocene Epoch (11,700 years ago to today; see Table 2). In coastal southern Alaska, the largest and most recent of these Holocene advances occurred in two pulses (1540s–1710s and 1810s–1880s) that are termed the Little Ice Age (Barclay et al. 2009). Deposits formed during the Little Ice Age have not been studied in or immediately around the park. Elsewhere in southern Alaska, however, glacial deposits dating to the Little Ice Age show the extent of this advance. For example, glaciers to the southwest of the park in Glacier Bay were considerably larger and coalesced to form an icefield during the Little Ice Age (Larsen et al. 2005). The post–Little Ice Age collapse of this icefield caused uplift throughout much of southeast Alaska because of the process of glacial isostatic rebound (Larsen et al. 2005).

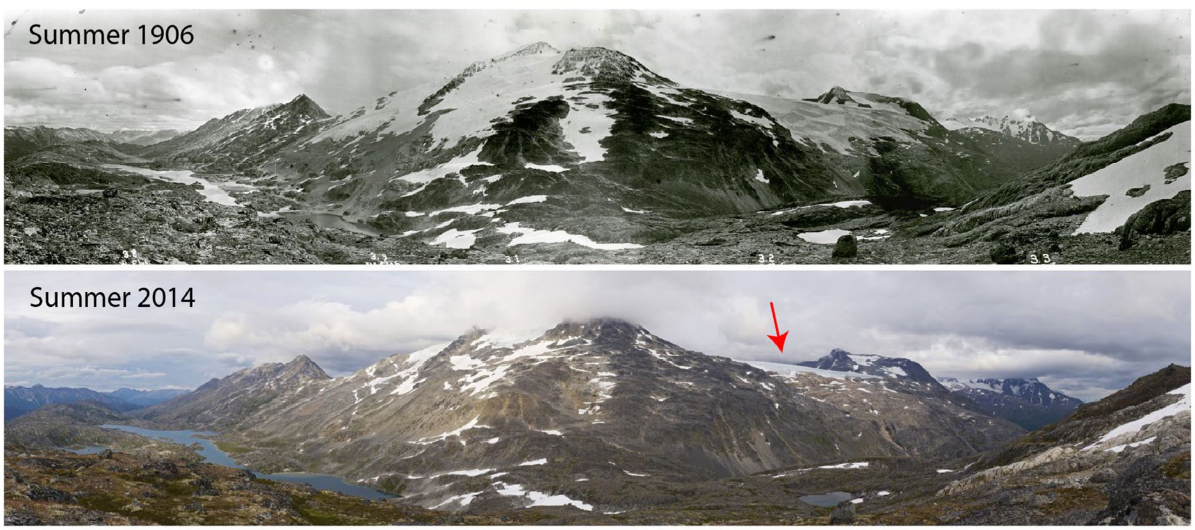


Figure 6. Photographs of Chilkoot Pass showing the park's unnamed glacier in 1906 and 2014. A red arrow indicates the glacier that is partially within the park. In the 108–year time frame, the glacier has decreased in size. The photographs show a view looking to the east of Chilkoot Pass, with Crater Lake seen on the left side and glaciers on both sides of the United States–Canada border. The park boundary cuts through the central part of the photographs. See Figure 7 for the photograph location. The top photograph was taken in late summer by G. White-Fraser of the International Boundary Commission, and the bottom photograph was taken on 5 August 2014 by R. D. Karpilo Jr. of Colorado State University. For more information about this photograph, and other repeat photographs throughout the park and surrounding area, see Karpilo and Venator (2015).

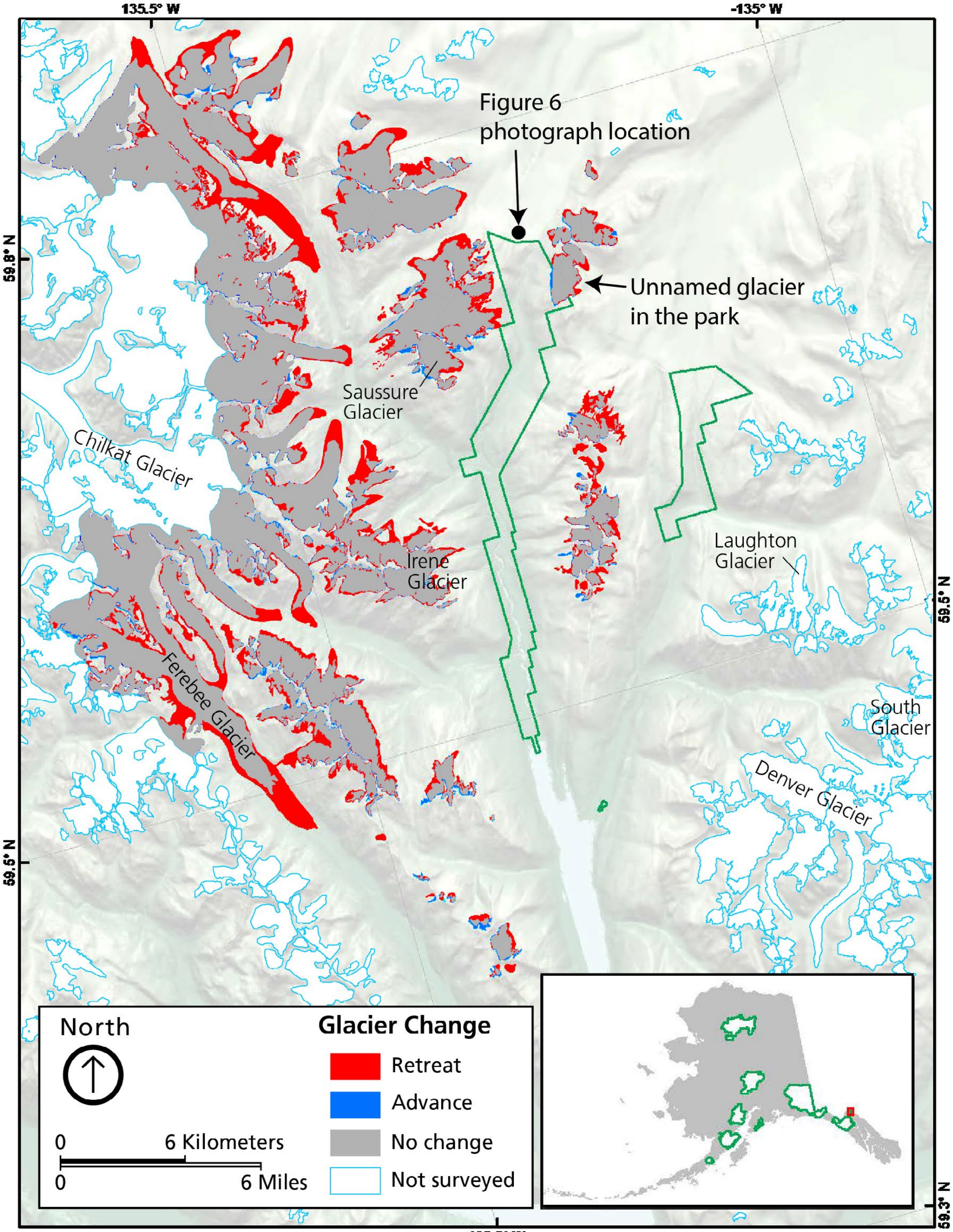


Figure 7. Map of modern glaciers and glacier change between 1957 and 2008.
Changes were measured using 1950s topographic maps and 2008 satellite imagery. Red indicates areas that experienced glacier retreat in this time frame, blue indicates areas of advance, gray indicates areas of no change, and white areas were glaciers that were not surveyed. Most of the glaciers in the Klondike Gold Rush area have retreated since 1957, with significant retreat seen at Ferebee Glacier and the glaciers located at the head of Nourse River. In the park, glacier area reduced by 74%, from 5.3 to 1.4 km2 (2.0 to 0.54 mi2). Green lines are park boundaries. Named glaciers in the map area are labeled. Black dot indicates the location of the photographs in Figure 6. Map modified from Loso et al. (2014).

Southeast Alaska is experiencing the world's fastest glacial isostatic rebound because of glacier retreat since the Little Ice Age (Larsen et al. 2005). Glacial isostatic rebound is uplift that occurs in areas that were formerly overlain by heavy glacial ice. Accelerated post-glacier uplift in southeast Alaska began in about 1770 CE and is centered on Glacier Bay and the Yakutat icefield (Larsen 2005). The park is within the region experiencing high isostatic rebound. The modern (1992–2007) ground motion at Skagway has been measured using repeated GPS surveys, with results showing an average uplift rate of 22.7 mm/yr (0.894 in/yr; Freymueller et al. 2008).

Glaciers in southeast Alaska have primarily retreated since the end of the Little Ice Age and continue to retreat today. Between about 1957 and 2008, area covered by glacier ice in the park reduced by 74%, from 5.3 to 1.4 km^2 (2.0 to 0.54 mi^2; Figure 7; Loso et al. 2014). This loss is mainly a reflection of the loss of one glacier in the upper Taiya River. The terminus of this glacier, which was within park boundaries in the 1950s, retreated out of the park by 2008 (Loso et al. 2014). Glaciers both between the Taiya and Skagway River valleys and to the west of the park retreated during this time frame, including substantial terminus retreat for the Ferebee Glacier and in the headwaters of the Nourse River (Loso et al. 2014). Reduction in the size of the park's current glacier can be visually seen in a pair of repeat photographs of the Chilkoot Pass taken by G. White-Fraser in 1906 and R. D. Karpilo Jr. in 2014 (see Figure 6; Karpilo and Venator 2015).

Although the park has only one small glacier and little evidence remains of deposits associated with the last ice age, the entire region has been shaped by glaciers, and active glacial processes continue to modify the landscape. All the streams and rivers in the park are fed by glacier melt, and much of the sediment carried by these waterways is sourced from glaciers. Glacial features and deposits include landforms formed through modern glacial processes as well as those formed when glaciers were more extensive than today. Examples in and around the park include sharply carved peaks and ridges referred to as "horns" and "arêtes," U-shaped valleys and fjords, and accumulations of rocks that mark the former extent of glaciers called "moraines."

Active Margin Tectonics and Faults

Map unit: faults

Southeastern Alaska is on a tectonically active continental margin, where the Pacific plate is sliding past the North American plate at a rate of about 54 mm/yr (2.1 in/yr; DeMets et al. 2010). The North American and Pacific plates have been colliding and grinding against each other in this part of Alaska for millions of years; evidence of this long history of deformation is found in rocks throughout the region in the form of faults. Faults are planes along which rocks slip past one another and can be active (accommodating motion today) or inactive (accommodated motion in the past). Major active or potentially active faults in southeast Alaska include the Queen Charlotte–Fairweather fault system, eastern Denali fault, and Chatham Strait fault (Figure 8). The bedrock in and around the park is cut by splays of the Chatham Strait fault, and most of the major valleys in the region are fault controlled (see poster).

The Queen Charlotte–Fairweather fault system is south and west of the park, trending along the outer coast of the Alexander Archipelago and cutting through Glacier Bay National Park and Preserve. Most of the plate motion in southeast Alaska is being accommodated by this fault system, which is experiencing slip at a rate of 50–55 mm/yr (1.9–2.2 in/yr; Brothers et al. 2017). As such, the large historical earthquakes in the region are concentrated on the Queen Charlotte–Fairweather fault system, and the area adjacent to the fault is at the highest risk for future large earthquakes (https://earthquake.usgs.gov/earthquakes/search/, accessed 10 July 2021; Wesson et al. 2007).

The Chatham Strait fault follows a prominent 400-km- (250-mi-) long trench in southeast Alaska that encompasses the Chatham Strait and Lynn Canal. Comparisons of rocks mapped on either side of the Chatham Strait fault indicate about 190 km (120 mi) of right-lateral offset (Lathram 1964). Movement on the Chatham Strait fault must have occurred after the Oligocene Epoch (33.9 million–23.0 million years ago; see Table 2) because volcanic rocks dated to 28 million years ago are offset by the fault (Brothers et al. 2018). While the most recent seismic hazard assessment (Wesson et al. 2007) includes the Chatham Strait fault as potentially active, recent research suggests the Chatham Strait fault has not generated coseismic (during an earthquake) deformation in the last 13,000 years, and the modern slip rate is less than 1 mm/yr (0.04 in/yr; Brothers et al. 2017).

Near its northern extent, the Chatham Strait fault splits into several strands, one of which runs through the park (Figure 8). In Lynn Canal, the Chatham Strait fault splits into the Chilkat fault and the Chilkoot Inlet fault. The Chilkat fault is the largest structure in the region, with an estimated right-lateral offset of about 170 km (106 mi; Ovenshine and Brew 1972). The Chilkat fault is covered by fluvial deposits, but it cuts through rocks that exhibit shearing and, along the trace of the fault, catalastic textures (wholly or partially crushed; MacKevett et al. 1974; Redman et al. 1984).

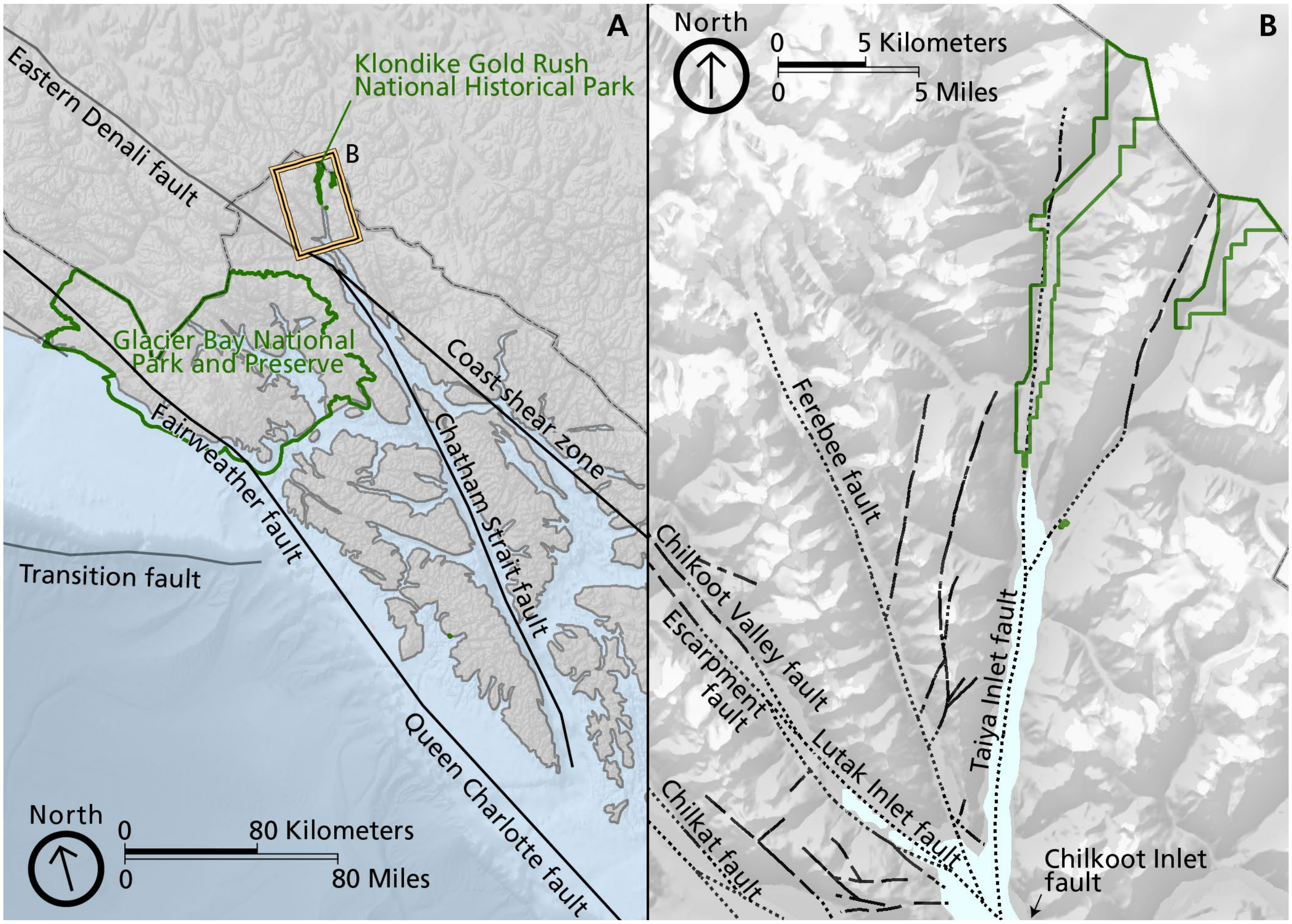


Figure 8. Maps of faults in southeast Alaska.
(A) Regional map showing major active or potentially active faults, including the Queen Charlotte–Fairweather fault, the Chatham Strait fault, and the eastern Denali fault. Most seismic activity in southeast Alaska is along the Queen Charlotte–Fairweather Fault. Although the eastern Denali fault and Chatham Strait fault are considered active in the most recent seismic hazard analysis (Wesson et al. 2007), more recent studies found minimal to no modern movement along these faults (Brothers et al. 2018; Choi et al. 2021). The smaller fault strands at the northern ends of the Chatham Strait fault are not shown in view A but can be seen in view B. (B) Map showing the topography and faults in and around the park. The Chatham Strait fault splits into several splays near its northern extent, which occupy most of the major valleys in the region. The Chilkat fault (seen in the bottom left) is the westernmost of the strands and trends into the eastern Denali fault (see view A). The easternmost splay, the Taiya Inlet fault, extends into the Chilkoot Unit of the park. Fault locations from Wilson et al. (2015) and Brothers et al. (2018).

Near Haines, the Chilkoot Inlet fault splits into three splays: the Taiya Inlet fault, Ferebee fault, and Lutak Inlet fault (Redman et al. 1984). The Lutak Inlet fault is the largest of the Chilkoot Inlet strands and has two strands (the Chilkoot Valley fault and the Escarpment fault). The Chilkoot Valley fault is the older of the two strands, juxtaposing the 64-million-year-old Ferebee pluton (large body of intrusive rock) to the east and the 110-million-year-old Mount Kashagmak pluton to the west (Redman et al. 1984). The Ferebee fault is the central splay of the Chilkoot Inlet fault. It forms a conspicuous trace occupied by the Ferebee Glacier and Ferebee River, however, it probably only has a few kilometers of offset (Redman et al. 1984). The Taiya Inlet fault is the easternmost of the Chilkoot Inlet fault splays, running northward through Taiya Inlet and through the Chilkoot Unit of the park.

The Chatham Strait fault connects in the north to the eastern Denali fault. The Denali fault is a 2,100-km- (1,300 mi-) long right-lateral strike-slip fault system (characterized by horizontal displacement to the right) that stretches from southeastern Alaska, through Canada, to central Alaska. The Denali fault has been partitioned into segments that have different levels of recent seismicity. The central Denali fault is known to be active, rupturing in 2002 to produce the magnitude 7.9 Denali earthquake (Erbhard-Phillips et al. 2003). The eastern Denali fault has a less active recent history. Choi et al. (2021) investigated the stress regime and tectonic implications of a pair magnitude 6.2 and 6.3 earthquakes in the vicinity of the eastern Denali fault that occurred in 2017. The findings suggest that stress in the region is causing deformation between the eastern Denali fault and the Queen Charlotte–Fairweather fault; however, this stress is not conducive to strike-slip motion along the eastern Denali fault, and the fault is no longer active (Choi et al. 2021).

Bedrock Geology

Map units: **Tcpp** and **Tcp**

The park's bedrock consists of the Coast plutonic complex of Brew and Morrell (1979b) (**Tcpp, Tcp**), which is a plutonic-metamorphic belt that extends 1,750 km (1,090 mi) along the west coast of North America from Alaska to Vancouver (Brew et al. 1995). It is composed of plutons emplaced during the Cretaceous Period (145.0 million–66.0 million years ago; see Table 2) and early Tertiary (66.0 million–2.6 million years ago), specifically the Eocene Epoch (56.0 million–33.9 million years ago; see Table 2). A pluton is a large body of igneous rock that was emplaced, cooled, and crystallized underground, resulting in a coarse-grained crystalline rock such as granite.

The plutonic complex also contains metamorphic rocks derived from pre-Tertiary protoliths (original rock prior to metamorphism; Gehrels and Berg 1994). Metamorphic rocks are often created when plutons are emplaced because the heat of the magma alters the surrounding rock. Full descriptions of the geologic units in the park and in the surrounding area can be found in the ancillary map information document that accompanies the GRI GIS data.

The Coast plutonic complex formed as a continental arc associated with the accretion of a crustal block called the Wrangellia composite terrane (also referred to as the Insular superterrane) to the western margin of North America. The Wrangellia composite terrane consists of a series of rocks that formed as part of or adjacent to ancient volcanic arcs (series of volcanoes in an arcuate arrangement). These rocks were transported by plate tectonics (i.e., displaced) from offshore in the proto-Pacific Ocean to the western edge of North America. During the Mesozoic Era, the buoyant Wrangellia composite terrane accreted to North America, adding a significant amount of crust that includes most of southern Alaska. The accretion of the Wrangellia composite terrane may have occurred at a more southerly latitude prior to hypothesized translation northward along major strike-slip faults during the Cenozoic Era. This hypothesis, termed "Baja-BC" because it argues that the Wrangellia composite terrane was situated near the latitude of Baja California when it accreted, has generated considerable debate among geologists and is still somewhat contentious today (see Cowan et al. 1997 for a summary).

The most extensive geologic unit in the park primarily consists of porphyritic granodiorite (**Tcpp**). It underlies the entire Chilkoot Trail corridor and northwestern half of the White Pass corridor (see poster). Figure 9 is a diagram that shows how intrusive igneous rocks are classified based on the percentage of different types of minerals. These rocks have been informally referred to as the Skagway Pluton and have been dated to late Paleocene–early Eocene Epochs (Gehrels et al. 1990; Brew and Ford 1994; Symons et al. 2000; Symons and Kawaski 2011). Porphyritic rocks, such as the porphyritic granodiorite found in **Tcpp**, contain a set of crystals that are distinctly larger than the rest of the crystals in the rock. This type of texture is produced by two different cooling rates: (1) a slower cooling rate that allows the larger phenocrysts to form, and (2) a faster cooling rate that forms the rest of the smaller crystals. In addition to granodiorite, **Tcpp** also contains minor amounts of quartz diorite and quartz monzonite, as well as metamorphic rocks such as migmatite (Figure 9). Migmatites are a type of metamorphic rock that represents the transition from metamorphic to igneous in the rock cycle; it is characterized by partial melting.

The southeastern half of the White Pass corridor is underlain by a geologic unit also primary composed of granodiorite (**Tcp**; see poster). One of the key differences between **Tcpp** and **Tcp** is their age. The rocks grouped together in **Tcpp** were emplaced or metamorphosed during the late Paleocene–early Eocene Epochs while the rocks of **Tcp** were emplaced later, during the early–middle Eocene Epoch (Barker et al. 1986; Gehrels et al. 1991; Brew and Ford 1994; Symons et al. 2000; Symons and Kawaski 2011). **Tcp** is referred to by Brew and Ford (1994) as the "Clifton Pluton," which is part of the larger White Pass plutons suite. In addition to granodiorite, **Tcp** contains subordinate amounts of quartz monzonite, quartz diorite, leucogranite (light-colored igneous rock), and migmatite (Figure 9).

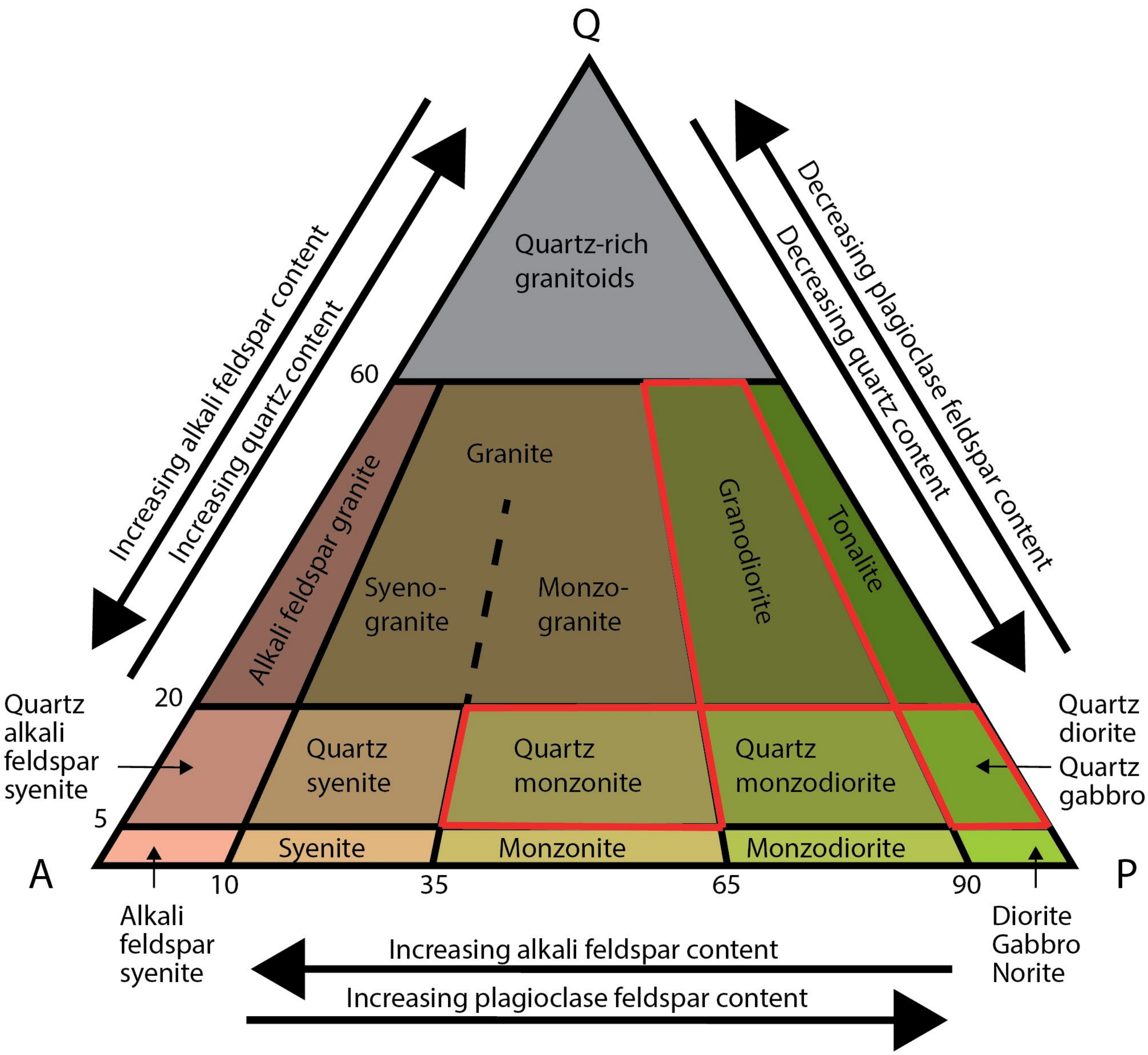


Figure 9. Diagram showing the classification of felsic intrusive igneous rocks.
Classification is based on the relative percentages of quartz (Q), alkali feldspar (A), and plagioclase feldspar (P). The plutons within the park are classified as granodiorite, quartz monzonite, and quartz diorite (outlined in red) based on their mineral composition. Graphic by Trista Thornberry-Ehrlich (Colorado State University) after Le Bas and Steckeisen (1991).

Geologic Resource Management Issues

This chapter describes geologic features, processes, or human activities that may require management to address safety needs and preservation of natural and cultural resources in Klondike Gold Rush National Historical Park. The NPS Alaska Regional Office Natural Resources Team and the NPS Geologic Resources Division provide technical and policy assistance for these issues.

At the previously described GRI meetings in 2009 and 2020, participants identified the following geologic resource management issues as priorities for resource management at the park:

- Geohazards
- Erosion
- Uplift and Sea Level Change
- Abandoned Mineral Lands

Geohazards

The dynamic landscape of the park presents a variety of geologic hazards ("geohazards") that threaten NPS resources, facilities, staff, and visitors. Geohazards are active geologic processes, such as landslides, earthquakes, and tsunamis, that have the potential to cause damage to structures, facilities, or the loss of life. Management plans to address geohazards could include identifying and mapping potential geohazards, understanding the processes that lead to geohazards, quantifying the frequency and magnitude of geohazards, developing monitoring or detection tools, conducting vulnerability assessments of threatened people or infrastructure, creating plans to avoid or respond to geohazards, and educating employees and visitors (Hults et al. 2019). NPS Policy Memorandum 15-01 (Jarvis 2015) directs NPS managers and their teams to proactively identify and document facility vulnerabilities to climate change and other natural hazards (including geohazards). Geohazards with the potential to impact the park include earthquakes, tsunamis, landslides, snow avalanches, and floods.

Earthquakes

Earthquakes are common in southeast Alaska because it is on a tectonically active plate margin. Most of the plate motion is being accommodated by the Queen Charlotte–Fairweather fault, which runs offshore along the Alexander Archipelago and cuts through Glacier Bay National Park and Preserve (see Figure 8). Consequently, almost all the earthquakes in southeast Alaska greater than magnitude 6.0 since 1950 have been near the Queen Charlotte-Fairweather fault (https://earthquake.usgs.gov/earthquakes/search/, accessed 10 July 2021). Recent studies indicate that the Chatham Strait fault, which runs through the park, and the eastern Denali fault are minimally active to not active at all (Brothers et al. 2018; Choi et al. 2021).

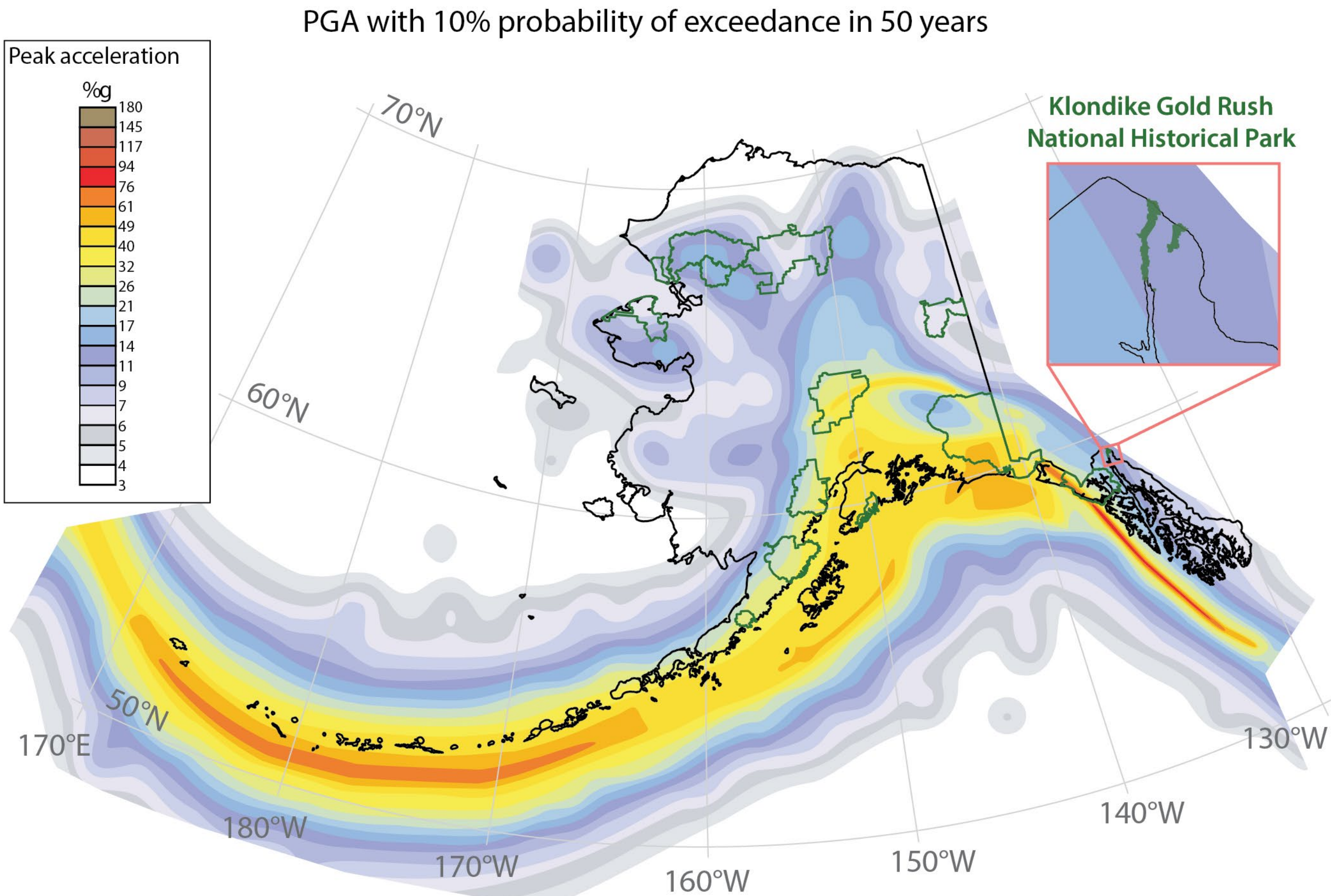
The Alaska Earthquake Center maintains seismic monitoring stations near the park and actively monitors earthquake hazards in conjunction with the USGS (see http://earthquake.alaska.edu/). According to Wesson et al. (2007), the park has a 10% probability for an earthquake to cause peak ground acceleration of between 11% and 14% of the acceleration of gravity (9.8 m/s^2 [32 ft/s^2]) in the next 50 years (Figure 10). This amount of peak horizontal acceleration would be perceived as strong shaking and could cause light to moderate damage.

Ground shaking from an earthquake can damage infrastructure, which in turn can directly threaten human safety. Indirect effects of an earthquake, such as rockfalls, landslides, and tsunamis, can also be hazardous. A strong earthquake could pose a threat to park staff, visitors, and infrastructure, including the park headquarters, visitor center, and historic buildings in Skagway. Visitors and staff along the coast of the park may be at an increased risk in the event of a large earthquake due to earthquake-induced or submarine landslide–generated tsunamis, which are described in the "Tsunamis" section of this report.

Tsunamis

The coast of southern Alaska is vulnerable to tsunamis, which are large waves caused by displacement of water, either by fault surface rupture associated with an earthquake or landslides. Both underwater landslides and those entering a body of water can cause tsunamis.

Tsunamis can be extremely destructive. For example, tsunamis associated with the 1964 Alaska earthquake—also referred to as the "Great Alaska earthquake" or "Good Friday earthquake"—accounted for most of the fatalities (122 out of 131) and overall damage caused during that event (Lander 1996). Earthquake-caused (tectonic) tsunamis, such as the 1964 tsunami, have occurred at the head of the Taiya Inlet in the past, and modeling shows a potential tectonic tsunami wave reaching up to 2.7 m (8.9 ft) in the upper Taiya Inlet (Nicolsky et al. 2018). In Skagway, the 1964 tsunami height was estimated at about 5 m (16 ft); water inundated about 3 m (10 ft) above the bay level



Peak acc. (%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
Perceived shaking	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential damage	None	None	None	Very Light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy

Figure 10. Earthquake probability map of Alaska.
The map shows the greatest amount of acceleration (as a percentage of the acceleration of gravity) produced by an earthquake that has the probability of 10% to occur in the next 50 years. Green outlines are National Park System units. Klondike Gold Rush National Historical Park is entirely within the 11%–14%g peak acceleration range, corresponding to strong shaking and light damage. Map modified from Wesson et al. (2007). Values for the table located at the bottom of the figure are from Wald et al. (1999). These values were developed for southern California but provide a general sense of perceived shaking and damage for earthquakes elsewhere.

(Lander 1996). Although no damage was caused by the 1964 tsunami in Skagway, if a future tsunami were to arrive during high tide, it could be more destructive. Earthquakes on the Fairweather-Queen Charlotte fault system are typically strike-slip, which lack the vertical displacement of the sea floor needed to trigger large tsunamis. However, in 2012, an unusual thrust event called the Haida Gwaii earthquake occurred on the southern part of the Fairweather–Queen Charlotte fault, generating a tsunami that caused up to 7.5 m (25 ft) of run-up near the rupture area (Nicolsky et al. 2018). Nicolsky et al. (2018) modeled the tsunami inundation at Skagway for seven earthquake-caused tsunami scenarios. Of these scenarios, modeling of a multi-segment Tohoku-type earthquake (i.e., 2011 earthquake in Tohoku, Japan) in the Gulf of Alaska resulted in the highest waves, up to 2.7 m (8.9 ft) in the upper Taiya Inlet.

Submarine landslide-caused tsunamis have also occurred at Skagway in the past, and modeling identified two potential slide areas at the head of Taiya Inlet (Figure 11; Nicolsky et al. 2018). Factors that contribute to the potential for tsunami-inducing landslides include the instability of recently deglaciated slopes, high sedimentation rates along the margins

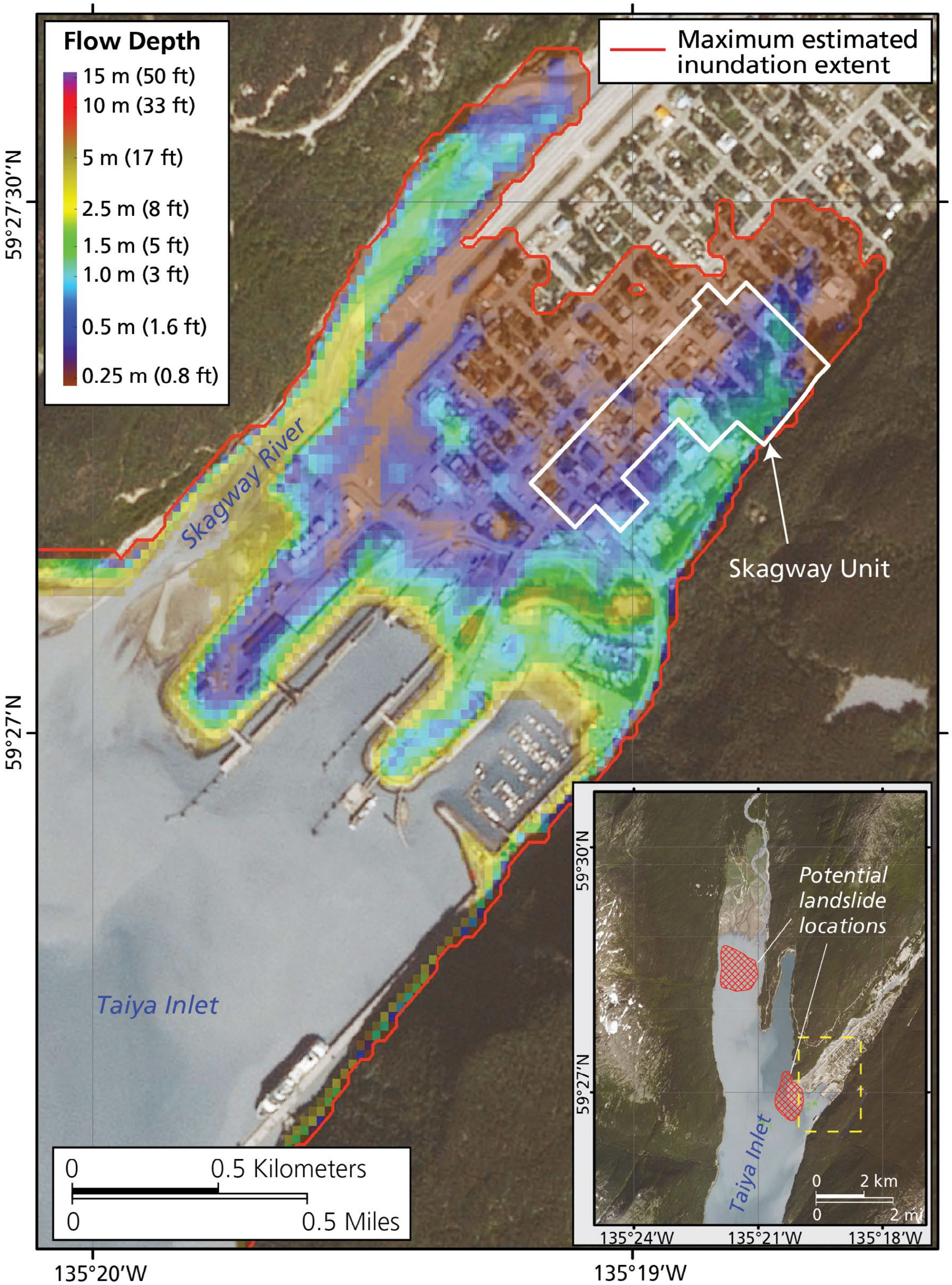


Figure 11. Maximum water flow depth from all hypothetical landslide scenarios at Skagway. While the waves that reach the boat harbor are only about 2 m (6 ft) high, modeling shows that they will flood an extensive area beyond the harbor because the municipality is located on flat, low-lying ground. The red line indicates the extent of maximum estimated inundation, and the red hatched areas on the inset map show the location of potential tsunami-inducing landslides. The park's Skagway Unit boundary is outlined in white. Map modified from Nicolsky et al. (2018).

of steep-sided fjords, and abundant seismic activity. On 3 November 1994, a cruise-ship dock undergoing construction collapsed on the eastern side of Skagway Harbor, triggering an underwater landslide and a series of tsunami waves estimated by eyewitnesses to be 5–6 m (15–20 ft) high in the inlet and 9–11 m (30–35 ft) high at the shoreline (Rabinovich et al. 1999). This landslide and accompanying tsunami caused one fatality and an estimated $21 million in damage (Rabinovich et al. 1999). Nicolsky et al. (2018) modeled the tsunami inundation at Skagway generated by underwater landslides at the fronts of the Taiya River delta and Skagway River delta. Tsunamis caused by these submarine landslides could reach Skagway in less than a minute and reach heights of about 2 m (6 ft) at the boat harbor, which would flood low-lying areas (Figure 11; Nicolsky et al. 2018).

Landslides and Snow Avalanches

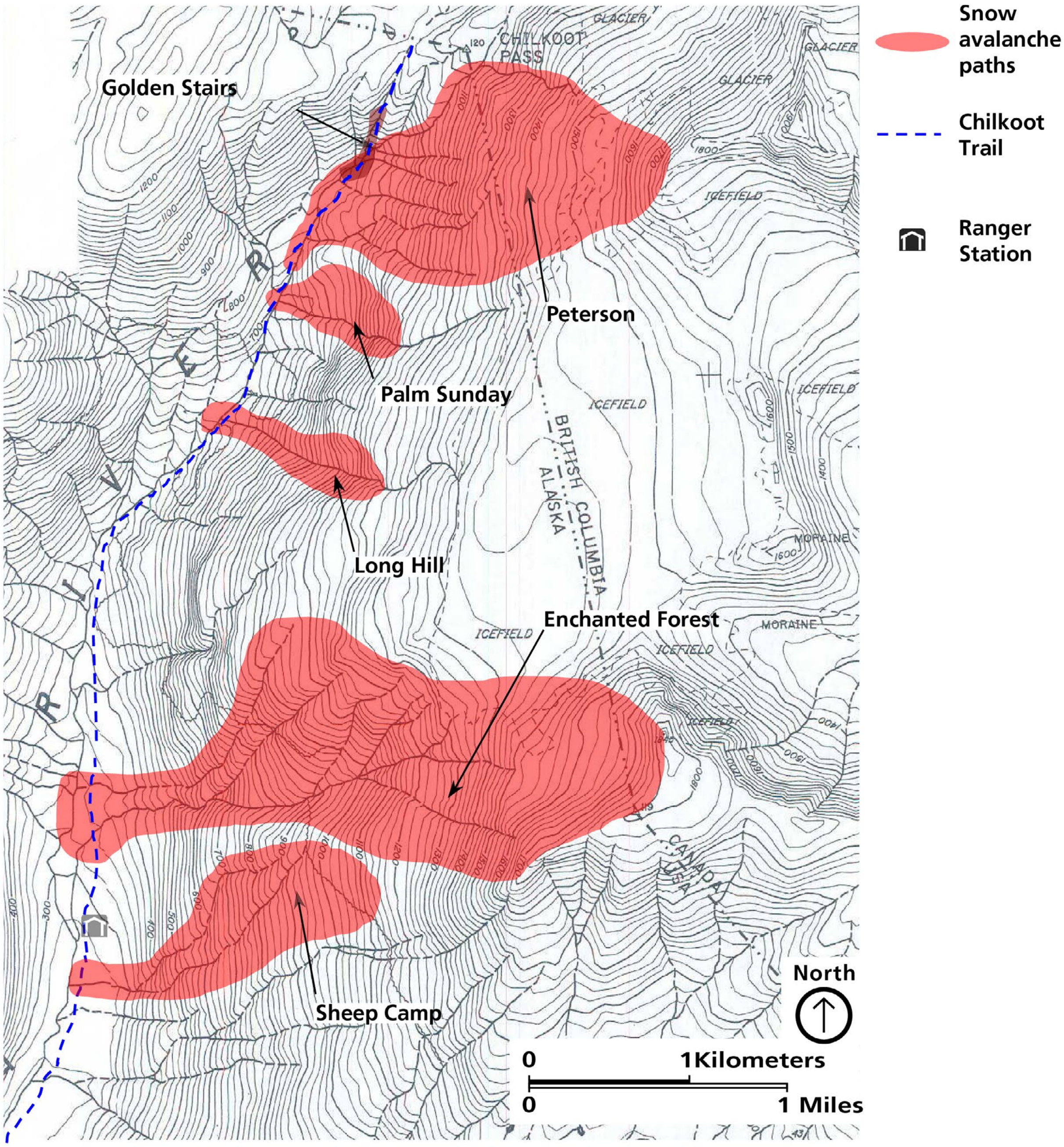
Many areas of the park have steep slopes that may be prone to slope movements such as landslides and snow avalanches. Landslides can include fast-moving rockfalls, rock avalanches, and debris flows, and slow-moving debris slides, ridge spreading (also known as sackung or sackungen), and earth flows (Varnes 1978). Landslides typically occur on steep slopes, particularly those greater than 30°. Retreating glaciers may increase the risk for landslides because of a process known as glacial debuttressing. As a glacier retreats, slopes over-steepened by glacial erosion that were formerly supported by ice lose lateral support and become prone to landslides. Landslides can be triggered by periods of elevated rainfall or earthquakes. When a landslide occurs in a coastal area or underwater, it may generate a tsunami. For example, the 2015 Taan Fiord landslide and associated tsunami in Wrangell-St. Elias National Park and Preserve was one of the largest tsunamis ever documented worldwide, reaching elevations of almost 200 m (650 ft; Higman et al. 2018). Underwater landslides commonly occur in prograding delta environments, such as the Skagway and Taiya deltas. Past underwater landslides have caused damage in the Skagway area (see the “Tsunami” section for more information).

Snow avalanches can occur in the park during winter and spring months when steep slopes are covered by snow. The 1898 Palm Sunday avalanche was the deadliest event in the park’s history. On 3 April 1898, a series of avalanches engulfed hundreds of people on the Chilkoot Trail, killing 65 people (Klondike Gold Rush National Historical Park 2021). An avalanche risk assessment was conducted in 2007 for the Chilkoot Trail for the early summer period (1 June–15 July) when trail use is typically high (Figure 12; Statham et al. 2007). Six avalanche paths were identified on the US section of the Chilkoot Trail, and the avalanche hazard along the entire Chilkoot Trail was identified as being very low (Statham et al. 2007). The reason the risk assessment found a low hazard despite the deadly avalanche in 1898 may be because the Palm Sunday avalanche occurred in April whereas the risk assessment was focused on the early summer period when there is less snow. During the gold rush, many stampeders used the Chilkoot Trail during the winter, putting them at a greater risk for snow avalanches than today’s summer hikers. The very low avalanche hazard indicates that no active measures or closures need to be undertaken. Nevertheless, although the hazard index is very low, a risk to hikers still exists; see Statham et al. (2007) for more information on specific risks to hikers and staff as well as recommendations.

Floods

Historical floods in the Taiya River and Skagway River watersheds have been caused by the catastrophic (sudden, rapid) draining of glacial lakes and by heavy rainfall. The largest flood recorded on the Taiya River since the 1800s occurred in September 1967 (Curran 2020). Between 14 and 15 September 1967, about 130 mm (5.1 in) of precipitation fell in the Skagway area, causing flooding throughout the region (Curran 2020). The Taiya River reached a peak discharge of 708 m^3/s (25,000 ft^3/s), which is a flood with an annual exceedance probability of about 0.5%, equivalent to a recurrence interval of 200 years (Curran 2020). Effects of the 1967 flood included extensive road damage. In addition to the 1967 flood, the Skagway River experienced flooding in late autumn in 1943 and 1981, which were both likely driven by rainfall (Curran 2020).

Glacial ice or deposits can block the flow of water from surrounding drainages, forming lakes that may drain catastrophically in an event known as a glacial outburst flood (GLOF, commonly referred to by the Icelandic term jökulhlaup). At least three GLOFs have occurred in the Taiya River watershed in historical times (Capps 2004). The largest GLOF occurred in the Nourse River watershed sometime during the 19th century. A smaller GLOF in 1897 killed at least one person in the upper Taiya River drainage area. The most recent GLOF occurred in 2002, when a lateral moraine at the head of West Creek failed. The resulting flood caused severe damage in the lower Taiya River area and prompted evacuation of the NPS campground. Capps (2004) identified a large moraine-dammed lake at the head of the Nourse River subwatershed as the most notable hazard in the Taiya River watershed. In 2004, this lake was 2.1 km (1.3 mi) long and at least 30 m (100 ft) deep and dammed by a 120-m- (390- ft-) high moraine. If



Level of Hazard as Determined by the Hazard Index

Very Low	≤1
Low	2 – 10
Moderate	10 – 40
High	40 – 150
Very High	>150

Figure 12. Map of the snow avalanche hazard along the US portion of the Chilkoot Trail.
Six snow avalanche paths—south to north, Sheep Camp, Enchanted Forest, Long Hill, Palm Sunday, Peterson, and Golden Stairs—have been identified along the trail. Each of these paths was rated for avalanche hazard for the early summer period (1 June to 15 July). The hazard rating considers the magnitude of the potential avalanche and the time a hiker is within the avalanche zone. The overall hazard rating for the whole trail is 1, indicating a very low hazard. Map modified from Statham et al. (2007).

the dam failed catastrophically, causing the lake to empty completely, the resulting flood could destroy all infrastructure located on the valley bottom downslope from the lake, including the townsite of Dyea; see Capps (2004) for more details.

Erosion of Dyea

The development of a meander in the Taiya River next to Dyea has caused erosion that threatens park infrastructure and cultural resources in the area. The Dyea historic townsite is a part of the Chilkoot Trail and Dyea Site National Historic Landmark and a fundamental park resource (NPS 2009). Located at the mouth of the Taiya River, Dyea started out as a Tlingit settlement and trading post and grew into a boomtown during the 1887–1889 gold rush. By the early 1900s, the Dyea townsite was virtually abandoned, and many of the buildings were deconstructed and the wood repurposed elsewhere. After a period of agriculture and livestock grazing that lasted until the in the 1940s, successional species have reclaimed most of the once-bustling historic town and Tlingit settlement. Collapsed gold rush era structures and historical artifacts dot the surface beneath the newly established forest canopy.

The Taiya River had a relatively straight path along the east side of Dyea when the town was booming in 1897 and 1898 (Figure 13; Pranger and Inglis 2002). In the 1920s, the river started to change course, migrating westward through Dyea and eroding a large section of the town just downstream of the current campground location (Pranger and Inglis 2002). The meander has continued to develop, causing about 300 m (980 ft) of erosion since 1918 (Curran 2020). Erosion in the Dyea area has been exacerbated by the Alaska Department of Transportation using large rocks to armor the bank around the West Creek bridge and downstream bank areas (Paul Burger, NPS Alaska Regional Office, hydrologist, personal communication, 7 January 2022). As of 2018, more than half of the original townsite has been lost to erosion, including nearly all the cemeteries (Figure 13; Curran 2020). In the 1970s, several graves were relocated. Since then, park response to the erosion of the Dyea town cemetery has been complicated by State of Alaska ownership of a portion of the cemetery and descendants' conflicting views as to whether gravesites should be relocated. See Richards et al. (2017) for a more detailed history and discussion of erosion at the Dyea town cemetery.

Park staff has been monitoring the riverbank of the Taiya River in the Dyea townsite, particularly in the area around the cemetery, since 1979 (Richards et al. 2017). Some evidence indicates bank erosion is linked to high flow events in the late summer and early autumn (Curran 2020). Erosion slowed down in the 1990s (Curran 2020), but in May 2017, monitoring revealed a new episode of accelerated erosion compared to preceding years (Richards et al. 2017). Large sections of the informal trail that previously ran along the edge of the bank were eroded away, and a historical stone property marker was moved back from the bank edge twice during the summer to prevent its loss (Figure 14; Richards et al. 2017). GPS mapping between May and October 2017 recorded a bank loss of up to 14 m (46 ft; Richards et al. 2017). The northeast portion of the Dyea townsite trail was closed because of severe erosion in August 2019. In 2021, about 37 m (120 ft) of erosion occurred at the historic townsite cutbank (Elaine Furbish, NPS Klondike Historical Park, biologist, personal communication, 3 February 2022).

Uplift and Sea Level Change

Isostatic rebound is causing the park area to uplift, which in turn results in changes to the park's landscape over time. The average uplift rate in Skagway between 1992 and 2007 was 22.7 mm/yr (0.894 in/yr; Freymueller et al. 2008). This uplift is probably most evident along the coast, where vertical land changes affect relative sea level. Sea level measurements at the Skagway tide station since about 1945 show a local decrease in sea level by 17.98 ± 0.49 mm/yr (0.7079 ± 0.02 in/yr; https://www.tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9452400, accessed 18 May 2021). Impacts along the coast include changes to the following: coastal ecosystems, patterns of erosion and accretion, and the location of the coastline. Examples of coastal change are evident in some of the infrastructure and stories from the gold rush era. Based on the uplift rate of Freymueller et al. (2008), the Skagway area has risen approximately 2.8 m (9.2 ft) since the gold rush. The Vining and Wilkes Warehouse in Dyea, which housed provisions for miners prior to entering Canada, was so close to the high-tide mark during the gold rush that it was built on pilings; today the ruins of this warehouse are about 2 km (1 mi) from water (KellerLynn 2009). Similarly, the highest tides during the gold rush occasionally peaked at 5th Avenue in Skagway, but now this cross street is unaffected by tides (KellerLynn 2009).

Abandoned Mineral Lands

The park has one documented mineral occurrence (silver-lead prospect) that was mined during the 1930s. The site, known as Inspiration Mine, was staked around 1924, explored between 1925 and 1929, and developed between 1930 and 1932. Development of the mine included a 67-m- (220-ft-) deep upper adit (passageway to underground mine), 15-m- (52-ft-) deep inclined shaft, 6-m- (20-ft-) deep vertical shaft, an open cut, and another adit on a lower level. Structures associated with

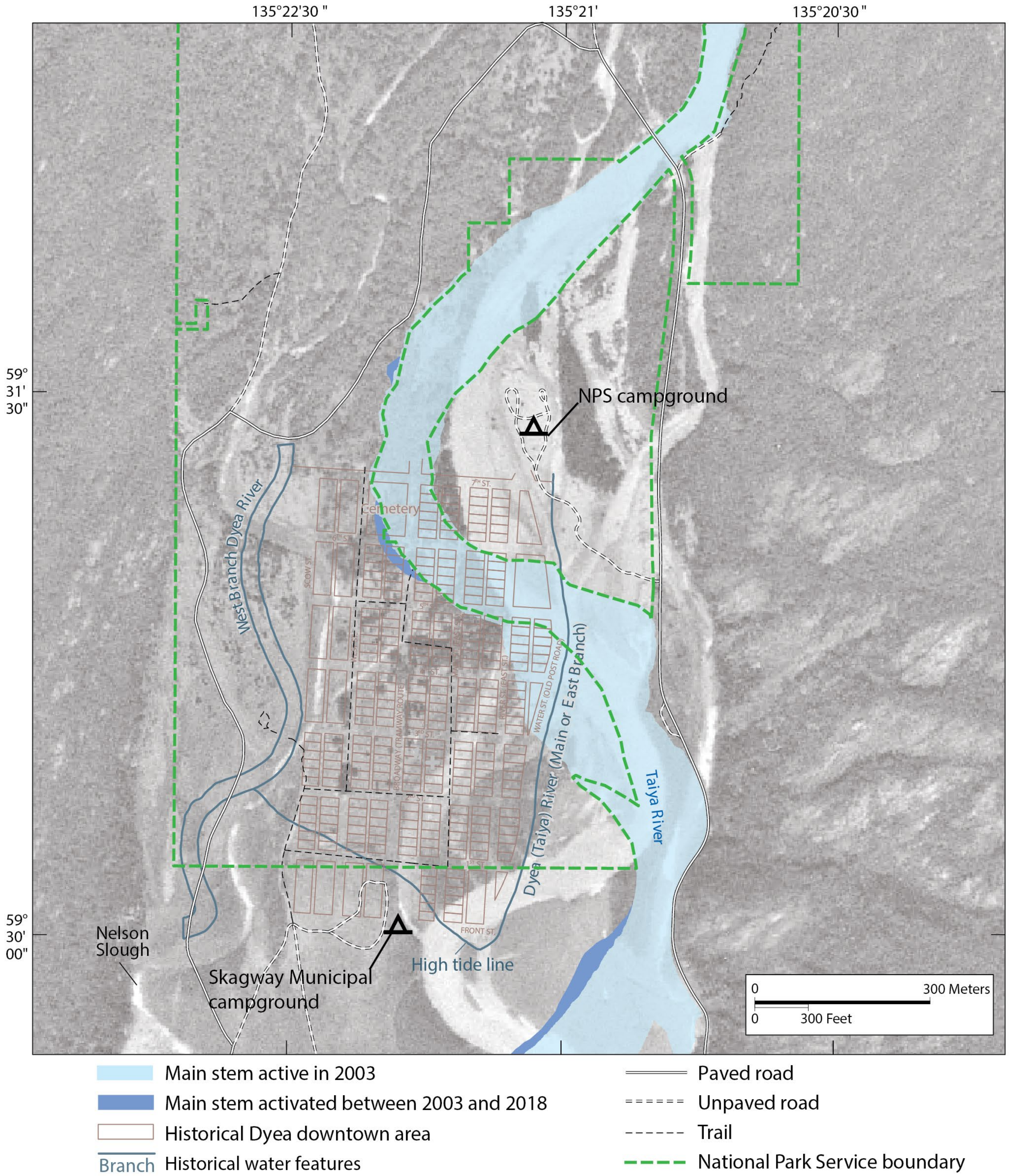


Figure 13. Map showing changes to the Taiya River between 1948 and 2018 near the townsite of Dyea. The historical map of Dyea (in tan) show the locations of streets and lots and the approximate locations of the West Branch Dyea River (now Nelson Slough), the Main or East Branch of the Taiya River (now Taiya River), and the high tide line during the gold rush (1897–1898). Since that time, a meander has developed and swept across the northern part of historic townsite. The main stem of the Taiya River in 2003 is shown in light blue; migration of the stem between 2003 and 2018 is shown in dark blue. Figure modified from Curran (2020).

Figure 14. Photographs of Taiya River erosion in 2017.
(A) Location of a historical property marker in May 2017. This marker had to be moved back from the bank edge twice during the summer to avoid being lost to the river. Photograph taken looking south. (B) Truncation of the informal trail that had previously run along the edge of the bank. Large portions of this trail were eroded away during the 2017 summer because of accelerated erosion. Photograph taken looking north. NPS photos from Richards et al. (2017).

the mine included a mess house, dormitory, blacksmith shop, repair shop, and aerial tram. Inspiration Mine had rich ore in small quantities; only about 15,240 kg (15 tons) of ore is estimated to have been shipped from the mine while it was operational (NPS 2017). In 1933, work was discontinued because of high operating costs (Cobb 1978). The site was re-staked in 1988, but no evidence indicates any serious subsequent exploration (NPS 2014).

Inspiration Mine is now considered an abandoned mineral lands (AML) site found at least partially within the administrative boundary of the park on land owned by the Alaska Department of Natural Resources (DNR; NPS 2014). Abandoned mineral lands are lands, waters, and surrounding watershed that contain features such as facilities, structures, improvements, and disturbances associated with past mineral exploration, extraction, processing, and transportation. The NPS acts under various authorities to mitigate, reclaim, or restore AML features in order to reduce hazards and impacts to resources. A 2014 site survey identified three hazardous features at Inspiration Mine on DNR land; these included the upper adit, which contained sticks of dynamite; the adjacent inclined shaft; and a scatter of degraded dynamite (see NPS 2014 for more details). During this site survey, AML warning signs were posted at the upper adit and shaft, explosive warning signs were posted at the portal of the upper adit and near concentrations of dynamite, and flagging was put around the perimeter of the dynamite scatter (NPS 2014). In 2015, the NPS and State of Alaska AML programs partnered to remove 1,500 sticks of dynamite from the site; because of time constraints, an estimated 1,600 sticks of dynamite were left behind. In 2016, the State of Alaska AML program hired a contractor to dispose of the remaining abandoned explosives, close the inclined shaft with a metal barrier, and close the upper adit with a locked metal gate (Sarah Venator, NPS Alaska Regional Office, geologist, personal communication, 4 March 2022).

Guidance for Resource Management

These references, resources, and websites may be of use to resource managers. The laws, regulations, and policies apply to NPS geologic resources. The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (§ 204), National Park Service 2006 Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75).

To receive geologic resource management assistance, park staff can contact the Alaska Regional Office Natural Resources Team (https://www.nps.gov/orgs/1349/whoweare.htm) or the NPS Geologic Resources Division (http://go.nps.gov/geology). GRD staff members provide technical and policy support for geologic resource management issues in three emphasis areas: (1) geologic heritage, (2) active processes and hazards, and (3) energy and minerals management. GRD staff can provide technical assistance with resource inventories, assessments and monitoring; impact mitigation, restoration, and adaptation; hazards risk management; law, policy, and guidance; resource management planning; and data and information management. Park managers can formally request assistance via https://irma.nps.gov/STAR/.

Park managers can submit a proposal to receive geoscience-focused internships through Scientists in Parks (see https://www.nps.gov/subjects/science/scientists-in-parks.htm). This program places scientists (typically undergraduate students) in parks to complete geoscience-related projects that may address resource management issues. The Geological Society of America and Environmental Stewards are partners of the Scientists in Parks program. The Geologic Resources Division can provide guidance and assistance with submitting a proposal. Proposals may be for assistance with research, interpretation and public education, inventory, and/or monitoring.

Resource managers may find the book Geological Monitoring (Young and Norby 2009) useful for addressing geologic resource management issues. Chapters of this book are available online at http://go.nps.gov/geomonitoring. The manual provides guidance for monitoring vital signs, which are measurable parameters of the overall condition of natural resources. Each chapter covers a different geologic resource and includes detailed recommendations for resource managers, suggested methods of monitoring, and case studies.

Klondike Gold Rush National Historical Park Documents

The park's foundation statement (NPS 2009), natural resource condition assessment (Bernatz et al. 2010), and state of the park report (NPS 2013) are primary sources of information for resource management within the park.

NPS Resource Management Guidance and Documents

- NPS *Management Policies 2006* (Chapter 4: Natural Resource Management): https://npspolicy.nps.gov/
- 1998 National Parks Omnibus Management Act: https://www.congress.gov/bill/105th-congress/senate-bill/1693
- Natural Resource Inventory and Monitoring Guideline (NPS 75): https://irma.nps.gov/DataStore/Reference/Profile/622933
- Natural Resource Management Reference Manual #77 (NPS 77): https://irma.nps.gov/DataStore/Reference/Profile/572379
- Resist-Accept-Direct (RAD)—A Framework for the 21st-Century Natural Resource Manager: https://doi.org/10.36967/nrr-2283597

Geologic Resource Laws, Regulations, and Policies

The following table (Table 3), which was developed by the NPS Geologic Resources Division, summarizes laws, regulations, and policies that specifically apply to NPS minerals and geologic resources. The table does not include laws of general application (e.g., Endangered Species Act, Clean Water Act, Wilderness Act, National Environmental Policy Act, or National Historic Preservation Act). The table does include the NPS Organic Act when it serves as the main authority for protection of a particular resource or when other, more specific laws are not available.

Table 3. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Soils	**Soil and Water Resources Conservation Act, 16 USC §§ 2011–2009** provides for the collection and analysis of soil and related resource data and the appraisal of the status, condition, and trends for these resources. **Farmland Protection Policy Act, 7 USC § 4201 et. seq.** requires NPS to identify and take into account the adverse effects of Federal programs on the preservation of farmland; consider alternative actions, and assure that such Federal programs are compatible with State, unit of local government, and private programs and policies to protect farmland. NPS actions are subject to the FPPA if they may irreversibly convert farmland (directly or indirectly) to nonagricultural use and are completed by a Federal agency or with assistance from a Federal agency. Applicable projects require coordination with the Department of Agriculture's Natural Resources Conservation Service (NRCS).	**7 CFR Parts 610 and 611** are the US Department of Agriculture regulations for the Natural Resources Conservation Service. **Part 610** governs the NRCS technical assistance program, soil erosion predictions, and the conservation of private grazing land. **Part 611** governs soil surveys and cartographic operations. The NRCS works with the NPS through cooperative arrangements.	**Section 4.8.2.4** requires NPS to -prevent unnatural erosion, removal, and contamination; -conduct soil surveys; -minimize unavoidable excavation; and -develop/follow written prescriptions (instructions).
Mining Claims (Locatable Minerals)	**Mining in the Parks Act of 1976, 54 USC § 100731 et seq.** authorizes NPS to regulate all activities resulting from exercise of mineral rights, on patented and unpatented mining claims in all areas of the System, in order to preserve and manage those areas. **General Mining Law of 1872, 30 USC § 21 et seq.** allows US citizens to locate mining claims on Federal lands. Imposes administrative and economic validity requirements for "unpatented" claims (the right to extract Federally-owned locatable minerals). Imposes additional requirements for the processing of "patenting" claims (claimant owns surface and subsurface). Use of patented mining claims may be limited in Wild and Scenic Rivers and OLYM, GLBA, CORO, ORPI, and DEVA. **Surface Uses Resources Act of 1955, 30 USC § 612** restricts surface use of unpatented mining claims to mineral activities.	**36 CFR § 5.14** prohibits prospecting, mining, and the location of mining claims under the general mining laws in park areas except as authorized by law. **36 CFR Part 6** regulates solid waste disposal sites in park units. **36 CFR Part 9, Subpart A** requires the owners/operators of mining claims to demonstrate bona fide title to mining claim; submit a plan of operations to NPS describing where, when, and how; prepare/submit a reclamation plan; and submit a bond to cover reclamation and potential liability. **43 CFR Part 36** governs access to mining claims located in, or adjacent to, National Park System units in Alaska.	**Section 6.4.9** requires NPS to seek to remove or extinguish valid mining claims in wilderness through authorized processes, including purchasing valid rights. Where rights are left outstanding, NPS policy is to manage mineral-related activities in NPS wilderness in accordance with the regulations at **36 CFR Parts 6** and **9A**. **Section 8.7.1** prohibits location of new mining claims in parks; requires validity examination prior to operations on unpatented claims; and confines operations to claim boundaries.

Table 3, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Recreational Collection of Rocks Minerals	**NPS Organic Act, 54 USC. § 100101 et seq.** directs the NPS to conserve all resources in parks (which includes rock and mineral resources) unless otherwise authorized by law. **Exception: 16 USC. § 445c (c) – Pipestone National Monument enabling statute**. Authorizes American Indian collection of catlinite (red pipestone).	**36 C.F.R. § 2.1** prohibits possessing, destroying, disturbing mineral resources… in park units. **Exception: 36 C.F.R. § 7.91** allows limited gold panning in Whiskeytown. **Exception: 36 C.F.R. § 13.35** allows some surface collection of rocks and minerals in some Alaska parks (not Klondike Gold Rush, Sitka, Denali, Glacier Bay, and Katmai) by non-disturbing methods (e.g., no pickaxes), which can be stopped by superintendent if collection causes significant adverse effects on park resources and visitor enjoyment.	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.
Common Variety Mineral Materials (Sand, Gravel, Pumice, etc.)	**Materials Act of 1947, 30 USC § 601** does not authorize the NPS to dispose of mineral materials outside of park units. **Reclamation Act of 1939, 43 USC §387**, authorizes removal of common variety mineral materials from federal lands in federal reclamation projects. This act is cited in the enabling statutes for Glen Canyon and Whiskeytown National Recreation Areas, which provide that the Secretary of the Interior may permit the removal of federally owned nonleasable minerals such as sand, gravel, and building materials from the NRAs under appropriate regulations. Because regulations have not yet been promulgated, the National Park Service may not permit removal of these materials from these National Recreation Areas. **16 USC §90c-1(b)** authorizes sand, rock and gravel to be available for sale to the residents of Stehekin from the non-wilderness portion of Lake Chelan National Recreation Area, for local use as long as the sale and disposal does not have significant adverse effects on the administration of the national recreation area.	None applicable.	**Section 9.1.3.3** clarifies that only the NPS or its agent can extract park-owned common variety minerals (e.g., sand and gravel), and: -only for park administrative uses; -after compliance with NEPA and other federal, state, and local laws, and a finding of non-impairment; -after finding the use is park's most reasonable alternative based on environment and economics; -parks should use existing pits and create new pits only in accordance with park-wide borrow management plan; -spoil areas must comply with **Part 6** standards; and -NPS must evaluate use of external quarries. Any deviation from this policy requires a written waiver from the Secretary, Assistant Secretary, or Director.

Table 3, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Federal Mineral Leasing (Oil, Gas, and Solid Minerals)	**The Mineral Leasing Act, 30 USC § 181 et seq.**, and the **Mineral Leasing Act for Acquired Lands, 30 USC § 351 et seq.** do not authorize the BLM to lease federally owned minerals in NPS units. **Combined Hydrocarbon Leasing Act, 30 USC §181,** allowed owners of oil and gas leases or placer oil claims in Special Tar Sand Areas (STSA) to convert those leases or claims to combined hydrocarbon leases, and allowed for competitive tar sands leasing. This act did not modify the general prohibition on leasing in park units but did allow for lease conversion in GLCA, which is the only park unit that contains a STSA. **Exceptions**: Glen Canyon NRA (**16 USC § 460dd et seq.**), Lake Mead NRA (**16 USC § 460n et seq.**), and Whiskeytown-Shasta-Trinity NRA (**16 USC § 460q et seq.**) authorizes the BLM to issue federal mineral leases in these units provided that the BLM obtains NPS consent. Such consent must be predicated on an NPS finding of no significant adverse effect on park resources and/or administration. **American Indian Lands Within NPS Boundaries Under the Indian Allottee Leasing Act of 1909, 25 USC §396, and the Indian Leasing Act of 1938, 25 USC §396a, §398 and §399, and Indian Mineral Development Act of 1982, 25 USCS §§2101-2108,** all minerals on American Indian trust lands within NPS units are subject to leasing. **Federal Coal Leasing Amendments Act of 1975, 30 USC § 201** prohibits coal leasing in National Park System units.	**36 CFR § 5.14** states prospecting, mining, and… leasing under the mineral leasing laws [is] prohibited in park areas except as authorized by law. **BLM regulations at 43 CFR Parts 3100, 3400, and 3500** govern Federal mineral leasing. **Regulations re: Native American Lands within NPS Units:** **25 CFR Part 211** governs leasing of tribal lands for mineral development. **25 CFR Part 212** governs leasing of allotted lands for mineral development. **25 CFR Part 216** governs surface exploration, mining, and reclamation of lands during mineral development. **25 CFR Part 224** governs tribal energy resource agreements. **25 CFR Part 225** governs mineral agreements for the development of Indian-owned minerals entered into pursuant to the **Indian Mineral Development Act of 1982, Pub. L. No. 97-382, 96 Stat. 1938** (codified at **25 USC §§ 2101-2108**). **30 CFR §§ 1202.100-1202.101** governs royalties on oil produced from Indian leases. **30 CFR §§ 1202.550-1202.558** governs royalties on gas production from Indian leases. **30 CFR §§ 1206.50-1206.62** and **§§ 1206.170-1206.176** governs product valuation for mineral resources produced from Indian oil and gas leases. **30 CFR § 1206.450** governs the valuation coal from Indian Tribal and Allotted leases. **43 CFR Part 3160** governs onshore oil and gas operations, which are overseen by the BLM.	**Section 8.7.2** states that all NPS units are closed to new federal mineral leasing except Glen Canyon, Lake Mead and Whiskeytown-Shasta-Trinity NRAs.

Table 3, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Coastal Features and Processes	**NPS Organic Act, 54 USC § 100751 et. seq.** authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights). **Coastal Zone Management Act, 16 USC § 1451 et. seq.** requires Federal agencies to prepare a consistency determination for every Federal agency activity in or outside of the coastal zone that affects land or water use of the coastal zone. **Clean Water Act, 33 USC § 1342/ Rivers and Harbors Act, 33 USC 403** require that dredge and fill actions comply with a Corps of Engineers Section 404 permit. **Executive Order 13089** (coral reefs) (1998) calls for reduction of impacts to coral reefs. **Executive Order 13158** (marine protected areas) (2000) requires every federal agency, to the extent permitted by law and the maximum extent practicable, to avoid harming marine protected areas.	**36 CFR § 1.2(a)(3)** applies NPS regulations to activities occurring within waters subject to the jurisdiction of the US located within the boundaries of a unit, including navigable water and areas within their ordinary reach, below the mean high water mark (or OHW line) without regard to ownership of submerged lands, tidelands, or lowlands. **36 CFR § 5.7** requires NPS authorization prior to constructing a building or other structure (including boat docks) upon, across, over, through, or under any park area.	**Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks unless directed otherwise by Congress. **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety. **Section 4.8.1** requires NPS to allow natural geologic processes to proceed unimpeded. NPS can intervene in these processes only when required by Congress, when necessary for saving human lives, or when there is no other feasible way to protect other natural resources/ park facilities/historic properties. **Section 4.8.1.1** requires NPS to: -Allow natural processes to continue without interference, -Investigate alternatives for mitigating the effects of human alterations of natural processes and restoring natural conditions, -Study impacts of cultural resource protection proposals on natural resources, -Use the most effective and natural-looking erosion control methods available, and -Avoid putting new developments in areas subject to natural shoreline processes unless certain factors are present.
Nonfederal minerals other than oil and gas	**NPS Organic Act, 54 USC §§ 100101 and 100751**	**NPS regulations at 36 CFR Parts 1, 5, and 6** require the owners/operators of other types of mineral rights to obtain a special use permit from the NPS as a **§ 5.3** business operation, and **§ 5.7** – Construction of buildings or other facilities, and to comply with the solid waste regulations at **Part 6**.	**Section 8.7.3** states that operators exercising rights in a park unit must comply with **36 CFR Parts 1** and **5**.

Table 3, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Upland and Fluvial Processes	**Rivers and Harbors Appropriation Act of 1899, 33 USC § 403** prohibits the construction of any obstruction on the waters of the United States not authorized by congress or approved by the USACE. **Clean Water Act 33 USC § 1342** requires a permit from the USACE prior to any discharge of dredged or fill material into navigable waters (waters of the US [including streams]). **Executive Order 11988** requires federal agencies to avoid adverse impacts to floodplains. (see also **D.O. 77-2**) **Executive Order 11990** requires plans for potentially affected wetlands (including riparian wetlands). (see also **D.O. 77-1)**	None applicable.	**Section 4.1** requires NPS to manage natural resources to preserve fundamental physical and biological processes, as well as individual species, features, and plant and animal communities; maintain all components and processes of naturally evolving park ecosystems. **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks, unless directed otherwise by Congress. **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety. **Section 4.6.4** directs the NPS to (1) manage for the preservation of floodplain values; [and] (2) minimize potentially hazardous conditions associated with flooding. **Section 4.6.6** directs the NPS to manage watersheds as complete hydrologic systems and minimize human-caused disturbance to the natural upland processes that deliver water, sediment, and woody debris to streams. **Section 4.8.1** directs the NPS to allow natural geologic processes to proceed unimpeded. Geologic processes…include…erosion and sedimentation…processes. **Section 4.8.2** directs the NPS to protect geologic features from the unacceptable impacts of human activity while allowing natural processes to continue.

Table 3, continued. Geologic resource laws, regulations, and policies.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Climate Change	**Secretarial Order 3289** (Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources) (2009) requires DOI bureaus and offices to incorporate climate change impacts into long-range planning; and establishes DOI regional climate change response centers and Landscape Conservation Cooperatives to better integrate science and management to address climate change and other landscape scale issues. **Executive Order 13693** (Planning for Federal Sustainability in the Next Decade) (2015) established to maintain Federal leadership in sustainability and greenhouse gas emission reductions.	None Applicable.	**Section 4.1** requires NPS to investigate the possibility to restore natural ecosystem functioning that has been disrupted by past or ongoing human activities, inlcuding climate change. **Policy Memo 12-02** (Applying National Park Service Management Policies in the Context of Climate Change) (2012) applies considerations of climate change to the impairment prohibition and to maintaining "natural conditions". **Policy Memo 14-02** (Climate Change and Stewardship of Cultural Resources) (2014) provides guidance and direction regarding the stewardship of cultural resources in relation to climate change. **Policy Memo 15-01** (Climate Change and Natural Hazards for Facilities) (2015) provides guidance on the design of facilities to incorporate impacts of climate change adaptation and natural hazards when making decisions in national parks.

Additional References, Resources, and Websites

Geology of Alaska

- Geologic Map of Alaska: https://doi.org/10.3133/sim3340
- Alaska Digital Geologic Map and Geologic Data Online Viewer: https://mrdata.usgs.gov/geology/
- Alaska (Minerals) Resource Data File: https://ardf.wr.usgs.gov/index.php
- Alaska Division of Geological & Geophysical Surveys (and Alaska USGS) publications: https://dggs.alaska.gov/pubs/pubs

Geology of National Park Service Areas

- NPS Alaska Nature and Science, Active Geology: https://www.nps.gov/subjects/aknatureandscience/activegeology.htm
- NPS Alaska Nature and Science, Geohazards: https://www.nps.gov/subjects/aknatureandscience/geohazards.htm
- Alaska National Parks, Geology: https://sketchfab.com/alaska_nps_geology
- NPS America's Geologic Legacy: http://go.nps.gov/geology
- NPS Geologic Resources Division: https://home.nps.gov/orgs/1088/index.htm
- NPS Geologic Resources Inventory: http://go.nps.gov/gri
- NPS Geoscience Concepts: https://www.nps.gov/subjects/geology/geology-concepts.htm
- NPS Scientists in Parks: https://www.nps.gov/subjects/science/scientists-in-parks.htm NPS Geodiversity Atlas: https://www.nps.gov/articles/geodiversity-atlas-map.htm

Climate Change Resources

- Intergovernmental Panel on Climate Change: http://www.ipcc.ch/
- *Global and Regional Sea Level Rise Scenarios for the United States* (interagency report): https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report-sections.html
- US Global Change Research Program: http://www.globalchange.gov/home
- NPS Climate Change, Useful Resources: http://www.nps.gov/subjects/climatechange/resources.htm

- NPS Sea Level Change: https://www.nps.gov/subjects/climatechange/sealevelchange.htm/index.htm
- NPS Sea Level Rise Viewer: https://maps.nps.gov/slr/

Earthquakes

- University of Alaska Fairbanks, Alaska Earthquake Center: https://earthquake.alaska.edu/
- USGS Earthquake Hazards Program, Unified Hazard Tool: https://earthquake.usgs.gov/hazards/interactive/

Geologic Heritage

- NPS America's Geologic Heritage: https://www.nps.gov/subjects/geology/americas-geoheritage.htm
- NPS Geoheritage Sites - Examples on Public Lands, Natural Landmarks, Heritage Areas, and The National Register of Historic Places: https://www.nps.gov/subjects/geology/geoheritage-sites-listing-element.htm
- UNESCO Global Geoparks: http://www.unesco.org/new/en/natural-sciences/environment/earth-sciences/unesco-global-geoparks/
- U.S. Geoheritage & Geoparks Advisory Group: https://www.americasgeoheritage.com/

Geologic Maps

- American Geosciences Institute, Meeting Challenges with Geologic Maps: http://www.americangeosciences.org/environment/publications/mapping

Geological Surveys and Societies

- Alaska Division of Geological & Geophysical Surveys: http://dggs.alaska.gov/
- Alaska Geological Society: https://www.alaskageology.org/
- Alaska Volcano Observatory: https://avo.alaska.edu/
- American Geophysical Union (AGU): http://sites.agu.org/
- American Geosciences Institute (AGI): http://www.americangeosciences.org/
- Association of American State Geologists (AASG): http://www.stategeologists.org/http://www.stategeologists.org/
- Geological Society of America: http://www.geosociety.org/
- US Geological Survey (USGS): http://www.usgs.gov/

Landslide Information

- "Monitoring Slope Movements" (Geological Monitoring chapter by Wieczorek and Snyder 2009): https://www.nps.gov/articles/monitoring-slope-movements.htm
- The Landslide Handbook—A Guide to Understanding Landslides (Highland and Bobrowsky 2008): http://pubs.usgs.gov/circ/1325/
- USGS Landslide Hazards Program: https://www.usgs.gov/programs/landslide-hazards

NPS Reference Tools

- GEOREF, the premier online geologic citation database. The GRI team collaborates with TIC to maintain an NPS subscription to GEOREF via the Denver Service Center Library interagency agreement with the Library of Congress. Multiple portals are available for NPS staff to access these records.
- GRI Publications:https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm
- NPS Integrated Resource Management Applications (IRMA) portal (https://irma.nps.gov/). GRI staff uploads scoping summaries, maps, and reports to IRMA.
- Technical Information Center (TIC) (NPS repository for technical documents): https://www.nps.gov/orgs/1804/dsctic.htm

US Geological Survey Reference Tools

- National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html
- Geologic Names Lexicon (GEOLEX): http://ngmdb.usgs.gov/Geolex/search
- Geographic Names Information System (GNIS): https://www.usgs.gov/faqs/what-geographic-names-information-system-gnis
- USGS Store, Map Locator: http://store.usgs.gov
- USGS Publications Warehouse: http://pubs.er.usgs.gov
- A Tapestry of Time and Terrain: http://pubs.usgs.gov/imap/i2720/

Literature Cited

These references are cited in this report. Contact the Geologic Resources Division for assistance in obtaining them.

ADEC (Alaska Department of Environmental Conservation). 2010. Total maximum daily loads (TMDLs) for metals in the waters of Pullen Creek in Skagway, Alaska. Alaska Department of Environmental Conservation, Anchorage, Alaska.

Barclay, D. J., G. C. Wiles, and P. E. Calkin. 2009. Holocene glacier fluctuations in Alaska. Quaternary Science Reviews 28:2034–2048.

Barker, F., J. G. Arth, and T. W. Stern. 1986. Evolution of the Coast batholith along the Skagway traverse, Alaska and British Columbia. American Mineralogist 7:632–643.

Bernatz, G. C., A. G. Robertson, and B. W. Drazkowski. 2010. Klondike Gold Rush National Historical Park: natural resource condition assessment. Natural Resource Report NPS/NRPC/WRD/NRR—2010/288. National Park Service, Fort Collins, Colorado.

Brew, D. A., and A. B. Ford. 1994. The Coast Mountains plutonic-metamorphic complex and related rocks between Haines, Alaska, and Fraser, British Columbia—tectonic and geologic sketches and Klondike Highway road log. Open-File Report 94-268. US Geological Survey, Menlo Park, California. https://pubs.er.usgs.gov/publication/ofr94268.

Brew, D. A., A. B. Ford, G. R. Himmelberg, and J. L. Drinkwater. 1995. The Coast Mountains complex of southeastern Alaska and adjacent regions. Pages 21–28 *in* Stratigraphic notes, 1994: three short papers propose changes in stratigraphic nomenclature in Virginia, Kentucky, and Alaska. Bulletin 2135. US Geological Survey, Washington, DC. https://pubs.er.usgs.gov/publication/b2135.

Brew, D. A., and R. P. Morrell. 1979b. Intrusive rock belts of southeastern Alaska. Pages 116–121 *in* K. M. Johnson and J. R. Williams, editors. The United States Geological Survey in Alaska: accomplishments during 1978. Circular 804-B. US Geological Survey, Arlington, Virginia. https://pubs.er.usgs.gov/publication/cir804B. *Note*: A "b" is included with the year to reflect the unit name and reference cited in the source map (Wilson et al. 2015) as well as in the GRI GIS data.

Brothers, D. S., J. L. Elliott, J. E. Conrad, P. J. Haeussler, J. W. Kluesner. 2018. Strain partitioning in southeastern Alaska: Is the Chatham Strait fault active? Earth and Planetary Science Letters 481:362–371.

Brothers, D. S., P. Haeussler, A. E. East, U. ten Brink, B. Andrews, P. Dartnell, N. Miller, and J. Kluesner. 2017. A closer look at an undersea source of Alaskan earthquakes. Online article. Eos 98. https://doi.org/10.1029/2017EO079019 (accessed 4 May 2022).

Capps, D. L. 2004. Geohazards of the Taiya watershed, Klondike Gold Rush National Historical Park, Skagway, Alaska. Unpublished report. National Park Service, Geoscientists-in-the-Parks Program, Lakewood, Colorado.

Choi, M., D. W. Eaton, and E. Enkelmann. 2021. Is the eastern Denali fault still active? Geology 49(6):662–666.

Cobb, E. H. 1978. Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Mt. Fairweather and Skagway quadrangles, Alaska. Open-File Report 78-316. US Geological Survey, Reston, Virginia. https://pubs.er.usgs.gov/publication/ofr78316.

Cowan, D. S., M. T. Brandon, and J. I. Garver. 1997. Geologic test of hypotheses for large coastwise displacements—a critique illustrated by the Baja British Columbia controversy. American Journal of Science 297:117–173.

Crafford, T. C. 2001. Alaska resource data file, Skagway quadrangle (scale 1:250,000). Open-File Report 01-193. US Geological Survey, Anchorage, Alaska.

Curran, J. H. 2020. Hydrology and geomorphology of the Taiya River near the West Creek tributary, southeast Alaska. Scientific Investigations Report 2020-5059. US Geological Survey, Reston, Virginia. https://pubs.er.usgs.gov/publication/sir20205059.

Curran, J. H., N. A. Barth, A. G. Veilleux, and R. T. Ourso. 2016. Estimating flood magnitude and frequency at gaged and ungagged sites on streams in Alaska and conterminous basins in Canada, based on data through water year 2012. Scientific Investigations Report 2016-5024. US Geological Survey, Reston, Virginia. https://pubs.er.usgs.gov/publication/sir20165024.

DeMets, C., R. G. Gordon, and D. F. Argus. 2010. Geologically current plate motions. Geophysical Journal International 181(1):1–80.

Eberhart-Phillips, D., P. J. Haeussler, J. T. Freymueller, A. D. Frankel, C. M. Rubin, P. Craw, N. A. Ratchkovski, G. Anderson, G. A. Carver, A. J. Crone, T. E. Dawson, H. Fletcher, R. Hansen, E. L. Harp, R. A. Harris, D. P. Hill, S. Hreinsdóttir, R. W. Jibson, L. M. Jones, R. Kayen, D. K. Keefer, C. F. Larsen, S. C. Moran, S. F. Personius, G. Plafker, B. Sherrod, K. Sieh, N. Sitar, and W. K. Wallace. 2003. The 2002 Denali fault earthquake, Alaska: a large magnitude, slip-partitioned event. Science 300(5622):1113–1118.

Farley, K. A., M. E. Rusmore, and S. W. Bogue. 2001. Post–10 Ma uplift and exhumation of the northern Coast Mountains, British Columbia. Geology 29(2):99–102.

Freymueller, J. T., H. Woodard, S. C. Cohen, R. Cross, J. Elliott, C. F. Larsen, S. Hreinsdóttir, and C. Zweck. 2008. Active deformation processes in Alaska, based on 15 years of GPS measurements. Pages 1–42 *in* J. T. Freymueller, P. J. Haeussler, R. L. Wesson, and G. Ekström, editors. Active tectonics and seismic potential of Alaska. Geophysical Monograph 179. American Geophysical Union, Washington, DC. http://gps.alaska.edu/jeff/Chapman_GPS_velocities.html.

Gehrels, G. E., and H. C. Berg. 1994. Geology of southeastern Alaska. Pages 451–467 *in* G. Plafker and H. C. Berg, editors. The geology of Alaska. Decade of North American Geology (DNAG): The Geology of North America, Volume G-1. Geological Society of America, Boulder, Colorado.

Gehrels, G. E., W. C. McClelland, S. D. Samson, P. J. Patchett, and J. L. Jackson. 1990. Ancient continental margin assemblages in the northern Coast Mountains, southeast Alaska and northwest Canada. Geology 18:208–211.

Gehrels, G. E., W. C. McClelland, S. D. Samson, P. J. Patchett, and D. A. Brew. 1991. U-Pb geochronology and tectonic significance of Late Cretaceous–early Tertiary plutons in the northern Coast Mountains batholith. Canadian Journal of Earth Sciences 28:899–911.

Highland, L. M. and P. Bobrowsky. 2008. The landslide handbook—a guide to understanding landslides. Circular 1325. US Geological Survey, Reston, Virginia. http://pubs.usgs.gov/circ/1325/.

Higman, B., D. H. Shugar, C. P. Stark, G. Ekström, M. N. Koppes, P. Lynett, A. Dufresne, P. J. Haeussler, M. Geertsema, S. Gulick, A. Mattox, J. G. Venditti, M. A. L. Walton, N. McCall, E. Mckittrick, B. MacInnes, E. L. Bilderback, H. Tang, M. J. Willis, B. Richmond, R. S. Reece, C. Larsen, B. Olson, J. Capra, A. Ayca, C. Bloom, H. Williams, D. Bonno, R. Weiss, A. Keen, V. Skanavis, and M. Loso. 2018. The 2015 landslide and tsunami in Taan Fiord, Alaska. Scientific Reports 8:12993.

Hood, E., and L. Berner. 2009. Effects of changing glacial coverage on the physical and biogeochemical properties of coastal streams in southeastern Alaska. Journal of Geophysical Research 114(G03001). https://doi.org/10.1029/2009JG000971.

Hood, E., G. Eckert, S. Nagorski, and C. Talus. 2006. Assessment of coastal water resources and watershed conditions at Klondike Rold Rush National Historical Park, Alaska. Technical Report NPS/NRWRD/NRTR-2006/349. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/659925.

Hults, C., D. Capps, and E. Bilderback. 2019. Geohazards in Alaska's national parks. Alaska Park Science 18(1):1–5. https://irma.nps.gov/DataStore/Reference/Profile/2265547.

ICS (International Commission on Stratigraphy). 2022. International chronostratigraphic chart (v2022/02). Drafted by K. M. Cohen, D. A. T. Harper, P. L. Gibbard, and N Car, February 2022. International Union of Geological Sciences (IUGS), International Commission on Stratigraphy (ICS), Durham, England [address of current ICS chair]. https://stratigraphy.org/chart.

Jarvis, J. E. 2015. Addressing climate change and natural hazards for facilities. Policy Memorandum 15-01. US Department of the Interior, National Park Service, Washington DC. https://npspolicy.nps.gov/PolMemos/policymemoranda.htm.

Karpilo, R. D. Jr., and S. C. Venator. 2015. Documenting over a century of natural resource change with repeat photography in Klondike Gold Rush National Historical Park, Alaska. Natural Resource Report NPS/KLGO/NRR—2015/1017. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2224006.

Kaufman, D. S., and W. F. Manley. 2004. Pleistocene maximum and Late Wisconsinan glacier extents across Alaska, USA. Developments in Quaternary Sciences 2(B):9–27.

KellerLynn, K. 2009. Geologic Resources Inventory scoping summary, Klondike Gold Rush National Historical Park, Alaska. National Park Service, Fort Collins, Colorado. http://go.nps.gov/gripubs.

Klondike Gold Rush National Historical Park. 2021 [access date]. The Palm Sunday Avalanche. Online information. National Park Service, Klondike Gold Rush National Historical Park, Skagway, Alaska. https://www.nps.gov/articles/palm-sunday-avalanche.htm (accessed 24 January 2021).

Lander, J. F. 1996. Tsunamis affecting Alaska, 1737–1996. NGDC key to Geophysical Research Documentation 31. National Oceanic and Atmospheric Administration, Boulder, Colorado.

Larsen, C. F., R. J. Motyka, J. T. Freymueller, K. A. Echelmeyer, and E. R. Ivins. 2005. Rapid viscoelastic uplift in southeast Alaska caused by post-Little Ice Age glacial retreat. Earth and Planetary Science Letters 237:548–560.

Lathram, E. H. 1964. Apparent right-lateral separation on Chatham Strait fault, southeastern Alaska. Geological Society of America Bulletin 75:249–252.

Loso, M., A. Arendt, C. F. Larsen, J. Rich, and N. Murphy. 2014. Alaskan national park glaciers—status and trends. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/App/Reference/Profile/2217472.

MacKevett, E. M. Jr., E. C. Robertson, and G. R. Winkler. 1974. Geology of Skagway B-3 and B-4 quadrangles, southeastern Alaska. Professional Paper 832. US Geological Survey, Washington, DC. https://pubs.er.usgs.gov/publication/pp832.

Martin, L., and F. E. Williams. 1924. An ice-eroded fiord: the mode of origin of Lynn Canal, Alaska. Geographical Review 14(4):576–596.

Nicolsky, D. J., E. N. Suleimani, and J. B. Salisbury. 2018. Tsunami inundation maps for Skagway and Haines, Alaska. Report of Investigation 2018-2. Alaska Division of Geological & Geophysical Surveys, Fairbanks, Alaska. https://dggs.alaska.gov/pubs/id/30029.

NPS (National Park Service). 2009. Klondike Gold Rush National Historical Park foundation statement. National Park Service, Anchorage, Alaska. https://www.nps.gov/klgo/learn/management/documents.htm.

NPS (National Park Service). 2014. 2014 abandoned mineral lands survey, Inspiration Mine: Klondike Gold Rush National Historical Park. National Park Service, Anchorage, Alaska.

Ovenshine, A. T., and D. A. Brew. 1972. Separation and history of the Chatham Straits fault, southeast Alaska. Pages 245–254 (Report 3) *in* Proceedings of the 24th North American Geological Congress, Montreal, Quebec, Canada.

Parrish, R. R. 1983. Cenozoic thermal evolution and tectonics of the Coast Mountains of British Columbia: 1. Fission track dating, apparent uplift rates, and patterns of uplift. Tectonics 2(6):601–631.

Pojar, J., and A. MacKinnon. 1994. Plats of the Pacific Northwest coast. Lone Pine Publishing, Vancouver, British Columbia.

Pranger, H., and R. Inglis. 2002. Trip and technical report, May 6–10, 2002, site visit—erosion of historic Dyea townsite by Taiya River, Klondike Gold Rush National Historical Park (KLGO). National Park Service, Water Resources Division, Fort Collins, Colorado.

Rabinovich, A. B., R. E. Thomson, E. A. Kulikov, B. D. Bornhold, and I. V. Fine. 1999. The landslide-generated tsunami of November 3, 1994, in Skagway harbor, Alaska: a case study. Geophysical Research Letters 26(19):3009–3012.

Redman, E.C., R. M. Retherford, and B. D. Hickok. 1984. Geology and geochemistry of the Skagway B-2 quadrangle, southeastern Alaska (scale 1:40,000). Report of Investigation 84-31. Alaska Division of Geological & Geophysical Surveys, Fairbanks, Alaska. https://doi.org/10.14509/2390.

RGI Consortium. 2017. Randolph Glacier Inventory—A Dataset of Global Glacier Outlines, Version 6. NSIDC: National Snow and Ice Data Center, Boulder, Colorado. https://doi.org/10.7265/4m1f-gd79.

Richards, J., S. Jones, C. Mog, and H. Rockwell, compilers. 2017. Dyea townsite: Taiya riverbank erosion monitoring project. Unpublished report. National Park Service, Klondike Gold Rush National Historical Park, Skagway, Alaska.

Rohr, K. M. M., and L. Currie. 1997. Queen Charlotte basin and Coast Mountains: paired belts of subsidence and uplift caused by a low-angle normal fault. Geology 25(9):819–822.

Statham, G., C. Stethem, and J. Rudisill. 2007. Chilkoot Trail National Historic Site, avalanche risk assessment for hikers, custodial groups and staff for the period of June 1 to July 15. Parks Canada, Gatineau, Quebec, Canada.

STC (Skagway Traditional Council). 2006. Pullen Creek waterbody recovery plan best management practices. Prepared for the Alaska Department of Environmental Conservation, Alaska Clean Water Action Program. Skagway Traditional Council, Skagway, Alaska.

Symons, D. T. A., M. J. Harris, J. E. Gabites, and C. J. R. Hart. 2000. Eocene (51 Ma) end to northward translation of the Coast plutonic complex: paleomagnetism and K-Ar dating of the White Pass dikes. Tectonophysics 326:93–109.

Symons, D. A. T., and K. Kawasaki. 2011. Eocene rotation of the Coast plutonic complex and intermontane belt: paleomagnetism of Eocene plutons along the Klondike Highway. Canadian Journal of Earth Sciences 48:645–660.

Synolakis, C. E., A. C. Yalciner, J. C. Borrero, and G. Plafker. 2002.Modeling of the November 3, 1994 Skagway, Alaska tsunami. Pages 915–927 *in* Proceedings of the Solutions to Coastal Disasters 2002 Conference, 24-27 February 2002, San Diego, California.

US 94th Congress. 1976. An act to authorize the secretary of the Interior to establish the Klondike Gold Rush National Historical Park in the states of Alaska and Washington, and for other purposes. Public Law 94-323. Statute 90:717–719. https://www.congress.gov/public-laws/94th-congress.

US Army Corps of Engineers. 2008. Erosion information paper—Skagway, Alaska. Alaska Baseline Erosion Assessments. US Army Corps of Engineers, Alaska District, Joint Base Elmendorf-Richardson, Anchorage, Alaska. https://www.poa.usace.army.mil/Library/Reports-and-Studies/Alaska-Baseline-Erosion-Assessments/.

US Geological Survey. 2016. USGS National Hydrography Dataset (NHD) Downloadable Data Collection - National Geospatial Data Asset (NGDA) National Hydrography Dataset (NHD). USGS - National Geospatial Technical Operations Center (NGTOC), Rolla, MO and Denver, CO, http://nhd.usgs.gov.

Varnes, D. J. 1978. Slope movement types and processes. Pages 11–33 *in* Landslides: analysis and control. Special Report 176. Transportation Research Board, Washington, DC.

Wald, D. J., V. Quitoriano, T. H. Heaton, and H. Kanamori. 1999. Relationships between peak ground acceleration, peak ground velocity, and Modified Mercalli Intensity in California. Earthquake Spectra 15(3):557–564.

Wesson, R. L., O. S. Boyd, C. S. Mueller, C. G. Bufe, A. D. Frankel, and M. D. Petersen. 2007. Revision of time-independent probabilistic seismic hazard maps for Alaska. Open-File Report OFR-2007-1043. US Geological Survey, Reston, Virginia. http://pubs.usgs.gov/of/2007/1043/.

Wieczorek, G. F. and J. B. Snyder. 2009. Monitoring slope movements. Pages 245–271 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado. http://go.nps.gov/geomonitoring.

Wilson, F. H., C. P. Hults, C. G. Mull, and S. M. Karl. 2015. Geologic Map of Alaska (scale 1:1,584,000). Scientific Investigations Map 3340. US Geological Survey, Anchorage, Alaska. https://pubs.er.usgs.gov/publication/sim3340.

Yehle, L. A., and R. W. Lemke. 1972. Reconnaissance engineering geology of the Skagway area, Alaska, with emphasis on evaluation of earthquake and other geologic hazards. Open-File Report OFR-72-454. US Geological Survey, Reston, Virginia. https://pubs.er.usgs.gov/publication/ofr72454.

Young, R. and L. Norby, editors. 2009. Geological monitoring. Geological Society of America, Boulder, Colorado. http://go.nps.gov/geomonitoring.

Ziesler, P. S. 2020. Statistical abstract: 2019. Natural Resource Data Series NPS/NRSS/EQD/NRDS—2020/1272. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2272525.

NPS 461/182811, July 2022

National Park Service
U.S. Department of the Interior

Natural Resources Stewardship and Science
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

https://www.nps.gov/nature/index.htm