

Geologic Resources Inventory Scoping Summary Klondike Gold Rush National Historical Park, Alaska

Prepared by Katie KellerLynn
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Geologic Resources Division
National Park Service
U.S. Department of the Interior



The Geologic Resources Inventory (GRI) Program provides each of 270 identified natural area National Park System units with a geologic scoping meeting, a digital geologic map, and a geologic resource evaluation report. Geologic scoping meetings generate an evaluation of the adequacy of existing geologic maps for resource management, provide an opportunity for discussion of park-specific geologic management issues and, if possible, include a site visit with local experts. The purpose of these meetings is to identify geologic mapping coverage and needs, distinctive geologic processes and features, resource management issues, and potential monitoring and research needs. Outcomes of this scoping process are a scoping summary (this report), a digital geologic map, and a geologic resources inventory report.

The National Park Service held a GRI scoping meeting for Klondike Gold Rush National Historical Park in Skagway, Alaska, on June 16 and 17, 2009, in the refurbished, former White Pass and Yukon Railroad Depot (built in 1898), which now serves as the park headquarters and visitor center. Train tracks once ran down Broadway Street to the depot (from Whitehorse, Yukon Territory, Canada, 180 km [112 mi] to the north) but are now located south of the building. Train rides amuse visitors and startle scoping participants, unprepared for train whistles and the site of an engine on 1st Avenue during meeting introductions.

During the meeting, Tim Connors (Geologic Resources Division) facilitated the group's assessment of map coverage and needs, and Bruce Heise (Geologic Resources Division) led the discussion of geologic processes, features, and issues at the park. Dave Brew (U.S. Geological Survey emeritus) presented the geologic story of southeast Alaska. Participants at the meeting included NPS staff from the park, Alaska Regional Office, Geologic Resources Division, and Southeast Alaska Network; and cooperators from Colorado State University and the U.S. Geological Survey.

On June 17, Dave Brew and park staff led participants on a field trip that highlighted the area's geologic resources. The group made stops at various exposures, overlooks, and points of historical and ecological interest within Klondike Gold Rush National Historical Park and along the Klondike Highway.

This scoping summary highlights the GRI scoping meeting for Klondike Gold Rush National Historical Park including the geologic setting; the plan for providing a digital geologic map; a list of geologic features, processes, and issues; and a record of meeting participants (table 2).

Park and Geologic Setting

Klondike Gold Rush National Historical Park celebrates the famed Klondike Gold Rush of 1897–1898. The national historical park, including 15 historic structures in downtown Skagway, is central to the historic district and enhances the city's appeal to visitors. With Skagway as the anchor, the national historical park also reaches up the White Pass and Chilkoot trails and includes the old town site of Dyea (the trailhead of the Chilkoot Trail). During the gold rush, Dyea and Skagway were the

most popular jumping off points to the Klondike goldfields. The White Pass Trail is 16 km (10 mi) longer than the Chilkoot Trail, but the summit is less steep and 180 m (600 ft) lower. Either way, gold-rush stampeders were headed for Bennett Lake, British Columbia, where they would float down the Yukon River for 800 km (500 mi) to Dawson City and the Yukon Territory beyond. Within Klondike Gold Rush National Historical Park, the Chilkoot Trail extends 26.5 km (16.5 mi) north to the Canadian border where it continues in Chilkoot Trail National Historic Site of Canada. The White Pass Trail area of the park starts 11 km (7 mi) northeast of Skagway and extends about 8 km (5 mi) north to the Canadian border. The National Park Service and Parks Canada collaborate to interpret the Klondike Gold Rush and maintain trail operations on both sides of the border. The White Pass Trail unit of the park also contains portions of the historic Brackett Wagon Road and remnants of White Pass City. During the scoping field trip on July 17, 2009, participants stopped at overlooks with interpretive waysides highlighting these locales. Modern features of the White Pass Trail unit include portions of the White Pass and Yukon Route Railroad right-of-way and 1.6 km (1.0 mi) of the Klondike Highway. The National Park Service also maintains a visitor center at Pioneer Square in downtown Seattle, Washington, where many stampeders acquired supplies and boarded boats for Alaska on their rush towards the Klondike.

As observed during the scoping field trip, a noteworthy feature of Klondike Gold Rush National Historical Park is that it spans from coastal to alpine terrain. The Chilkoot Trail unit starts at sea level, hosting intertidal sand flats, and extends to high elevations with glaciers, tundra, and relict permafrost.

The landscape that surrounds Klondike Gold Rush National Historical Park is part of a massive 1,750-km- (1,088-mi-) long belt of plutonic and associated metamorphic rocks. This plutonic complex, called the “Coast Mountain Complex” by Brew et al. (1995), extends from the Fraser River valley near Vancouver north-northwestward to the Yukon Territory. During the scoping field trip, Dave Brew showed participants specific rock units of this complex near Skagway, Dyea, and along the Klondike Highway: (1) Paleocene-Eocene (65.5–33.9 million years ago [Ma]) biotite granodiorite and biotite tonalite of the Burro Creek, Porcupine Creek, and Mount Cleveland plutons; (2) Paleocene-Eocene gneiss and migmatite associated with the plutonic suite; and (3) Eocene (55.8–33.9 Ma) biotite granite of the Clifton and Summit Lake plutons. Though lithologically similar to the Clifton granite, Summit Lake granite, which crops out in the White Pass area, is older. Interestingly, the museum in Skagway is constructed of Clifton granite, and the Chilkoot Trail ascends through the Burro Creek pluton. Exposures of migmatite along the Klondike Highway show five phases of folding in this very “messy” (and very complicated) rock (Brew and Ford 1994).

The plutonic suite is a result of tectonic activity. From 70 to 55 million years ago, the Alexander terrane was moving northeastward into North America. Terranes are geologic “bits and pieces” such as island arcs, chunks of seafloor, and fragments of land that have shattered, scraped off, and smeared along the leading edge of a continent. The plutonic and associated metamorphic rocks in the vicinity of the park are the result of the compression between the Alexander terrane and North American plate. Tectonically, compression resulted in convergence and crustal thickening, which was followed by metamorphism and igneous intrusion (of plutons) 58–48 million years ago.

In some parts of Alaska (e.g., the Gulf of Alaska), investigators have found evidence of 2.5-million-year-old glaciations. However, evidence of glacial advances in most parts of southeast Alaska is much younger, and the complete glacial history is often unclear because of (1) erosion or burial of older drift during the latest Pleistocene ice advance, (2) dissipation of sediments where glaciers flowed into the sea, (3) obliteration of glacial features by tectonic activity, and (4) accelerated erosion and deposition owing to high relief caused by tectonism (Hamilton 1994). Evidence of only the most recent periods of glaciation is preserved around Skagway (NPS brochure, “Geology, Glaciers & Gold,” p. 7). Some 49,000 years ago, glaciers filled the Skagway River valley up to the level of craggy peaks and burdened the land with flowing ice. The weight of glacial ice isostatically depressed coastal areas 100 to 250 m (Hamilton 1994). Abrading and plucking glaciers ground down along the valley’s faulted course; carved a steep-sided, U-shaped valley; and polished rock protrusions into massive, rounded shoulders. Around 24,000 years ago, a smaller ice age blanketed the area; deglaciation began about 13,000 years ago (Hamilton 1994). During this time, glaciers excavated the previous period’s broad valleys, carving the present smaller U-shaped valley into the preexisting valley floor. Most recently, during the Little Ice Age (1,500 to 250 years ago), small glaciers formed at high altitudes. Harding Glacier, visible from downtown Skagway, is a remnant from this time (NPS brochure, “Geology, Glaciers & Gold,” p. 7).

Geologic Mapping for Klondike Gold Rush National Historical Park

During the scoping meeting, Tim Connors (Geologic Resources Division) showed some of the main features of the GRI Program’s digital geologic maps, which reproduce all aspects of paper maps, including notes, legend, and cross sections, with the added benefit of being GIS compatible. The NPS GRI Geology-GIS Geodatabase Data Model incorporates the standards of digital map creation for the GRI Program and allows for rigorous quality control. Staff members digitize maps or convert digital data to the GRI digital geologic map model using ESRI ArcGIS software. Final digital geologic map products include data in geodatabase and shapefile format, layer files complete with feature symbology, Federal Geographic Data Committee (FGDC)–compliant metadata, a Windows HelpFile that captures ancillary map data, and a map document that displays the map and provides a tool to directly access the HelpFile. Final products are posted at <http://science.nature.nps.gov/nrdata/> (accessed August 21, 2009). The data model is available at <http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm> (accessed August 21, 2009).

When possible, the GRI Program provides large-scale (1:24,000) digital geologic map coverage for each unit’s area of interest, which is generally composed of the 7.5-minute quadrangles that contain NPS-managed lands. Maps of this scale (and larger) are useful to resource managers because they capture most geologic features of interest and are spatially accurate within 12 m (40 ft). The process of selecting maps for management begins with the identification of existing geologic maps in the vicinity of the National Park System unit. Scoping participants then discuss mapping needs and select appropriate source maps for the digital geologic data (table 1) or, if necessary, develop a plan to obtain new mapping. In Alaska, large-scale mapping is usually defined as “one inch to the mile” or quadrangles produced at a scale of 1:63,360.

Klondike Gold Rush National Historical Park has three “inch to the mile” quadrangles of interest: Skagway C-1, Skagway C-2, and Skagway B-1 (fig. 1). The park is situated mostly within the Skagway C-1 quadrangle and partially in the Skagway B-1. The Skagway C-2 does not contain

parklands but is of interest to park staff because it contains a significant portion of the Taiya River watershed. Along with the Skagway River and Pullen Creek, the Taiya River runs through the park and terminates in the Taiya Inlet. Processes in this watershed fully impacts park resources.

Table 1. Existing Source Maps for Klondike Gold Rush National Historical Park¹

GMAP ID ²	References
15335	Gehrels, G. E., and H. C. Berg. 1992. <i>Geologic map of southeastern Alaska</i> . Miscellaneous Investigations Series Map I-1867. Scale 1:600,000. Reston, VA: U.S. Geological Survey. http://pubs.er.usgs.gov/usgspubs/i/i1867 (accessed August 21, 2009).
74499	Gehrels, G. E., H. C. Berg, N. Shew, C. S. Peterson, N. Grabman, S. Mohadjer, D. Grunwald, F. H. Wilson, and C. K. Hulst. 2006. <i>Preliminary integrated geologic map databases for the United States: Digital data for the geology of southeast Alaska, Skagway sheet</i> . Scale 1:500,000. Open-File Report OF-2006-1290. Reston, VA: U.S. Geological Survey. http://pubs.usgs.gov/of/2006/1290/ (accessed August 21, 2009).

¹Future publications by Dave Brew (USGS) will supersede existing source maps.

²GMAP numbers are identification codes for the GRI Program's database.

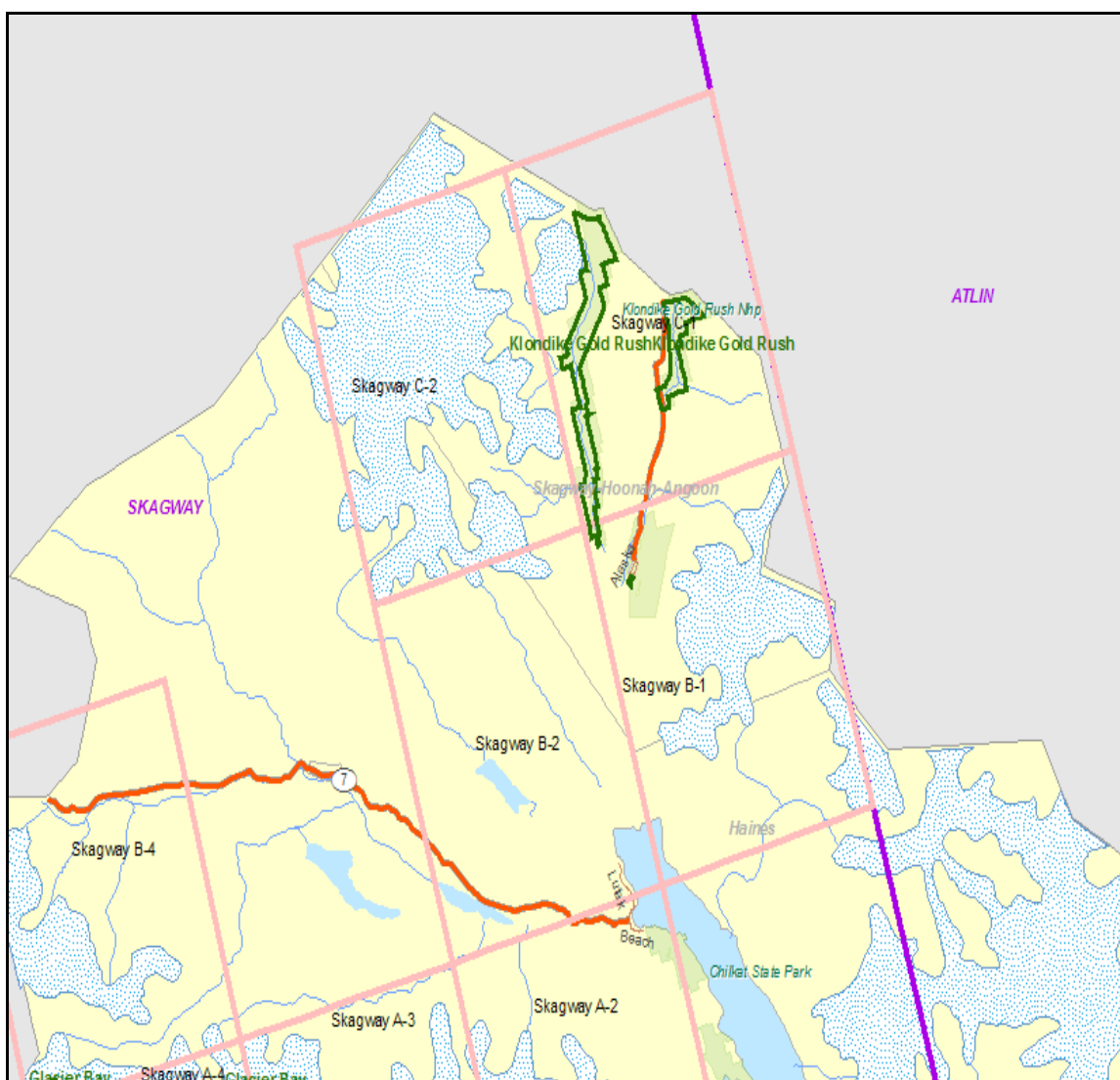


Figure 1. Area of Interest for Klondike Gold Rush National Historical Park. The national historical park boundaries are shown in green. The park is situated in the Skagway C-1 and B-1 quadrangles. Skagway C-2 contains the Taiya River watershed. The “inch to a mile” (scale 1:63,360) quadrangles surrounding the park are outlined in pink and labeled in black.

During scoping, Dave Brew told the group that he is working on a new and improved version of the Skagway 1°×3° sheet to supersede any existing USGS iterations of mapping in the area. His mapping compilation is based on original 1:63,360-scale mapping; ice cover is based on 1948 base maps, so some once-glacier-covered areas are now exposed. Ric Wilson (U.S. Geological Survey) is responsible for USGS mapping projects in Alaska and concurred that this mapping will supersede any existing mapping of the area and will become available in a digital GIS format. During scoping, the U.S. Geological Survey unofficially requested \$5,000 in financial support from the GRI Program to help complete mapping. The map would probably be published as an open-file report, which would facilitate review and completion; however, at the time of scoping, Ric Wilson and Dave Brew could not provide a definite time estimate for completion.

Scoping participants defined the maximum coverage needed for the national historical park as the Skagway B-1 portion that contains parklands and the Skagway C-1 and C-2 that comprise the Skagway River and Taiya River watersheds. Including the adjacent Canadian area as part of the dataset is also desirable. Ric Wilson has these data from the British Columbia Geological Survey. Dave Schirokauer (Klondike Gold Rush National Historical Park) has watershed polygon coverage that he can supply to the U.S. Geological Survey in Anchorage when it comes time to finalize the park's geologic map.

Geologic Features, Processes, and Issues

The scoping meeting for Klondike Gold Rush National Historical Park provided the opportunity to develop a list of geologic features and processes at the park to be further explained in the final GRI report. Many of these features and processes have associated issues of resource management concern. Scoping participants did not prioritize the issues discussed during scoping, and the features and processes are listed in alphabetical order here.

Caves and Karst Features and Processes

Marble occurs as a result of regional metamorphism in the gneiss and schist rock units in Klondike Gold Rush National Historical Park. In addition, some of the granitic units contain large remnants of marble (Dave Brew, U.S. Geological Survey, e-mail, August 18, 2009). These marbleized zones are thin and do not support cave or karst systems, however.

Climate Change

Similar to geologic resources, collecting information on past and present climate is one of the 12 basic inventories for the National Park Service Inventory & Monitoring Program. In 2007 the Western Regional Climate Center (WRCC) prepared an inventory report on the existing data for weather and climate of the Southeast Alaska Network (Davey et al. 2007). The climate inventory includes an evaluation of the adequacy of coverage of existing weather stations and provides recommendations for improving monitoring weather and climate. At present, there are no weather stations within the boundaries of Klondike Gold Rush National Historical Park (Davey et al. 2007). To address this coverage gap, the WRCC report recommended that the National Park Service consider installing one or two automated stations along the Chilkoot Trail. The National Park Service could partner with outside agencies to install either a remote automated weather station (RAWS) or snowfall telemetry network (SNOTEL) for this purpose (Davey et al. 2007).

Climate-related changes for Klondike Gold Rush National Historical Park are isostatic rebound and plant succession, namely encroaching forests on what was once the town of Dyea. During the gold rush, Dyea was covered by grassland. At that time, this area was too close to the water for a forest to establish itself (U.S. Government Printing Office 2005).

Isostatic rebound was a repeated topic of conversation during scoping. Dave Brew mentioned a study by Christopher F. Larsen and others that addressed isostatic rebound in southeast Alaska. According to this study (i.e., Larsen et al. 2005), southeast Alaska has “the world’s fastest present-day glacio-isostatic uplift yet documented.” Larsen et al. (2005) used global positioning system (GPS) geodesy combined with raised shorelines to determine that the rate of uplift is as much as 32 mm (1.6 in) per year in parts of southeast Alaska. Peak uplift is occurring at the Yakutat Icefield, situated in the Tongass National Forest west of Klondike Gold Rush National Historical Park. At 30 mm (1.2 in) per year, Glacier Bay has the second greatest area of uplift. According to National Park Service publications, the rate of uplift at Klondike Gold Rush National Historical Park is about 19 mm (0.76 in) per year (see NPS brochure, “Geology, Glaciers & Gold”). In 1972, Yehle and Lemke published similar rates of 0.059 ft (17.98 mm) per year. Larsen et al. (2005) showed uplift rates of 14–16 mm per year (Hood et al. 2006). Based on these estimates, the Skagway landmass has risen between 1.6 m (5.1 ft) and 2.1 m (6.9 ft) since the gold rush. An excellent interpretive example of isostatic rebound at work in the park is the Vining and Wilkes Warehouse at Dyea. This warehouse (now ruins) was used to hold stampedeers’ “ton of goods”—the year’s supply of provisions required to enter Canada. Being so close to the high-tide mark, this building was built on pilings; today, water is a mile away. Moreover, during the gold rush, the highest tides occasionally peaked at 5th Avenue in Skagway; now this cross street is high and dry (“Geology, Glaciers & Gold”).

Investigators attribute the majority of uplift to viscoelastic rebound following the post–Little Ice Age deglaciation, with extreme uplift beginning about 1770 AD (Larsen et al. 2005). Other contributors to uplift are current ice thinning, tectonic forcing, and global glacial isostatic adjustment.

The Intergovernmental Panel on Climate Change determined that over the past 120 years, global relative sea-level rise has been 1.8 mm (0.07 in) per year (Houghton et al. 2001). Comparing this number to rates of uplift determined by Larsen et al. (2005), sea-level rise is not a threat to national parks in southeast Alaska. However, isostatic rebound is resulting in other changes. For instance, rebound can affect fault stability (Arvidsson 1996; Stewart et al. 2000). According to Sauber and Molnia (2004), release of overburden stress caused by thinning glaciers has increased rates of seismicity in tectonically active southern Alaska. Larsen et al. (2005) concluded that the remarkably large amplitude and short timescale of uplift since the Little Ice Age deglaciation is evidence that recent changes of glacial systems triggered by climate can excite a very large solid earth response, much larger than investigators previously appreciated.

Coastal and Marine Features and Processes

Deltas, which comprise the park’s tidal flats, are the primary coastal feature at Klondike Gold Rush National Historical Park. The deltas of the Skagway and Taiya rivers provide the substrate of the intertidal zone (area between high and low tide) of Skagway and Dyea respectively. Although the areal extent of the intertidal zone is small relative to contiguous marine and terrestrial

ecosystems, its high species diversity and productivity make it ecologically important to a large number of terrestrial and marine animals (Moynahan and Johnson 2008).

Yehle and Lemke (1972) documented the deltaic deposits of Skagway and Dyea. The very gently sloping top of the Skagway delta, which is exposed at low tide, extends seaward as an offshore sediment wedge of decreasing thickness. This delta is an active geomorphic feature. Historical submarine slides may have occurred several times on or near the delta front (Yehle and Lemke 1972). Most natural processes promote extension of the delta (Yehle and Lemke 1972). That is, sedimentation, not erosion, is the driving geomorphic force along the delta front. The principal growth factor is the nearly continual addition of sediment to the outer margin of the delta from the Skagway River. Another factor helping to extend the delta seaward is the slow emergence of land in the area.

The Taiya delta at Dyea probably has a higher content of silt and fine sand than the Skagway delta, as indicated by the dominantly sandy nature of deposits exposed in the farthest downstream banks of the Taiya River (Yehle and Lemke 1972). The delta of the Taiya River is gradually extending into the head of Taiya Inlet as sediment continues to be deposited at the front of the delta. During this extension process, subaqueous slides similar to those along the front of the Skagway River delta occur (Yehle and Lemke 1972).

Disturbed Lands

No gold was ever found in the Skagway valley. The goldfields were located approximately 965 km (600 mi) to the north, near the confluence of the Klondike and Yukon rivers at today's Dawson City. Skagway became internationally known solely as a gateway to the Klondike goldfields. Some historic logging occurred during the gold rush days; stampeders and inhabitants used wood for building materials and heating.

Although some exploration and prospecting have occurred in the vicinity of Skagway, the only sustained mining is for gravel. The Alaska Department of Transportation and Public Facilities uses gravel for road base from a quarry along the Klondike Highway. The City of Skagway extracts gravel from the Skagway River and West Creek for roads and other construction projects. The Alaska Resource Data File (ARDF) contains five records of mineral occurrences in the vicinity of Klondike Gold Rush National Historical Park: ARDF number SK021—Skagway uranium prospect (Skagway B-1 quadrangle), SK022 and SK023—silver and copper occurrences at unnamed sites at the headwaters of Burro Creek and on Mount Harding (Skagway B-2 quadrangle), SK072—the Clifton molybdenum prospect (Skagway C-1 quadrangle), and SK073—Inspiration Mine, a silver and lead prospect (Skagway C-1 quadrangle) (Crafford 2001).

During the scoping field trip, Dave Schirokauer showed participants one of seven core wetlands being monitored for the recovery of western toads (*Bufo boreas*) in the park. The International Union for the Conservation of Nature and Natural Resources (IUCN) lists the species as “near threatened” because of population decline throughout its range. In an effort to improve habitat within the park, staff would like to restore a segment of an abandoned road that traverses the wetland. Although this road has been blocked since the mid-1970s when a new paved road was built to the historic town site of Dyea, illegal ORV traffic has recently compromised the site.

Many aspects of this restoration project are geological such as returning the roadbed to natural grade using geologically appropriate materials. Furthermore, the Geologic Resources Division administers the NPS Disturbed Lands Restoration Program. Disturbed lands are those parklands where the natural conditions and processes have been impacted directly by mining, oil and gas production, development (e.g., facilities, roads, dams, abandoned campgrounds, and user trails), agricultural practices (e.g., farming, grazing, timber harvest, and abandoned irrigation ditches), overuse, or inappropriate use. Park staff originally requested funding for this project in 2007 through the Natural Resources Preservation Program (NRPP) and updated the Project Management Information System (PMIS) statement (139147) in 2009.

Eolian Features and Processes

The name “Skagway” has many definitions: One interpretation is that the word comes from “Skagua,” meaning “home of the north wind.” Frank Carpenter, a travel writer in the 1920s, stated that “Skag-waugh” meant “cruel wind” (Norris 2006). Regardless of the word’s actual meaning, these adaptations insinuate the often dusty and extremely windy setting of Skagway.

The Skagway and Taiya rivers transport sand and silt from the glacial valleys upstream to the floodplains and tidal flats downstream. Wind then reworks the glacial/fluvial sediments on these landforms. Wind and tidal activity create dunes, which have been vegetated, on the tidal flats at Dyea. These dunes are a result of glacial, fluvial, tidal, and eolian processes. Additionally, isostatic rebound adds “bare ground,” leading to increased erosion (Hallett et al. 1996; Jaeger et al. 2001), thereby affecting the amount of sediment available for redistribution by the wind.

Fluvial Features and Processes

Two primary rivers run through Klondike Gold Rush National Historical Park—the Skagway and Taiya. Additionally, Pullen Creek flows entirely within the City of Skagway and drains into the Skagway Harbor. Faults determined the placement of the Skagway and Taiya river valleys. The rivers start at elevations of nearly 1,828 m (6,000 ft) and drain into the Taiya Inlet at Skagway and Dyea respectively. Major tributaries of the Skagway River include the East Fork and the White Pass Fork, and major glaciers feeding the river are the Laughton, Denver, and South glaciers. The Nourse River and West Creek are tributaries of the Taiya River, and the major glaciers that feed the Taiya River are the No Name, Norse, and West Creek. Both rivers carry large amounts of glacial silt, causing them to shift course frequently as new bars and channels form (Moynahan and Johnson 2008).

The Taiya River has shifted several times across Dyea, washing historic buildings into the sea and destroying parts of the Slide Cemetery, which holds the graves of those killed during the Palm Sunday Avalanche (see “Hillslope Features and Processes” section). Investigators estimate that approximately 50% of the historic town site has washed into the river (Inglis and Pranger 2002). The losses include Healy and Wilson’s Trading Post (1884–1900), a Chilkoot Indian village, and the U.S. Military Reservation. However, significant structural artifacts still remain such as Matthews Cabin, Pullen Barn, the collapsed Vining and Wilkes warehouse, and the A. M. Gregg real estate false front. In 2002, specialists from the NPS Water Resources and Geological Resources divisions examined the area and concluded that in order to protect the remaining portions of Dyea, the Taiya channel bank needed to be stabilized. They recommended that engineered log jams be used for this purpose because the jams (1) are made of naturally occurring materials, (2) mimic

existing conditions in the Taiya River, and (3) enhance habitat in addition to stabilizing channel banks (Inglis and Pranger 2002). In 2005, park staff requested NRPP funding for this project and submitted PMIS statement 117398.

Flooding also occurs higher in the Taiya River watershed, most recently in 2002 at Sheep Camp Campground on the Chilkoot Trail. In response to this event, an interdisciplinary team of specialists hiked a portion of the trail and visited the campground in 2005 to evaluate areas suitable for the campground's relocation. The team selected two potential sites (Hahr 2005). The National Park Service needs to complete archaeological surveys; contract and select campground, trail, and bridge designs; and prepare an environmental assessment before relocation efforts can begin (Hahr 2005).

Glacial Outburst Floods

Glacial outburst floods combine glacial, fluvial, hillslope, and lacustrine features and processes. Moreover, their significance to resource management at Klondike Gold Rush National Historical Park warrants a discussion of their own. Global warming has increased the rate of melting and receding of glaciers in the mountains above the park and subsequently caused an increase in the size of glacial lakes and the weakening of the glacial moraines that typically impound these lakes. Melting of ice cores within some moraines also contributes to destabilization. Catastrophic downstream flooding and debris flows have resulted from increased meltwater and higher lake levels behind loosely consolidated and saturated moraines. Where such moraines serve as dams, they pose a threat to park infrastructure and neighboring properties. Most recently, on July 23, 2002, a lateral moraine of the West Creek glacier failed causing a glacial outburst flood, which impacted private landowners' and NPS properties, including the lower Chilkoot Trail, Dyea Campground, and the historic Dyea town site. West Creek is a tributary of the Taiya River. Denny Capps presented information about this flood at the 2003 Geological Society of America annual meeting (Capps 2003).

Although the glaciers in the vicinity of Klondike Gold Rush National Historical Park occur on Bureau of Land Management (BLM) and USDA Forest Service (USDA-FS) lands, glacial outburst floods (and associated debris flows) fully impact NPS resources. During post-scoping follow-up, GRD staff suggested that USDA-FS geologist Jim Baichtal (Tongass National Forest, Ketchikan, 907-225-3101) may be a good partner for park staff (Deanna Greco, Geologic Resources Division, e-mail, August 3, 2009). In addition, Dave Brew suggested that Lynn Yehle, who is still active at the U.S. Geological Survey in Denver (yehle@usgs.gov), may be a good resource on this issue.

Areas of concern for flooding are the Taiya River, Norse River, and West Creek valleys in the Taiya River watershed (Deanna Greco, Geologic Resources Division, oral communication, July 23, 2009). According to Lawson (2007), lakes in the Skagway River watershed are also of concern. In 2007, Dan Lawson (Cold Regions Research and Engineering Laboratory [CRREL]) surveyed moraine-dammed lakes in both the Taiya River and Skagway River watersheds and determined that four lakes—two in the Taiya and two in the Skagway watershed—warranted further investigation because of their potential for outburst floods: “Lake 1161” and Goat Lake in the Skagway watershed, and “Lateral Moraine Lake” and Norse Lake in the Taiya watershed (Lawson 2007).

Post and Mayo (1971) and Streveler (1995) provide evidence that Nourse Lake burst catastrophically down the Taiya River valley approximately 150 and 250 years ago. An 1894 photo

in the park's archives clearly shows the scar that resulted from a glacial outburst flood below this lake. Along with other evidence, this photo documents rapid retreat of glaciers in the 1880s (Hal Pranger, Geologic Resources Division, personal communication, July 23, 2009).

Glacial Features and Processes

Both the Skagway and Taiya River watersheds contain substantial area above tree line, portions of which are covered by glaciers and permanent snowfields. In 1994, investigators estimated that 33% of the Taiya River watershed and 17% of the Skagway River watershed were covered by glaciers (Jones and Fahl 1994). Scoping participants noted that 1948 maps of the park showed glaciers within its boundaries. The amount of glacial ice in these areas has undoubtedly decreased in the last decade with the thinning and retreat of glaciers in Alaska and the Canadian Yukon (Arendt et al. 2002); however, glaciers remain an important source of streamflow in both watersheds (Hood et al. 2006).

Although large ice fields once covered the entire region, major deglaciation began about 13,000 years ago (Hamilton 1994); the existing glaciers are most likely remnants of the Little Ice Age (1,500 to 250 years ago). Pre-Little Ice Age glaciers covered the area around Dyea and Skagway, and mile-thick ice gouged classic U-shaped valleys where the town sites now lie. Valley walls display glacial smoothing and rounding, as well as grooves. In the West Creek area, valley walls and mountain spurs are glacially eroded to an altitude as high as 1,219 m (4,000 ft) (Callahan and Wayland 1965). Other erosional features in the vicinity of the park are horns, arêtes, nunataks, cirques, tarns, and hanging valleys. Goat Lake—a tarn and currently the source of Skagway's hydroelectric power—sits in a glacially scoured basin; Pitchfork Falls spills from the lake over the hanging-valley wall.

Depositional glacial features also abound at Klondike Gold Rush National Historical Park, primarily moraines but also outwash plains. Throughout the area, receding glaciers left recessional moraines that record recent glacial retreat; these moraines often impound proglacial lakes (Callahan and Wayland 1965). Near Skagway, a glacier that is the source of Reid Falls left an end moraine 0.6 km (0.4 mi) downvalley from the 1948 ice front. Moraines also are present at similar distances downvalley from Upper Dewey Lake and Devils Punch Bowl; second moraines lay slightly farther downvalley (Yehle and Lemke 1972).

Finally, a striking feature of the Skagway area is the linearity of fjords and major valleys in northerly and northeasterly directions. The orientation is fault directed, but the form is glacial. Fjords are glacially eroded inlets or arms of the sea. Like terrestrial glacial valleys, fjords are U-shaped and steep walled.

Hillslope Features and Processes

As a result of the Palm Sunday Avalanche, the most notorious hillslope process at Klondike Gold Rush National Historical Park is undoubtedly avalanches. This historic series of avalanches on April 3, 1898, caused approximately 80 fatalities and became “the deadliest event of the Klondike Gold Rush” (<http://www.nps.gov/klgo/historyculture/avalanche.htm>; accessed August 21, 2009). The slides occurred between Sheep Camp and the Scales on the Chilkoot Trail.

Avalanches are geomorphic agents that produce accumulations (talus slopes) of rock fragments of any size or shape, mixed with soil and vegetation. Avalanches occur in mountainous areas (e.g., below ridge tops and *arêtes*) where drifting snow builds cornices that collapse, releasing a torrent of snow, ice, trees, and rocks.

In 2007, avalanche specialists prepared an avalanche-hazard index along the Chilkoot Trail for the time period, June 1–July 15, when most hiking occurs along the trail. Investigators have not conducted a similar assessment for the lesser-used White Pass Trail area. Investigators rated all 11 avalanche areas along the Chilkoot Trail (United States and Canada) as very low risk during this high-use time period. This risk value indicates that no active measures or closures would usually be necessary, not that no hazard exists. Investigators recommended that hikers receive information that describes hazards, identifies avalanche areas in which not to stop, and emphasizes traveling early (thus avoiding daily melt periods) (Statham et al. 2007). Of note to NPS staff is that their risk is three times greater than individual hikers because of increased exposure time (Statham et al. 2007).

Many other types of gravity-driven processes occur within Klondike Gold Rush National Historical Park. Scoping participants noted rockfall as prevalent at higher elevations; for example, numerous skree slopes and talus fields are evidence of mass-wasting, gravity-driven processes at high elevations along the Chilkoot Trail. Yehle and Lemke (1972) mapped colluvium in the Skagway area that incorporated deposits from landslides, rockfalls, rockslides, earthflows, and avalanches. Hahr (2005) recorded rockfall as an inherent geologic risk in the upper Taiya River watershed. Considering these processes, Deanna Greco described Klondike Gold Rush National Historical Park as having “geomorphology on crack” (Deanna Greco, Geologic Resources Division, oral communication, July 23, 2009). Such processes make the relocation of Sheep Camp Campground problematic (see Hahr 2005). In addition, rockfall also occurs regularly along the Klondike Highway, a mile of which runs through the park. Scoping participants assumed that the Alaska Department of Transportation and Public Facilities has prepared reports on geologic hazards that affect the Klondike Highway; these may be of use for park staff and the forthcoming GRI report.

Lacustrine Features and Processes

Lakes within and in the vicinity of Klondike Gold Rush National Historical Park have both historic and geologic significance. Historically, stampedeers were headed toward Bennett Lake via the White Pass and Chilkoot trails. Geologically, lakes illustrate past glacial phases and present climate warming (see “Glacial Outburst Floods” section). Past glacial activity scoured out basins in which lakes are now situated (e.g., Upper Dewey and Lower Dewey lakes), and many lakes in the area are dammed by moraines (see “Glacial Outburst Floods” section). Pulverized rock called “glacial flour” gives glacially fed lakes such as Summit Lake a milky blue color.

Permafrost Features and Processes

The summit of the Klondike Highway was once the site of an ice field that served as the zone of accumulation that fed all the glaciers flowing south. Today this area is neither permanently covered with snow and ice, nor is its soil permanently frozen. Hence, scoping participants suggested the area has “fossil” permafrost.

An interesting effect in very cold climates is ice-crystal growth (ground ice) in soils, which causes rock fragments to move upward towards the surface. This process causes large angular blocks of

rock to accumulate in conspicuous displays called *felsenmeer* (German for “rock sea”). Writers have described *felsenmeer* as “tombstone rocks” (Kiver and Harris 1999) because ice-crystal growth heaves these rocks on end, resembling tombstones. Frost action can also move rocks sideways, creating bands, circles, nets, and polygons called patterned ground. However, these processes may not be active under current climatic conditions at White Pass.

Seismic Features and Processes

Most major earthquakes in southeastern Alaska have occurred southwest, west, or northwest of Skagway, near the coast of the Pacific Ocean, and most epicenters are offshore. Most earthquakes appear to be related to movement along the Queen Charlotte–Fairweather fault system. Investigators have inferred several local faults by indirect methods, chiefly topographic evidence as interpreted from aerial photos (Yehle and Lemke 1972). Two of these local faults have names (i.e., Porcupine Creek and Taiya Inlet faults) (Dave Brew, U.S. Geological Survey, e-mail, August 18, 2009). However, local faults, particularly in the Skagway River Valley, have not been extensively studied (Dave Brew, U.S. Geological Survey, e-mail, August 18, 2009).

Skagway frequently experiences minor earthquakes, but according to scoping participants, it is not possible to determine whether the felt earthquakes are from local or long-distance sources. Most earthquakes that “strike” Skagway are too small to feel. For example, on June 7, 2009, the National Earthquake Information Center reported a magnitude (M)=4.8 earthquake at 3:24 p.m. local time, 105 km (65 mi) southwest of Skagway. The Modified Mercalli intensity was II in Skagway; that is, only a few people probably felt this earthquake, and they were most likely at rest or on the upper floors of buildings. Delicately suspended objects may have swung. The most recent earthquake to cause some damage in Skagway was the earthquake of July 10, 1958, with an epicenter about 153 km (95 mi) distant. It was felt by most people in Skagway; the shaking, which was in a north-south direction, caused some concrete foundations to crack (Davis and Sanders 1960).

As a result of the 1958 earthquake, many landslides occurred along valley sides and two abnormal waves reached Skagway, but harbor works were not damaged (Manager, Alaska Power and Telephone Company, oral communication, 1965, *in* Yehle and Lemke 1972, p. 55). Offshore, however, underwater landslides broke submarine communication cables in four places (Heezen and Johnson 1969; D. Alford, Alaska Communications System, written communication, 1966, 1968, *in* Yehle and Lemke 1972, p. 55).

According to Yehle and Lemke (1972), damage in the Skagway area caused by earthquake-generated waves would depend on wave height, tidal stage, and warning time. Furthermore, “the waves most likely will be generated by subaqueous sliding of delta fronts, although waves of other origins, especially those from subaerial slides, should be expected” (Yehle and Lemke 1972, p. 87). Skagway experienced earthquake-induced waves on July 9, 1958; May 22, 1960; and March 27–28, 1964. The tsunami of the 1964 Alaska earthquake (M =9.2) had a height of 3 m (10 ft) for the initial wave height at Skagway (Yehle and Lemke 1972). None of these waves caused much damage at Skagway, probably because of low wave height or low tidal stage at the time of arrival (Yehle and Lemke 1972).

During scoping, participants noted that human activities also can cause tsunamis. For example, on November 3, 1994, a landslide associated with the collapse of a dock under construction for the

Pacific and Arctic Railway and Navigation Company on the east side of Skagway Harbor generated a tsunami wave estimated at 5.0–6.0 m (16–20 ft) high in Taiya Inlet and 9.0–11.0 m (30–36 ft) high at the shoreline. The tsunami claimed the life of one dock worker in Skagway, impacted the Alaska State Ferry Terminal, a cargo terminal, and 1.5 km (0.9 mi) of railway, and caused an estimated \$21 million in damage (Rabinovich et al 1999).

Infrastructure in the area illustrates the potential for seismic activity at Klondike Gold Rush National Historical Park. For example, during the field trip, participants drove over Moore Bridge on the Klondike Highway. This bridge has a cantilevered design; that is, the south end is moored to the rocks while the north end simply rests on the opposite side. As explained in “Geology, Glaciers & Gold,” this design is necessary because the bridge spans a fault. The river under the bridge exploits a preexisting line of weakness. Should movement occur along this fault, the bridge would detach from the north end but not fall. Thereby, repairs would be relatively minor (i.e., reattaching the road bed) as opposed to major (i.e., rebuilding the entire bridge). Engineering geology reports on proposed infrastructure also illustrates the potential for seismic activity. The City of Skagway has shown revitalized interest in producing hydroelectric power on West Creek. A USGS report published in 1965 cautioned that the proposed dam site at West Creek is in an area of strong seismic activity and near suspected lines of present-day movement; therefore, “the dam and all the appurtenant works should be designed to withstand earthquakes of maximum severity and should be founded on firm bedrock rather than on unconsolidated material” (Callahan and Wayland 1965, p. A6).

Unique Geologic Features

Often “unique geologic features” are mentioned in a park’s enabling legislation; these features are of widespread geologic importance and may be of interest to visitors and worthy of interpretation. Moreover, type localities and age dates are unique and of interest to a park’s geologic inventory. At Klondike Gold Rush National Historical Park, unique geologic features include the manifestations of plate tectonics in plutonic rocks. These rocks contain interesting features such as books of biotite mica (Burro Creek pluton) and ratio layering (Porcupine Creek pluton). Ratio layering occurs in granitic rock as alternating amounts of dark (mafic) and light (quartz and feldspar) minerals. The percentages of the darks and the lights may vary from layer to layer; that is, some layers may be very distinct, and some not so distinct. Geologists interpret such layering to have formed while the rock was still molten overall, but the dark minerals had already crystallized and could be concentrated by currents (and perhaps settling) in the magma (Dave Brew, U.S. Geological Survey, e-mail, August 18, 2009).

Many of the igneous rocks in the vicinity of the park have yielded geochemical data. Dave Brew indicated that investigators have acquired 12 age dates from these rocks. The U.S. Geological Survey has created an archive of geochemical data for Alaska that contains 330,000 samples, a few of which are from Klondike Gold Rush National Historical Park.

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Additional References

Note: The following references are the original geologic mapping for the area. All other map references are generally derived from these in some way (Ric Wilson, U.S. Geological Survey, e-mail, September 22, 2009).

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Table 2. Scoping Meeting Participants and Post-Meeting Cooperators

Name	Affiliation	Position	Phone	E-Mail
Susan Boudreau	Klondike Gold Rush National Historical Park	Superintendent	907-983-9216	susan_boudreau@nps.gov
Dave Brew	U.S. Geological Survey	Geologist	650-941-6485	dbrew@usgs.gov
Tim Connors	Geologic Resources Division	Geologist	303-969-2093	tim_connors@nps.gov
Bruce Giffen	Alaska Regional Office	Geologist	907-644-3572	bruce_giffen@nps.gov
Deanna Greco	Geologic Resources Division	Geologist	303-969-2351	deanna_greco@nps.gov
Bruce Heise	Geologic Resources Division	Geologist/GRI program coordinator	303-969-2017	bruce_heise@nps.gov
Ron Karpilo	Colorado State University	Research associate	253-777-2033	ron_karpilo@partner.nps.gov
Katie KellerLynn	Colorado State University	Research associate	801-608-7114	katiekellerlynn@msn.com
Dan Lawson	Cold Regions Research and Engineering Laboratory (CRREL)	Research physical scientist	603-646-4344	daniel.e.lawson@usace.army.mil
Brendan Moynahan	Southeast Alaska Network	Network coordinator	907-364-2621	brendan_moynahan@nps.gov
Hal Pranger	Geologic Resources Division	Geologist	303-969-2018	harold_pranger@nps.gov
Dave Schirokauer	Klondike Gold Rush National Historical Park	Natural resource specialist	907-983-9228	dave_schirokauer@nps.gov
Theresa Thibault	Klondike Gold Rush National Historical Park	Chief of natural resources	907-983-9244	theresa_thibault@nps.gov
Ric Wilson	U.S. Geological Survey	Geologist	907-786-7448	fwilson@usgs.gov