SATELLITE IMAGE ATLAS OF GLACIERS OF THE WORLD

GLACIERS OF NORTH AMERICA–

GLACIERS OF ALASKA

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Abstract

Glaciers cover about 75,000 km^2 of Alaska, about 5 percent of the State. The glaciers are situated on 11 mountain ranges, 1 large island, an island chain, and 1 archipelago and range in elevation from more than 6,000 m to below sea level. Alaska's glaciers extend geographically from the far southeast at lat 55°19'N., long 130°05'W., about 100 kilometers east of Ketchikan, to the far southwest at Kiska Island at lat 52°05'N., long 177°35'E., in the Aleutian Islands, and as far north as lat 69°20'N., long 143°45'W., in the Brooks Range.

During the "Little Ice Age," Alaska's glaciers expanded significantly. The total area and volume of glaciers in Alaska continue to decrease, as they have been doing since the 18th century.

Of the 153 1:250,000-scale topographic maps that cover the State of Alaska, 63 sheets show glaciers. Although the number of extant glaciers has never been systematically counted and is thus unknown, the total probably is greater than 100,000. Only about 600 glaciers (about 1 percent) have been officially named by the U.S. Board on Geographic Names (BGN). There are about 60 active and former tidewater glaciers in Alaska. Within the glacierized mountain ranges of southeastern Alaska and western Canada, 205 glaciers (75 percent in Alaska) have a history of surging. In the same region, at least 53 present and 7 former large ice-dammed lakes have produced jökulhlaups (glacier-outburst floods). Ice-capped volcanoes on mainland Alaska and in the Aleutian Islands have a potential for jökulhlaups caused by subglacier volcanic and geothermal activity. Because of the size of the area covered by glaciers and the lack of large-scale maps of the glacierized areas, satellite imagery and other satellite remote-sensing data are the only practical means of monitoring regional changes in the area and volume of Alaska's glaciers in response to short- and long-term changes in the maritime and continental climates of the State.

A review of the literature for each of the 11 mountain ranges, the large island, the island chain, and the archipelago was conducted to determine both the individual and the regional status of Alaskan glaciers and to characterize changes in thickness and terminus position of representative glaciers in each mountain range or island group. In many areas, observations used for determining changes date from the late 18th or early 19th century. Temperature records at all Alaskan meteorological recording stations document a 20th century warming trend. Therefore, characterizing the response of Alaska's glaciers to changing climate helps to quantify potential sea-level rise from past, present, and future melting of glacier ice (deglaciation of the 14 glacierized regions of Alaska), understand present and future hydrological changes, and define impacts on ecosystems that are responding to deglacierization.

Many different types of data were scrutinized to determine baselines and to assess the magnitude of glacier change. These data include the following: published descriptions of glaciers (1794–2000), especially the comprehensive research by Field (1975a) and his colleagues in the Alaska part of *Mountain Glaciers of the Northern Hemisphere*, aerial photography (since 1926), ground photography (since 1884), airborne radar (1981–91), satellite radar (1978–98), space photography (1984–94), multispectral satellite imagery (since1972), aerial reconnaissance and field observations made by many scientists during the past several decades, and various types of proxy data. The published and unpublished data available for each glacierized region and individual glacier varied significantly. Geospatial analysis of digitized U.S. Geological Survey (USGS) topographic maps is used to statistically define selected glaciological parameters in the eastern part of the Alaska Range.

The analysis determined that every mountain range and island group investigated can be characterized by significant glacier retreat, thinning, and (or) stagnation, especially those glaciers that end at lower elevations. At some locations, glaciers completely disappeared during the 20th century. In other areas, retreat that started as early as the early 18th century has continued into the 21st century. Ironically, in several areas, retreat is resulting in an increase in the total number of glaciers; even though individual glaciers are separating, the volume and area of ice continue to decrease.

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The key findings from the comprehensive analysis are the following:

- **Alexander Archipelago, Aleutian Islands, and Kodiak Island**: Every insular glacier examined showed evidence of thinning and retreat. Some glaciers have disappeared since being mapped in the middle 20th century.
- **Coast Mountains, St. Elias Mountains, Chugach Mountains, Kenai Mountains, Wrangell Mountains, Alaska Range, and the Aleutian Range**: More than 95 percent of the glaciers ending below an elevation of approximately 1,500 m are retreating and (or) thinning. Of those glaciers that are advancing, many have tidewater termini. The two largest Alaskan glaciers, Bering and Malaspina, are losing several cubic kilometers of ice each year to melting and calving.
- **Talkeetna Mountains, Wood River Mountains, Kigluaik Mountains, and the Brooks Range**: Every glacier scrutinized showed evidence of retreat. Of 109 glaciers in the Wood River Mountains, all are or were retreating; some have disappeared since they were first mapped, photographed, or imaged.

In spite of the significant changes at lower elevations, not every Alaskan glacier is thinning and retreating. In several ranges, no changes were noted in glaciers situated at higher elevations.

Glaciers that were surging or had recently advanced by surging were also noted. This type of glacier advances by redistributing existing glacier ice over a larger area rather than by increased accumulation. Consequently, following a surge, more ice surface area is exposed to ablation.

► ***Figure 1.****—Map of Alaska showing distribution of glaciers (shown in green).*

Part 1—Background and History

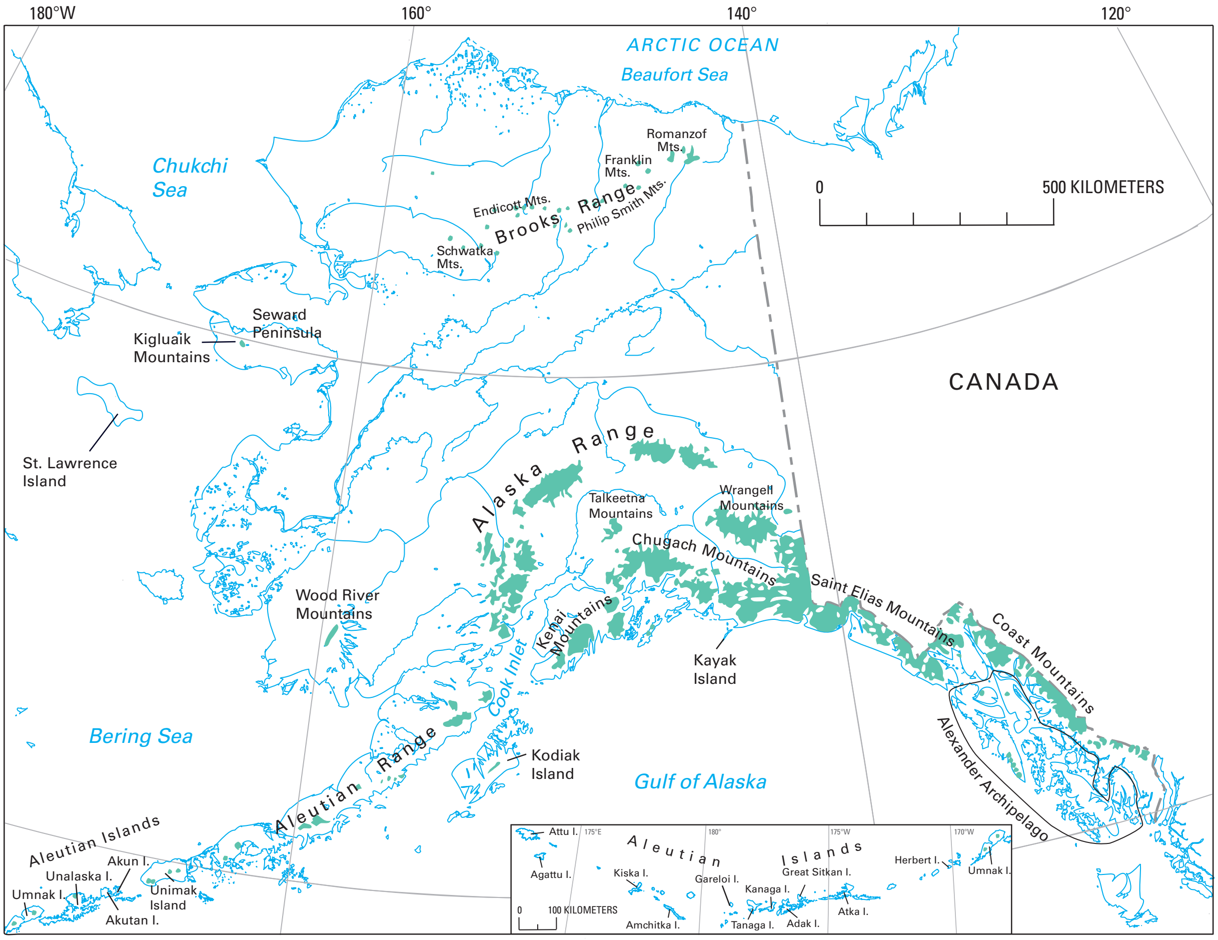
Introduction

Alaska, with an area of 1,530,693 km^2, is the northernmost and westernmost of the 50 United States. Because the Aleutian Islands extend across the International Date Line, it is also the easternmost State. Alaska is bounded by the Arctic Ocean and the Beaufort Sea to the north, the Pacific Ocean and the Gulf of Alaska to the south, Canada's Yukon Territory and British Columbia to the east, and the Bering Sea and the Chukchi Sea to the west. Glaciers are a major feature of much of Alaska's landscape, occurring in more than a dozen geographic regions of the State. Glaciers in Alaska extend from as far southeast as lat 55°19'N., long 130°05'W., about 100 km east of Ketchikan, to as far southwest as Kiska Island at lat 52°05'N., long 177°35'E., in the Aleutian Islands, to as far north as lat 69°20'N., long 143°45'W., in the Brooks Range. Glaciers cover about 75,000 km^2 (Post and Meier, 1980), or about 5 percent, of Alaska, occurring on 11 different mountain groups and several islands (figs. 1, 2). Of the 153 1:250,000-scale topographic quadrangle maps that cover the State of Alaska, glaciers are shown on 60 of the 68 topographic quadrangle maps of regions known to be glacierized (that is, to have present-day glaciers) (appendix A). In the text, where 1:63,360-scale maps of glaciers are discussed, information on these topographic quadrangle maps are given in appendix B. The total number of separate glaciers is unknown, having never been systematically counted, but probably exceeds 100,000 (Molnia, 2001, p. 5). More than 600 glaciers have been officially named by the BGN (appendix C).[2]

► ***Figure 2.****—NOAA Advanced Very High Resolution Radiometer (AVHRR) image mosaic of Alaska in 1991; National Oceanic and Atmospheric Administration image mosaic from Michael Fleming, Alaska Science Center, U.S. Geological Survey, Anchorage, Alaska.*

No comprehensive, detailed glacier inventory has been compiled for Alaska. Estimates of the total glacier area have been made by several scientists: Gilbert (1904) estimated an area of 52,000 km^2, Post and Mayo (1971) estimated 73,800 km^2, Post and Meier (1980) estimated an area of 74,700 km^2, and Molnia (2001) estimated 75,110 km^2. The significant retreat of Alaska glaciers during the last two decades of the 20th century would necessitate a further reduction in this estimate of glacier area. The difference between Gilbert's total and the later estimates is not owing to an expansion of glacier area in subsequent years but rather reflects an increase in geographic/cartographic knowledge and improvements in the quality of data and techniques

[2] Glacier place-names approved by the BGN are shown in standard font; glacier place-names not approved are shown in italicized font. Formal place-names of glaciers approved by the BGN will be used wherever possible. However, in order to provide information about unnamed glaciers, such glaciers will be described in terms of adjacent geographic features.


180°W
160°
140°
120°
65°N
55°
ARCTIC OCEAN
Beaufort Sea
Chukchi Sea
Romanzof Mts.
Franklin Mts.
Endicott Mts.
Brooks Range
Philip Smith Mts.
Schwatka Mts.
0
500 KILOMETERS
Seward Peninsula
Kigluaik Mountains
CANADA
St. Lawrence Island
Alaska Range
Talkeetna Mountains
Wrangell Mountains
Chugach Mountains
Saint Elias Mountains
Coast Mountains
Wood River Mountains
Kenai Mountains
Cook Inlet
Kayak Island
Alexander Archipelago
Bering Sea
Kodiak Island
Gulf of Alaska
Aleutian Range
Aleutian Islands
Akun I.
Unalaska I.
Umnak I.
Unimak Island
Akutan I.
Attu I.
Agattu I.
Aleutian Islands
Kiska I.
Gareloi I.
Great Sitkan I.
Herbert I.
Umnak I.
Kanaga I.
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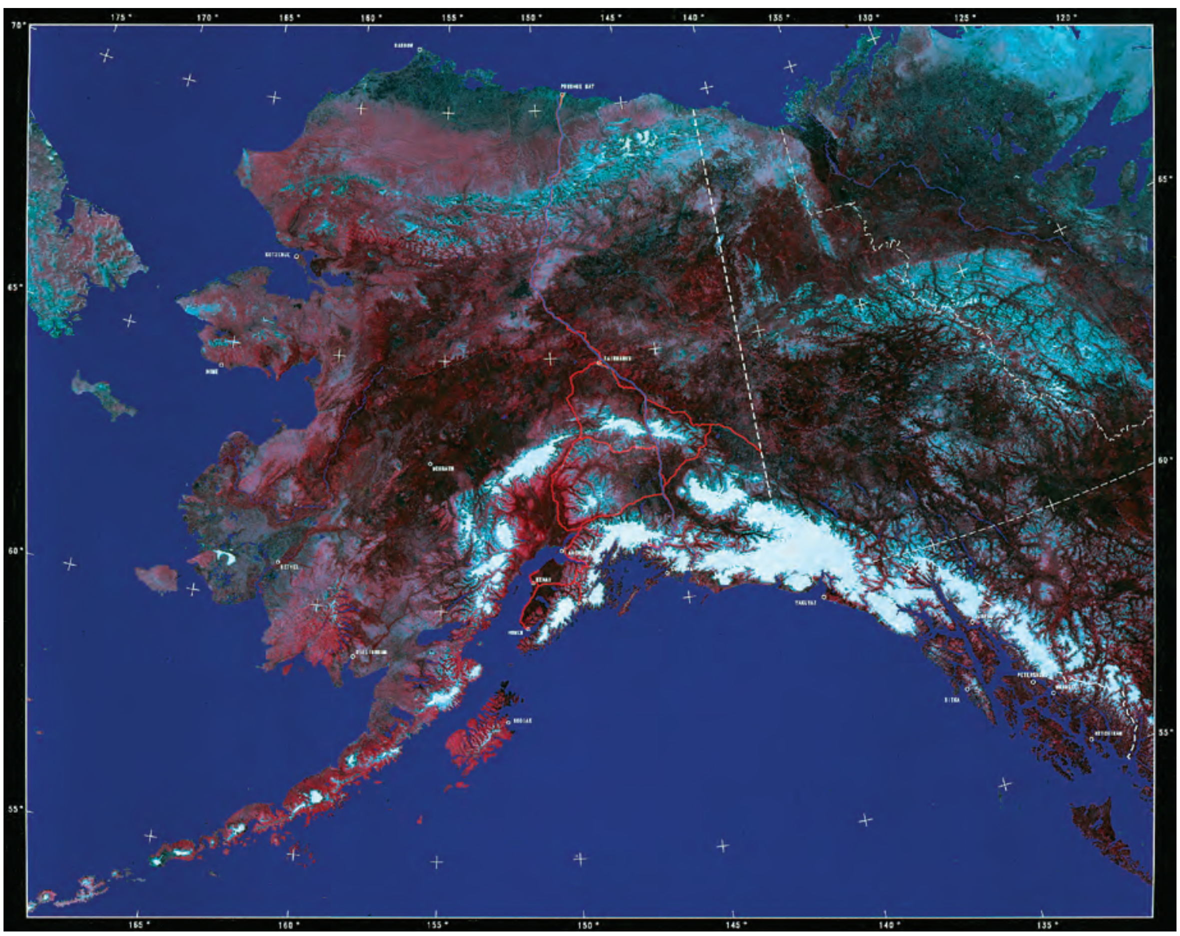
100 KILOMETERS


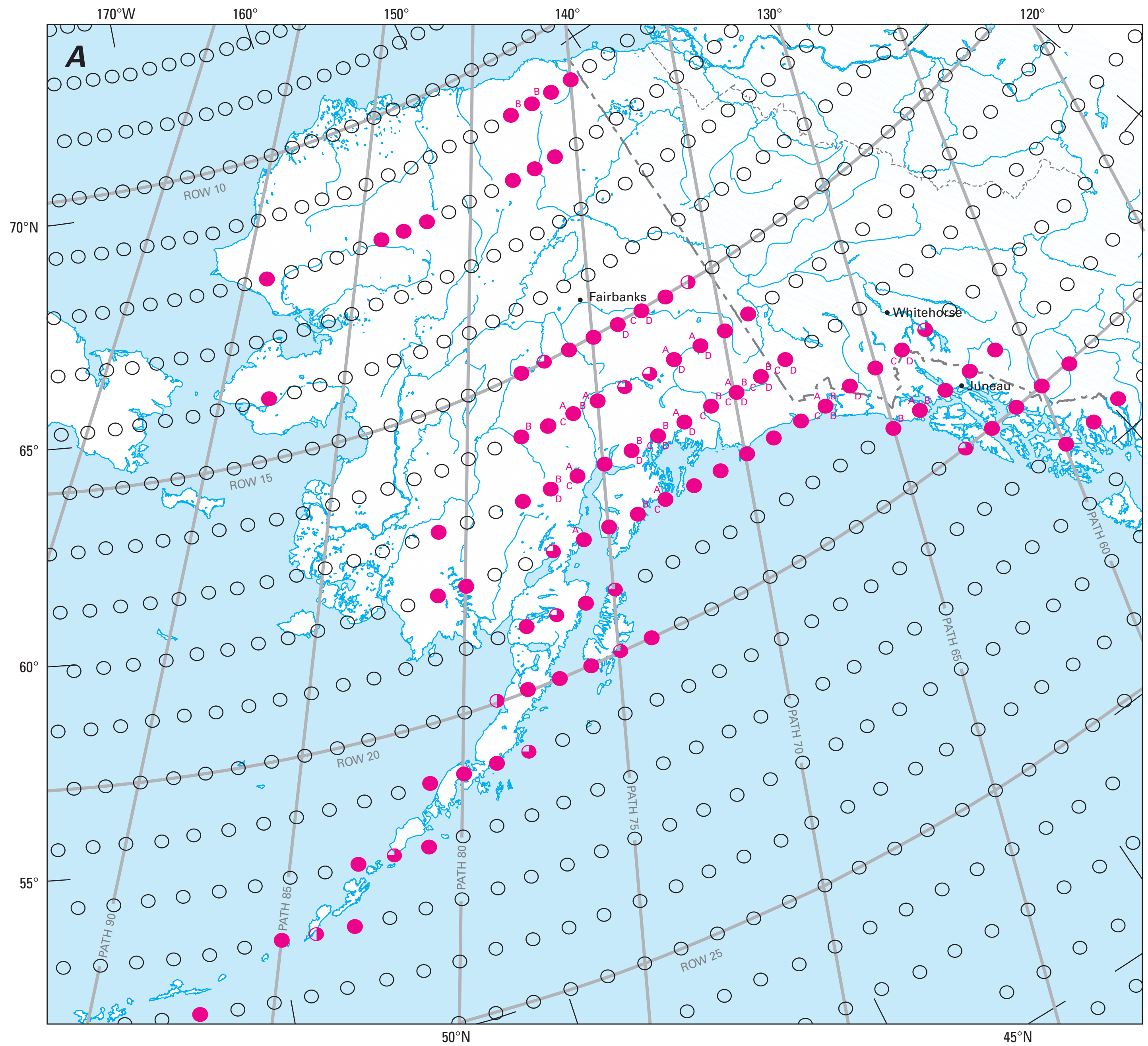
used to produce those estimates. In recent years, some glacier changes have been quite dramatic. Although a few glaciers are advancing, many are in retreat, especially those situated at lower elevations.

The most easily and frequently measured glacier-fluctuation parameter is the geographic position of the terminus. Modern maps, charts, satellite images, vertical and oblique aerial photographs, ground photographs, and field surveys are all used to determine terminus position. Charts from early navigators and explorers and "traditional knowledge" stories from the oral histories of Alaska's indigenous peoples also yield information about the past extent of glaciers. Proxy methods, such as tree coring, yield approximate dates for terminus position up to several millennia ago. Together, these methods play an important role in determining the location and changes in the position of the termini of Alaskan glaciers over time.

The primary purpose of this chapter is to summarize the areal extent and distribution of Alaska's glaciers from the 1970s to the early 1980s in order to present an improved baseline based on Landsat MSS images that can be used now and by future researchers to document change in the number, length, and area of Alaska's glaciers. In addition, descriptions of the results of scientific investigations that provide specific information about individual glaciers and glaciers within glacierized regions are presented to improve the overall understanding of the timing and magnitude of change.

The primary image data set used for establishing a baseline is the set of 90 Landsat MSS false-color composite images compiled by the author from the Landsat image archive of the USGS Earth Resources Observation Systems (EROS) Data Center (EDC) in Sioux Falls, S. Dak. The data set consists of individual false-color composite Landsat images for each path-row nominal scene center in the glacierized regions of Alaska (fig. 3*A*). Each image was prepared from digital data collected by Landsat Multispectral Scanner (MSS) sensors between 23 July 1972, the launch of the first Earth Resources Technology Satellite (ERTS–1, later renamed Landsat 1), and 1981. The digital MSS data were collected by sensors on the Landsat 1, 2, and 3 satellites. An image mosaic of most of Alaska was compiled by using many of these images (fig. 3*B*). The data set is supplemented by additional data and information about the areal extent and distribution of Alaska's glaciers derived from 18th- to 21st-century exploration, 19th- and 21st-century field-based scientific investigations, 19th- to 21st-century ground-based photography, and 20th-century aerial and space photography, digital satellite imagery, and airborne- and spaceborne-radar imagery to temporally extend the baseline both forward and backward in time. The work of Field (1975a) and his collaborators is the primary source for most of the quantitative area and length measurements of named and unnamed glaciers discussed in the individual glacierized geographic regions of this chapter.

In addition to all of the available imagery and photography, an important resource to develop the baseline and to assess change in Alaska's glaciers is the 1:250,000-scale (1×3°) map coverage of the State (appendix A). These maps are the same ones used by Field (1975a) in his landmark study of Alaska's glaciers. These maps, which are of variable accuracy and quality, were published between 1949 and 1979 by the USGS; they were compiled from data collected by the USGS; the U.S. Army Map Service (AMS) and its successor agency, the U.S. Defense Mapping Agency (DMA) [later the National Imagery and Mapping Agency (NIMA) and now the National Geospatial-Intelligence Agency (NGA)]; the U.S. Coast and Geodetic Survey (C&GS) [now the National Ocean Service (NOS)]; and the National Oceanic and Atmospheric Administration (NOAA). More detailed 1:63,360-scale (15-minute) maps exist for each glacierized quadrangle, although many are still provisional (appendix B). Many of the 1:250,000-scale maps have undergone limited revisions. In more than a dozen instances, these revisions have included the use of a purple pattern overprinted on glacial features to indicate glacier change, either



0 500 KILOMETERS

EXPLANATION OF SYMBOLS

Evaluation of image usability for glaciologic, geologic, and cartographic applications. Symbols defined as follows:

- Excellent image (0 to ≤5 percent cloud cover)
- Good image (>5 to ≤10 percent cloud cover)
- Fair to poor image (>10 to <100 percent cloud cover)
- Nominal scene center for a Landsat image outside the area of glaciers
- A B C D Usable Landsat 3 return beam vidicon (RBV) scenes. A, B, C, and D refer to usable RBV subscenes

Figure 3.—**A**, *Map showing the location of nominal scene centers for optimum Landsat 1, 2, and 3 MSS and RBV images that include Alaskan glaciers.*

Figure 3.—**B,** *Landsat MSS false-color infrared image mosaic of part of Alaska, showing most of the glacierized areas in Alaska except for the southeastern panhandle of the state and the westernmost part of the Aleutian Islands (see fig. 2), including many of the active and former tidewater glaciers. Image mosaic compiled by the former Branch of Alaskan Geology, U.S. Geological Survey, in 1978.*

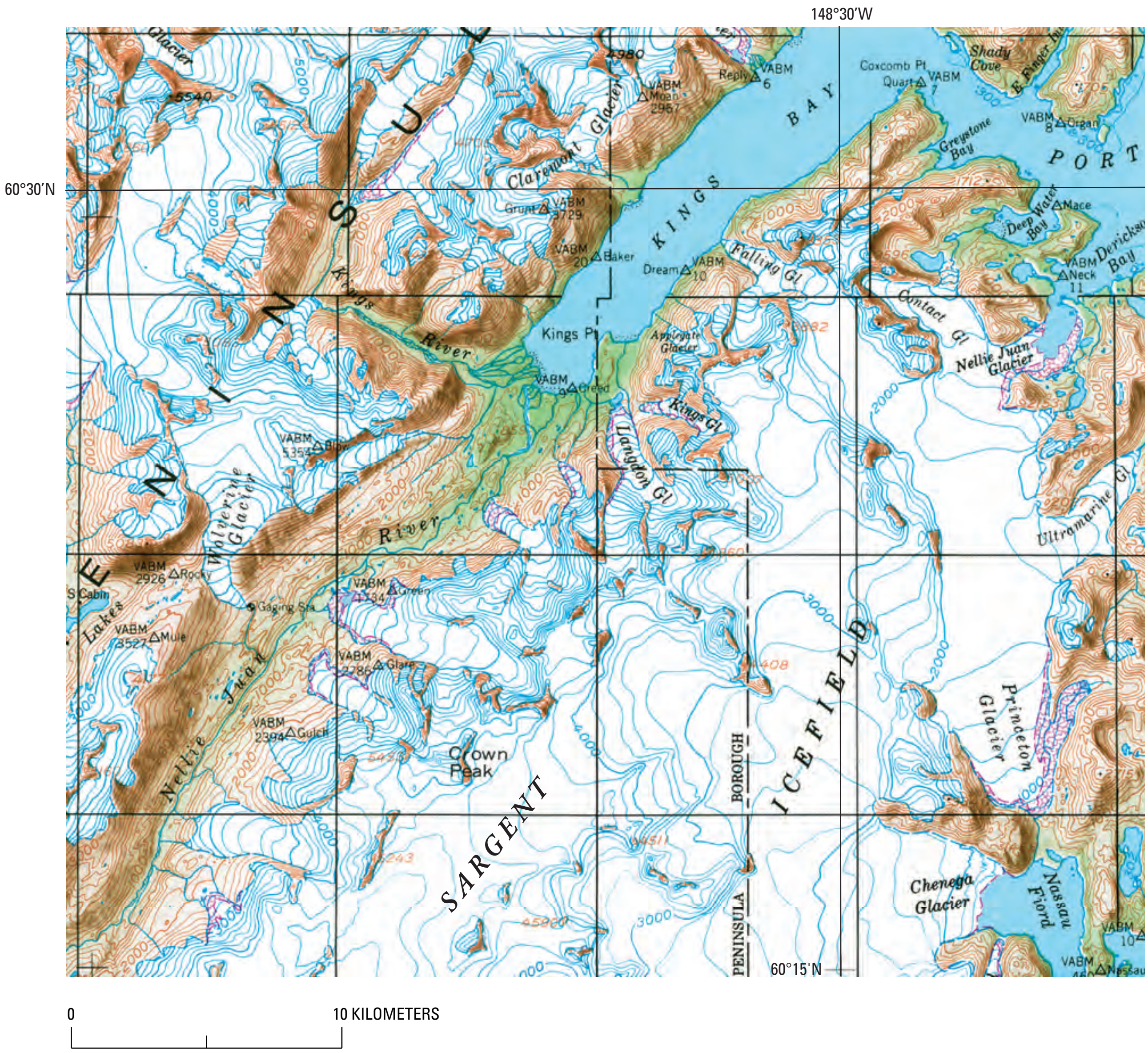


Figure 4.—Section of the USGS (1982) (selective revisions) 1:250,000-scale topographic map of Seward, Alaska (1951), showing the use of a purple-pattern overprint to indicate areas of selected glacier "advance or recession, visible as of the date of photography" (appendix A). The original surveys for the 1951 map (USGS, 1951) were done in 1945 and based on 1942 and 1945 vertical aerial photography. The map shown was revised in 1982 from vertical aerial photographs acquired in 1978. In this area east of Wolverine Glacier, all the outlet glaciers from the northern Sargent Icefield show recession.

advance or recession of its terminus (fig. 4, appendix A). Commercial vendors have released paper compilations (DeLorme Mapping, 1992, 1998, 2001) and CD-ROMs (Scarp Exploration, Inc., 1998–2003) of all of the USGS 1:250,000-scale topographic maps of Alaska. The DeLorme atlases are printed at a scale of 1:300,000; both commercial sources are particularly useful because of accompanying place-name indexes (lacking on USGS maps).

These abundant and diverse data clearly document the fact that the glaciers of Alaska are undergoing changes in length and area. In addition to long-term changes, calving-terminus glaciers may recede a kilometer or more in a single year; surge-type glaciers may advance several kilometers during a surge event. Such changes are of sufficient magnitude to be seen easily at the picture element (pixel) resolution (79 m) of Landsat MSS images. In many instances, Landsat may be the only permanent record of these changes.

In less than a century, major ocean inlets, such as Glacier Bay and Icy Bay, have been formed by glacier recession. The rapidly receding Columbia Glacier (and production of icebergs from its calving terminus, a recognized hazard to maritime shipping) has caused dramatic changes in this tidewater glacier (see separate sections on Columbia and Hubbard Tidewater Glaciers and the 1986 and 2002 Temporary Closures of Russell Fiord by the Hubbard Glacier in this chapter). Major lakes have formed and drained catastrophically (undergone outburst flooding [jökulhlaups]) owing to changes in their impounding ice

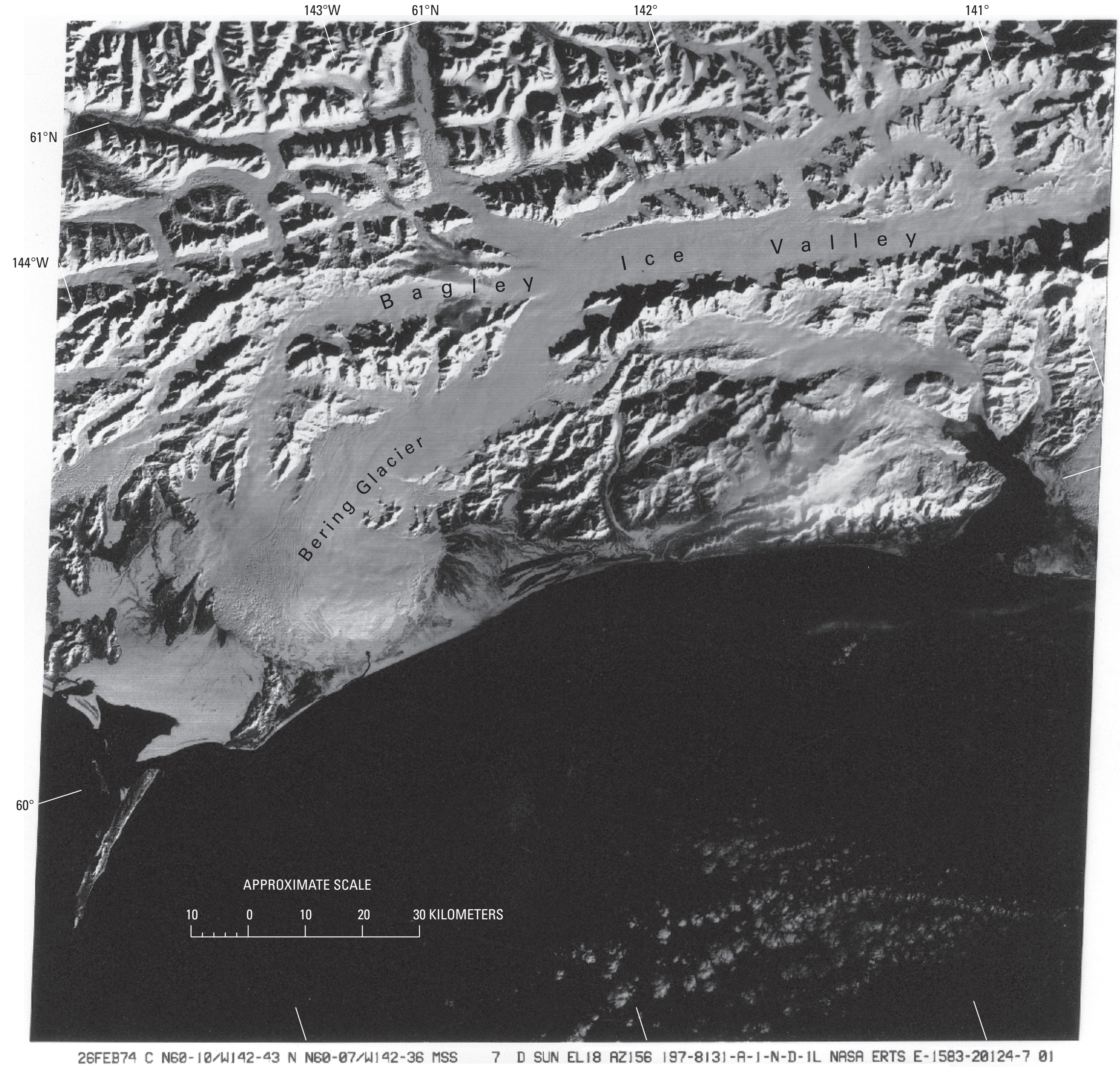


Figure 5.*—Landsat 1 black-and-white multispectral scanner (MSS) image of all but the very easternmost segment of the 200-km-long Bering Glacier and Bagley Ice Valley. The Landsat image (1583–20124, band 7; 26 February 1974; Path 69, Row 18) is from the USGS, EROS Data Center, Sioux Falls, S. Dak.*

dams. Glaciers, such as the Taku Glacier, have gone from being tourist attractions, accessible by oceangoing ships, to becoming impossible to reach other than in shallow-draft kayaks. Additionally, changing climate has affected the area and volume of nearly all of Alaska's glaciers, impacting the storage and release of freshwater and producing a discernible change in global eustatic sea level (Meier, 1984; National Research Council, 1984; Meier and Dyurgerov, 2002; Meier and Wahr, 2002; Arendt and others, 2002).

Today, more than two-thirds of Alaska's glaciers are located within 200 km of the shore of the Pacific Ocean in or on the Coast Mountains, the Alexander Archipelago, the St. Elias Mountains, the Chugach Mountains, the Kenai Mountains, Kodiak Island, the Aleutian Range, and the Aleutian Islands. The remaining glaciers are distributed in several interior mountain groups, including the Wrangell Mountains, the Talkeetna Mountains, the Alaska Range, the Wood River Mountains, the Kigluaik Mountains of the Seward Peninsula, and the Brooks Range (fig. 1). The glaciers of each of these 14 glacierized geographic regions are discussed in separate sections that follow. Each section contains one or more Landsat MSS false-color composite images and an index map (Field, 1975a) selected to provide a geographic reference for detailed information about the glaciers in each region.

Other sections provide a summary of early observations of Alaska's glaciers, pre-International Geophysical Year (IGY) 20th-century investigations of Alaska's glaciers, the photographic record of Alaska's glaciers, the naming of Alaska's glaciers, tidewater and surge-type Alaskan glaciers, and glacier-outburst floods (jökulhlaups). Table 1 presents a list of the optimum Landsat 1, 2, and 3 MSS and Return Beam Vidicon (RBV) imagery of Alaska's glaciers. A map showing the location of Landsat MSS nominal scene centers for images that include Alaska's glaciers is shown in figure 3*A*.

Landsat images, combined with ground and aerial observations and previously published work, provide an excellent source of data and information necessary to define the geographic distribution and areal extent of and the changes occurring in the glaciers of Alaska. The synoptic scale of Landsat (generally 1:250,000 to 1:1,000,000 scale) is required to conveniently show the major glacierized regions. For example, Bering Glacier—including its source, the Bagley Ice Valley (fig. 5)—is nearly 200 km long. About 100 1:40,000-scale aerial photographs or about 50 1:63,360-scale topographic maps or two 1:250,000-scale topographic maps are necessary to portray the glacier in its entirety; it can be seen on one Landsat MSS image. Because the Landsat MSS sensor has a pixel size of 79 m (6,241 m^2), an individual glacier must have an area of more than 20,000 m^2 to be recognized under optimum conditions (for example, minimum snowcover, not in shadow, and so on). One square kilometer in area is a more realistic minimum area for the MSS sensor. On a 1:250,000-scale Landsat image, a glacier 1 km^2 in area would encompass 16 mm^2 (4×4 mm). Glaciers of this size occur in 12 of the 14 glacierized geographic regions of Alaska listed above. One of the two exceptions is the tiny remnant glaciers in the Kigluaik Mountains. Because most of Alaska's glaciers are outlet glaciers from ice fields and ice caps that cover larger areas, these snow-covered source features are generally more easily seen, even at a scale of 1:1,000,000. For selected locations, Landsat Thematic Mapper (TM) data from Landsat 4 and 5 and Landsat Enhanced Thematic Mapper Plus (ETM+) data from Landsat 7 are also available. Landsat TM and ETM+, which have pixel sizes of about 30 m (900 m^2) and 15 m (225 m^2), respectively, can show glaciers and glaciological features too small to be identified on MSS images (fig. 6).

Some of Alaska's glaciers have experienced rapid changes of sufficient magnitude that they can be seen on Landsat images acquired only a few months or years apart. For instance, comparing early 1970s Landsat MSS images of the terminus of Bering Glacier with those obtained in the 1980s clearly shows significant retreat of the terminus following a 1967 surge. Between 1986 and 1987, the position of features on the Malaspina Glacier near the terminus changed by several kilometers. These changes were recorded on Landsat (fig. 7). Smaller changes can also be detected. During 1985 and 1986, changes in the terminus position of the advancing Hubbard and Turner Glaciers were monitored and measured by comparison of features on a sequential, geospatially registered, "temporal-change composite image" (composite of 1985 and 1986 Landsat MSS images) (fig. 8).

Landsat is a useful tool for glacier monitoring. Some surge-type glaciers can be identified by their distorted medial moraines, and the active phase of surge-type glaciers has been documented with Landsat. Features such as snowlines, medial and lateral moraines, ice-dammed lakes, sediment and iceberg plumes, and recent and "Little Ice Age" terminal moraines can be delineated on Landsat imagery.

TABLE 1.— *Optimum Landsat 1, 2, and 3 Multispectral scanner (MSS) and Return Beam Vidicon (RBV) images of glaciers of Alaska*

[USGS-GSP is the U.S. Geological Survey Glacier Studies Project; see figure 3 for explanation of symbols in the Code column]

Path-Row	Nominal scene center (lat., long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
58–21	55°45'N. 129°40'W.	21288–18435	2Aug78	45	●	0	Coast Mountains; Soule, Through, Chickamin, and Gracey Creek Glaciers.
58–21	55°45'N. 129°40'W.	22368–19000	17Jul81	50	●	0	Coast Mountains; Soule, Through, Chickamin, and Gracey Creek Glaciers.
59–20	57°08'N. 130°15'W.	5866–17552	01Sep77	31	●	0	Southwestern corner of image shows LeConte Glacier. Many Canadian glaciers are on this image.
59–21	55°45'N. 131°06'W.	5848–17574	14Aug77	36	●	0	Ketchikan and the southern end of southeastern Alaska; from Leconte Glacier to Through and Soule Glaciers about 100 km northwest of Ketchikan.
59–21	55°45'N. 131°06'W.	22027–19085	10Aug80	45	●	0	Coast Mountains; glaciers NNE of Bradfield Canal, Cone Mountain.
60–20	57°08'N. 131°41'W.	1772–19162	03Sep74	37	●	0	Glaciers of southeastern Alaska east and north of Petersburg; major glaciers are South Sawyer, Dawes, Baird, Patterson, and LeConte.
60–20	57°08'N. 131°41'W.	22028–19141	11Aug80	44	●	5	Coast Mountains; Shakes, LeConte, Patterson, Baird, Dawes and South Sawyer Glaciers.
60–21	55°45'N. 132°32'W.	1790–19160	21Sep74	32	●	0	Minor glaciers 50 km east of Wrangell.
60–21	55°45'N. 132°32'W.	1358–19275	16Jul73	51	●	5	Coast Mountains; glaciers east of Bradfield Canal between Burroughs Bay and Stikine River, Cone Mountain and Mount Cloud.
61–19	58°31'N. 132°13'W.	1791–19205	22Sep74	29	●	0	Glaciers 50 km east of Juneau; Wright and Sawyer Glaciers.
61–19	58°31'N. 132°13'W.	2931–18565	10Aug77	41	●	0	Coast Mountains; southeastern Juneau Icefield; Wright, Norris, Taku, Sawyer and South Sawyer Glaciers.
61–20	57°08'N. 133°07'W.	2931–18571	10Aug77	42	●	0	Southeast from Sawyer Glacier to LeConte Glacier.
61–20	57°08'N. 133°07'W.	2967–18550	15Sep77	31	◑	20	Coast Mountains; Sawyer, South Sawyer, Baird, and Dawes Glaciers.
62–19	58°31'N. 133°39'W.	1738–19284	31Jul74	46	◑	20	Glaciers north and east of Juneau.
62–19	58°31'N. 133°39'W.	21670–19195	19Aug79	40	●	5	Coast Mountains; Juneau Icefield, Taku, Mendenhall, Sawyer, and South Sawyer Glaciers.
62–19	58°31'N. 133°39'W.	20572–19180	16Aug76	41	●	0	Juneau Icefield; archived by the Canada Centre for Remote Sensing, Ottawa.
62–20	57°08'N. 134°33'W.	1738–19291	31Jul74	47	◕	10	Alexander Archipelago; small glaciers on Mount Ada and flanks of Patterson Bay.
62–20	57°08'N. 134°33'W.	22390–19221	08Aug81	44	●	0	Alexander Archipelago; small glaciers on Mount Ada and flanks of Patterson Bay.
63–18	59°54'N. 134°07'W.	1775–19324	06Sep74	34	◕	10	Glaciers near Skagway.
63–19	58°31'N. 135°05'W.	1775–19330	06Sep74	35	◕	10	Brady Glacier, eastern Glacier Bay National Park and Preserve, Juneau Icefield.
63–19	58°31'N. 135°05'W.	1667–19365	21May74	48	●	0	Coast Mountains; Juneau Icefield; Mendenhall, Herbert, Eagle, Meade, and Davidson Glaciers.
63–20	57°08'N. 135°59'W.	1775–19333	06Sep74	36	◕	10	Alexander Archipelago.
63–20	57°08'N. 135°59'W.	2897–19102	07Jul77	49	◕	10	Alexander Archipelago; glaciers on Mount Furuhelm.
64–18	59°54'N. 135°33'W.	30183–19375	04Sep78	34	●	0	Glaciers near Skagway.
64–18	59°54'N. 135°33'W.	30147–19373	30Jul78	45	●	5	Coast and St. Elias Mountains; Meade and Davidson Glaciers.
64–18	59°54'N. 135°33'W.	30525–19364–C	12Aug79	42	●	0	Landsat 3 RBV image of northeastern Glacier Bay National Park and Preserve; archived by USGS-GSP.
64–18	59°54'N. 135°33'W.	30525–19364–D	12Aug79	42	●	0	Landsat 3 RBV image of glaciers near Haines; archived by USGS-GSP.

Table 1.— *Optimum Landsat 1, 2, and 3 Multispectral scanner (MSS) and Return Beam Vidicon (RBV) images of glaciers of Alaska*—Continued

Path-Row	Nominal scene center (lat., long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
64–19	58°31'N. 136°31'W.	1416–19480	12Sep73	33	●	0	Glacier Bay National Park and Preserve; major glaciers in this image are Grand Plateau, Fairweather, La Perouse, Brady, Johns Hopkins, Margerie, Ferris, Grand Pacific, Carrol, Muir, Riggs, McBride, and Casement.
64–19	58°31'N. 136°31'W.	30147–19375	30Jul78	46	●	0	Glacier Bay National Park and Preserve.
64–19	58°31'N. 136°31'W.	1057–19542	18Sep72	31	●	0	
64–19	58°31'N. 136°31'W.	30525–19370–A	12Aug79	43	●	0	Glacier Bay National Park and Preserve; Landsat 3 RBV image; archived by USGS-GSP.
64–19	58°31'N. 136°31'W.	30525–19370–B	12Aug79	43	◕	10	Glacier Bay National Park and Preserve; Landsat 3 RBV image; archived by USGS-GSP.
65–18	59°54'N. 136°59'W.	5854–18301	20Aug77	33	●	0	Glaciers 50 km east of Yakutat.
65–19	58°31'N. 137°57'W.	1417–19534	13Sep73	33	●	0	Southeast from Yakutat Glacier to Brady Glacier.
65–19	58°31'N. 137°57'W.	2952–19124	31Aug77	35	●	5	Glacier Bay National Park and Preserve; Brady Glacier to Alsek Glacier.
65–19	58°31'N. 137°57'W.	30922–19315–B	12Sep80	32	●	5	Landsat 3 RBV image of all the major glaciers of Glacier Bay National Park and Preserve; archived by USGS-GSP.
66–18	59°54'N. 138°25'W.	21314–19297	28Aug78	36	●	0	Southeast from Hubbard Glacier to Grand Plateau Glacier.
66–18	59°54'N. 138°25'W.	30167–19491–D	19Aug78	39	●	0	Landsat 3 RBV image of glaciers east of Yakutat; Alaska glaciers: Chamberlain, Yakutat, Novatak, and Alsek Glaciers, Canada glaciers: Battle, Vern Ritchie, Tweedsmuir, Grand Pacific, and Melbern Glaciers. Archived by USGS-GSP.
67–18	59°54'N. 139°51'W.	2955–19292	03Sep77	33	●	0	Icy Bay east to Yakutat Glacier; major glaciers are Guyot, Yahtse, Tyndall, Agassiz, Seward, Malaspina, Marvine, Turner, Hubbard, Art Lewis, Nunatak, and Yakutat.
67–18	59°54'N. 139°51'W.	21675–19482	24Aug79	38	●	0	Tyndall Glacier east to Nunatak Glacier; major glaciers are Tyndall, Agassiz, Malaspina, Seward, Hubbard, Yakutat, and Novatak.
67–18	59°54'N. 139°51'W.	31194–19494– A, B, C, D	11Jun81	50	◕	0–10	Landsat 3 RBV images; archived by USGS-GSP.
68–17	61°16'N. 140°14'W.	2956–19343	04Sep77	32	●	0	Alaska glaciers: Russell, Hawkins, Barnard, Anderson, lower Chitina, Walsh, and Logan. Canada glaciers: Klutlan, Brabazon, Steel, Donjek and Kluane.
68–17	61°16'N. 140°14'W.	21676–19534	25Aug79	36	●	0	St .Elias and Chugach Mountains; Chitina, Logan, Barnard, Hawkins, and Klutlan Glaciers.
68–17	61°16'N. 140°14'W.	30853–19510– C, D	05Jul80	48	●	0	Landsat 3 RBV images of Russell, Klutlan, Hawkins, Barnard, Anderson, Walsh, Chitina, and Logan Glaciers; archived by USGS-GSP.
68–18	59°54'N. 141°17'W.	2956–19350	04Sep77	33	●	0	A major part of Bering Glacier, the Bagley Ice Valley, Tana, Jefferies, Yahtse, Guyat, Tyndall, Columbus, Seward, Agassiz, and Malaspina Glaciers.
68–18	59°54'N. 141°17'W.	1708–20035	01Jul74	50	●	0	St. Elias and Chugach Mountains; Malaspina, eastern Bering, Tana, and Logan Glaciers.
69–16	62°38'N. 140°33'W.	21677–19590	26Aug79	35	●	0	Nutzotin Mountains (southeastern part of Alaska Range); Carl and Nelson Creeks Glaciers, and glaciers on Mount Allen and northeastern part of Wrangell Mountains.
69–17	61°16'N. 141°40'W.	21677–19593	26Aug79	36	◕	10	Glaciers to the north, east, and south of McCarthy; major glaciers are Kennicott, Root, Regal, Rohn, Nizina, Chisana, Russell, Klutlan, Anderson, Walsh, Logan, Jefferies, and Barnard.
69–17	61°16'N. 141°40'W.	1709–20090	02Jul74	49	◕	10	Wrangell, St. Elias, and Nutzotin Mountains; Carl and Nelson Creeks Glaciers, Nabesna, Chisana, Kennicott, Root, Barnard, Hawkins, Chitina, and Logan Glaciers.

TABLE 1.— *Optimum Landsat 1, 2, and 3 Multispectral scanner (MSS) and Return Beam Vidicon (RBV) images of glaciers of Alaska*—Continued

Path-Row	Nominal scene center (lat., long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
69–17	61°16'N. 141°40'W.	30908–19542–B	29Aug80	35	◕	15	Landsat 3 RBV image of Klutlan Glacier; archived by USGS-GSP.
69–17	61°16'N. 141°40'W.	30908–19542–C	29Aug80	35	◕	10	Landsat 3 RBV images of Breman and Tana Glaciers; archived by USGS-GSP.
69–17	61°16'N. 141°40'W.	30908–19542–D	29Aug80	35	●	0	Landsat 3 RBV image of Hawkins, Barnard, Anderson, Walsh, Logan, Chitina Glaciers; archived by USGS-GSP.
69–18	59°54'N. 142°43'W.	2975–19394	23Sep77	26	●	0	Bagley Ice Valley, and Bering, Guyot, Yahtse, Turner, Jefferies, Tana, Bremmer, Fan, Martin River and Steller Glaciers.
70–16	62°38'N. 141°59'W.	2958–19453	06Sep77	30	●	0	Glaciers 100 km southwest and south of Northway.
70–16	62°38'N. 141°59'W.	21624–20035	04Jul79	47	◕	10	Wrangell Mountains; Nabesna, Chisana, and Copper Glaciers.
70–17	61°16'N. 143°06'W.	1422–20212	18Sep73	29	●	0	Glaciers of Mount Wrangell; Cooper, Nebesna, Chisana, Russell, Rohn, Regal, Root, Kennicott, Kaskulana, Long, Tana, Bremmer, Fan, and Wernicke Glaciers.
70–17	61°16'N. 143°06'W.	1692–20152	15Jun74	49	◕	10	St. Elias, Wrangell, and Chugach Mountains; Kennicott, Root, Copper, Nabesna, and Chisana Glaciers.
70–17	61°16'N. 143°06'W.	30309–20001–A	30Aug80	34	●	0	Landsat 3 RBV image of Mount Wrangell; archived by USGS-GSP.
70–17	61°16'N. 143°06'W.	30309–20001–B	30Aug80	34	●	0	Landsat 3 RBV image of Kennicott, Root, Rega, Rohn, Russell, Barnard, and Hawkins Glaciers; archived by USGS-GSP.
70–17	61°16'N. 143°06'W.	30309–20001–C	30Aug80	34	◑	20	Landsat 3 RBV image of Wernicke, Miles, Allen, and Schwan Glaciers; archived by USGS-GSP.
70–17	61°16'N. 143°06'W.	30309–20001–D	30Aug80	34	●	0	Landsat 3 RBV image of Bremmer and Tana Glaciers and Bagley Ice Valley; archived by USGS-GSP.
70–18	59°54'N. 144°09'W.	2976–19452	24Sep77	25	●	5	Sherman, Sheridan, Scott, Woodworth, Schwan, Allen, Childs, Miles, Wernicke, Fan, Bering, Steller, and Martin River Glaciers.
71–15	63°59'N. 142°11'W.	22399–20114	17Aug81	37	◑	50	Alaska Range, Mount Kimball area.
71–16	62°38'N. 143°25'W.	2941–19521	20Aug77	36	●	0	Glaciers of the eastern Alaska Range and northern Wrangell Mountains.
71–16	62°38'N. 143°25'W.	30532–20155	19Aug79	38	◑	35	Metasta and northeastern Wrangell Mountains; Chisana, Nabesna, and Copper Glaciers.
71–16	62°38'N. 143°25'W.	31270–20135–A	26Aug81	35	●	0	Landsat 3 RBV image of glaciers of the eastern Alaska Range; archived by USGS-GSP.
71–16	62°38'N. 143°25'W.	31270–20135–D	26Aug81	35	●	0	Landsat 3 RBV image of glaciers on the northern side of Mount Wrangell, Nabesna Glacier; archived by USGS-GSP.
71–17	61°16'N. 144°32'W.	2941–19524	20Aug77	37	●	0	Mount Wrangell and the Copper and Chitina Rivers. Major glaciers are Long, Kaskulana, Kennecott, Root, Fan, Wernicke, Miles, Allen, Schwan, Woodworth, Valdez, and Tonsina.
71–17	61°16'N. 144°32'W.	31270–20141–B	26Aug81	36	●	0	Landsat 3 RBV image of glaciers on the southern side of Mount Wrangell; archived by USGS-GSP.
71–17	61°16'N. 144°32'W.	31270–20141–C	26Aug81	36	●	0	Landsat 3 RBV image of glaciers to the north, east, and south of Valdez; archived by USGS-GSP.
71–18	59°54'N. 145°35'W.	2941–19530	20Aug77	37	●	0	Glaciers east and west of the Copper River delta.
71–18	59°54'N. 145°35'W.	1387–20281	14Aug73	42	●	0	Chugach Mountains; Scott and Sheridan Glaciers, Steller Lobe; Copper River and Bering Glacier sediment plumes.
72–15	63°59'N. 143°37'W.	2942–19573	21Aug77	34	◑	15	Glaciers on the northern side of the eastern Alaska Range.
72–15	63°59'N. 143°37'W.	2582–20131	26Aug76	33	●	5	Glaciers on the northern side of the eastern Alaska Range.

Table 1.— *Optimum Landsat 1, 2, and 3 Multispectral scanner (MSS) and Return Beam Vidicon (RBV) images of glaciers of Alaska*—Continued

Path-Row	Nominal scene center (lat., long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
72–15	63°59'N. 143°37'W.	2202–22020	5Aug80	40	◕	10	Northeastern Alaska Range, Mount Gakona area.
72–16	62°38'N. 144°51'W.	2942–19575	21Aug77	35	●	0	Southeastern Alaska Range and western portion of Mount Wrangell; Canwell, Castner, Gerstle, Johnson, Robertson, and Gakona Glaciers.
72–16	62°38'N. 144°51'W.	2510–20154	15Jun76	48	●	5	Southeastern Alaska Range, western Wrangell Mountains; Long, Kluvesna, Sanford, and Copper Glaciers.
72–16	62°38'N. 144°51'W.	30551–20212–A	07Sep79	31	●	0	Landsat 3 RBV image of eastern Alaska Range; archived by USGS-GSP.
72–16	62°38'N. 144°51'W.	30173–20225–D	25Aug78	35	●	0	Landsat 3 RBV image of Mounts Drum, Stanford, and Wrangell; archived by USGS-GSP.
72–17	61°16'N. 145°59'W.	30109–20233	30Sep78	24	◕	10	Chugach Mountains; glaciers from College Fiord to the Copper River; Columbia, Yale, Harvard, Nelchina, Tazlina, Valdez, Tonsina, Wortman, Woodworth, Schwan, Allen, Childs, Sheridan, and Scott Glaciers.
72–17	61°16'N. 145°59'W.	30551–20215	07Aug79	32	●	5	Chugach Mountains; glaciers from College Fiord to the Copper River; Columbia, Yale, Harvard, Nelchina, Tazlina, Valdez, Tonsina, Wortman, Woodworth, Schwan, Allen, Childs, Sheridan, and Scott Glaciers.
72–17	61°16'N. 145°59'W.	30551–20215–A	07Sep79	32	●	0	Landsat 3 RBV image of Nelchina and Tuzlina Glaciers; archived by USGS-GSP.
72–17	61°16'N. 145°59'W.	30551–20215–D	07Sep79	32	◕	10	Landsat 3 RBV image of Valdez, Tonsina, Wortmanns, Woodworth, Schwan, Sheridan, and Scott Glaciers; archived by USGS-GSP.
72–18	59°54'N. 147°02'W.	1406–20334	02Sep73	35	●	5	Eastern Sargent Icefield.
73–15	63°59'N. 145°03'W.	2925–20041	04Aug77	39	◕	10	Glaciers of the central and eastern Alaska Range; Hayes, Trident, Black Rapids, Susitna, Canwell, Johnson, and Gakona Glaciers.
73–15	63°59'N. 145°03'W.	2583–20190	27Aug76	33	●	0	Northeastern Alaska Range; Hayes, Trident, and Gerstle Glaciers.
73–15	63°59'N. 145°03'W.	31200–20230–C	17Jun81	47	●	0	Landsat 3 RBV image of central Alaska Range; Susitna, Hayes, Trident and Black Rapids Glaciers; archived by USGS-GSP.
73–15	63°59'N. 145°03'W.	31200–20230–D	17Jun81	47	●	0	Landsat 3 RBV image of eastern Alaska Range; Canwell, Fels, Castner, Gerstle, Johnson, Robertson, Chistochina, and Gakona Glaciers; archived by USGS-GSP.
73–16	62°38'N. 146°17'W.	2169–20275	10Jul75	47	◕	10	Central and eastern Alaska Range; West Fork, Hayes, Susitna, Black Rapids, and Gakona Glaciers.
73–16	62°38'N. 146°17'W.	2943–20033	22Aug77	35	◑	50	Talkeetna Mountains and Alaska Range; Susitna, West Fork, Maclaren, and Eureka Glaciers.
73–17	61°16'N. 147°25'W.	31074–20290	26Aug78	36	●	5	Chugach Mountains and Prince William Sound; Spencer, Twentymile, Harriman, Surprise, Lake George, Colony, Knik, Marcus Baker, Matanuska, Nelchina, Tazlina, Valdez, Shoup, Columbia, Meares, Yale, and Harvard Glaciers.
73–17	61°16'N. 147°25'W.	31272–20254–B	28Aug81	36	●	0	Landsat 3 RBV image of Nelchina, Tazlina, Stephens, Klutina, Tonsima, Valdez, Shoup, and Columbia Glaciers; archived by USGS-GSP.
73–17	61°16'N. 147°25'W.	30912–20171–C	02Sep80	33	●	0	Landsat 3 RBV image of Twentymile, Lake George, Colony, Knik, Marcus Baker, Harvard, Yak, Barry, Surprise, and Harriman Glaciers; archived by USGS-GSP.
73–17	61°16'N. 147°25'W.	30552–20273–D	08Sep79	32	●	5	Landsat 3 RBV image of Meares, Columbia, Shoup, and Valdez Glaciers; archived by USGS-GSP.
73–18	59°54'N. 148°28'W.	1389–20394	16Aug73	41	◕	10	Harding and Sargent Icefields, Skelak, Bear, Ellsworth, Excelsior, Chenega, Princeton, and Spencer Glaciers.

Table 1.— *Optimum Landsat 1, 2, and 3 Multispectral scanner (MSS) and Return Beam Vidicon (RBV) images of glaciers of Alaska*—Continued

Path-Row	Nominal scene center (lat., long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
73–18	59°54'N. 148°28'W.	2907–20062	17Jul77	46	●	0	Chugach and Kenai Mountains; Exit Glacier to McCarty, Holgate, Aialik, Northwest, and Bear Glaciers.
73–18	59°54'N. 148°28'W.	30912–20174–A	02Sep80	34	●	0	Landsat 3 RBV image of glaciers north and south of Kings Bay, Sargent Icefield; archived by USGS-GSP.
73–18	59°54'N. 148°28'W.	30912–20174–C	02Sep80	34	●	0	Landsat 3 RBV image of eastern Harding Icefield; archived by USGS-GSP.
74–15	63°59'N. 146°29'W.	2944–20085	23Aug77	34	●	0	Central Alaska Range; Yanert, Gillam, Hayes, Trident, Black Rapids, Maclaren, Susitna, and West Fork Glaciers.
74–15	63°59'N. 146°29'W.	21286–20130	31Jul78	41	●	5	Alaska Range; Black Rapids, Susitna, West Fork, Gillam and Yanert Glaciers.
74–15	63°59'N. 146°29'W.	31273–20304–D	29Aug81	33	●	0	Landsat 3 RBV image of central Alaska Range; archived by USGS-GSP.
74–16	62°38'N. 143°43'W.	30175–20342	27Aug78	35	◕	10	Glaciers of the Talkeetna Mountains.
74–17	61°16'N. 148°51'W.	30175–20345	27Aug78	36	●	0	Glaciers of the northern Kenai Peninsula and western Chugach Mountains; Spencer, Lake George, Colony, Knik, Marcus Baker, Matanuska, Nelchina, Tazlina, Yale, and Harvard Glaciers.
74–17	61°16'N. 148°51'W.	30553–20331	09Sep79	32	●	0	Chugach Mountains; Knik Arm, Turnagain Arm and College Fiord; Knik, Lake George, Portage, Spencer, and Meares Glaciers.
74–17	61°16'N. 148°51'W.	30553–20331–B	09Sep79	31	●	10	Landsat 3 RBV image of glaciers of the northwest-ern Chugach Mountains; archived by USGS-GSP.
74–17	61°16'N. 148°51'W.	30553–20331–D	09Sep79	31	●	0	Landsat 3 RBV image of glaciers north and south of Whittier; archived by USGS-GSP.
74–18	59°54'N. 149°54'W.	1390–20452	17Aug73	41	●	0	Glaciers of the southern Kenai Peninsula and the Harding and Sargent Icefields; Yalik, Grewingk, Portlack, Dixon, Dinglestadt, Chernof, Tustu-mena, Skilak, Bear, Ellsworth, and Excelsior Glaciers.
74–18	59°54'N. 149°54'W.	30553–20334–B	09Sep79	33	●	0	Landsat 3 RBV image of glaciers of the Sargent Icefield; archived by USGS-GSP.
74–20	57°08'N. 151°46'W.	2908–20125	18Jul77	47	●	0	Northeastern end of Kodiak Island with Mount Glotoff and Koniag Peak and Koniag Glacier.
75–11	69°17'N. 141°38'W.	2927–20135	06Aug77	35	●	0	Eastern Brooks Range, Romanzof Mountains.
75–12	67°59'N. 143°28'W.	30158–20387	10Aug78		◕	15	Brooks Range.
75–15	63°59'N. 147°55'W.	2945–20143	24Aug77	34	●	0	Alaska Range; Susitna, West Fork, Yanert, and Gillam Glaciers.
75–16	62°38'N. 149°09'W.	5864–19254	30Aug77	29	●	0	Eastern Denali National Park and Preserve, Talkeetna Mountains, Kahiltna, Tokositna, Ruth, Eldridge, and Muldrow Glaciers.
75–16	62°38'N. 149°09'W.	2531–20322	06Jul76	47	●	5	Alaska Range and Talkeetna Mountains; Ruth, Tokositna, Kahiltna, Muldrow and West Fork Glaciers.
75–16	62°38'N. 149°09'W.	30554–20383–A	10Sep79	30	◕	20	Landsat 3 RBV image of eastern Denali National Park and Preserve; archived by USGS-GSP.
75–17	61°16'N. 150°17'W.	1049–20505	10Sep72	31	◕	20	Parts of glaciers east and west of Anchorage.
75–17	61°16'N. 150°17'W.	22043–20390	26Aug80	36	●	5	Chugach Mountains; Knik and Turnagain Arms; Knik, Lake George, Capps, Triumvirate and Blockade Glaciers.
75–18	59°54'N. 151°20'W.	21323–20215	06Sep78	33	◕	10	Glaciers of southern Kenai Peninsula; Yulik, Grewingk, Portlock, Dixon, Dinglestadt, Chernof, Fustumena, Skilak, and Bear Glaciers.
75–18	59°54'N. 151°20'W.	22043–20393	26Aug80	37	●	0	Kenai Mountains and Aleutian Range; Harding Icefield, Tustumena, Dinglestadt, McCarty, Double, Lateral and Red Glaciers.

Table 1.— *Optimum Landsat 1, 2, and 3 Multispectral scanner (MSS) and Return Beam Vidicon (RBV) images of glaciers of Alaska*—Continued

Path-Row	Nominal scene center (lat., long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
75–19	58°31'N. 152°18'W.	2891–20190	01Jul77	49	◕	10	Kodiak Island and Aleutian Range; Spotted and Fourpeaked Glaciers.
75–20	57°08'N. 155°12'W.	2909–20183	19Jul77	47	◕	10	Kodiak Island; Koniag Glacier.
76–11	69°17'N. 143°04'W.	30177–20435	29Aug78	29	●	0	Glaciers of the Romanzof Mountains of the Brooks Range; McCall Glacier.
76–11	69°17'N. 143°04'W.	22386–20384	04Aug81	36	●	0	Brooks Range, Romanzof Mountains.
76–12	67°59'N. 144°54'W.	22386–20391	04Aug81	37	●	5	Brooks Range, Phillip Smith Mountains.
76–15	63°59'N. 149°21'W.	5865–19305	31Aug77	28	●	80	Central part of Alaska Range.
76–15	63°59'N. 149°21'W.	30537–20441	24Aug79	35	●	0	Alaska Range; small glaciers on Mount Pendleton that drain to form the Toklat River.
76–16	62E38'N.	30537–	24Aug79		●	0	Alaska Range.
76–16	62°38'N. 150°35'W.	30555–20442	11Sep79	30	●	0	Alaska Range; Eldridge, Ruth, Tokositna, Kahiltna, Yentna, and Dall Glaciers.
76–16	62°38'N. 150°35'W.	30555–20441–A	11Sep79	30	●	0	Landsat 3 RBV image of Denali National Park and Preserve; Heron, Foraker, Straightaway, Peters, and Muldrow Glaciers; archived by USGS-GSP.
76–16	62°38'N. 150°35'W.	30555–20441–B	11Sep79	30	●	0	Landsat 3 RBV image of Denali National Park and Preserve; Eldridge Glacier; archived by USGS-GSP
76–16	62°38'N. 150°35'W.	30555–20441–C	11Sep79	30	●	0	Landst 3 RBV image of Denali National Park and Preserve; Chedotlothna, Surprise, Dall, Yentna, Lacuna, Kahiltna, and Tokositna Glaciers; archived by USGS-GSP.
76–17	61°16'N. 151°43'W.	21288–20253	02Aug78	42	●	0	Tordrilla and Chigmit Mountains; Double, Blockade, Capps, Triumvirate, Trimble, Hayes, North Twin, and Barrier Glaciers.
76–17	61°16'N. 151°43'W.	2586–20365	30Aug76	34	◕	20	Alaska Range; Hayes, Trimble, Triumvirate, Capps, Shamrock, Blockade, and Tanaina Glaciers.
76–17	61°16'N. 151°43'W.	30555–20444–A	11Sep79	31	●	0	Landsat 3 RBV image of Triumvirate, Trimble, and Hayes Glaciers; archived by USGS-GSP.
76–17	61°16'N. 151°43'W.	30915–20342–C	05Sep80	32	◕	10	Landsat 3 RBV image of Double, Blockade, and Shamrock Glaciers; archived by USGS-GSP.
76–18	59°54'N. 152°46'W.	21288–20255	02Aug78	43	●	0	Illiamna and Redoubt Volcanoes; Red, Lateral, and Tuxedni Glaciers.
76–18	59°54'N. 152°46'W.	1734–20485	27Jul74	46	◕	10	Alaska and Aleutian Ranges; Double and Tuxedni Glaciers.
76–18	59°54'N. 152°46'W.	30915–20345–A	05Sep80	33	◕	10	Landsat 3 RBV image of Illiamna and Redoubt Volcanoes; archived by USGS-GSP.
76–19	58°31'N. 153°44'W.	1428–20563	24Sep73	29	●	0	Katmai National Park and Preserve; Serpent Tongue, Hook, Hallo, and Spotted Glaciers.
76–19	58°31'N. 153°44'W.	1734–20491	27Jul74	47	●	5	Katmai National Park and Preserve; Fourpeaked, Spotted, Hallo, Hook, and Serpent Tongue Glaciers.
76–20	57°08'N. 154°38'W.	1734–20494	27Jul74	48	●	0	Katmai National Park and Preserve.
77–11	69°17'N. 144°30'W.	5848–19364	14Aug77		●	0	Brooks Range, Romanzof Mountains.
77–11	69°17'N. 144°30'W.	22387–20443	05Aug81	36	●	0	Brooks Range, Romanzof Mountains.
77–11	69°17'N. 144°30'W.	30502–20481–B	20Jul79	40	◕	10	Landsat 3 RBV image of Romanzof Mountains, Brooks Range, McCall Glacier; archived by USGS-GSP.
77–12	67°59'N. 146°20'W.	22387–2044X	05Aug81	37	●	0	Brooks Range, Phillip Smith Mountains.
77–12	67°59'N. 146°20'W.	2605–20400	18Sep76	22	●	5	Brooks Range, Phillip Smith Mountains.

Table 1.— *Optimum Landsat 1, 2, and 3 Multispectral scanner (MSS) and Return Beam Vidicon (RBV) images of glaciers of Alaska*—Continued

Path-Row	Nominal scene center (lat., long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
77–15	63°59'N. 150°47'W.	21289–20303	03Aug78	40	◕	10	Denali National Park and Preserve; Muldrow Glacier.
77–15	63°59'N. 150°47'W.	22405–20460	23Aug81	35	◕	60	Denali National Park and Preserve; Muldrow Glacier.
77–16	62°38'N. 152°01'W.	5865–19312	31Aug77	29	◕	10	Denali National Park and Preserve; Dall, Yentna, Lacuna, Kahiltna, Tokositna, Ruth, Muldrow, and Peters Glaciers.
77–16	62°38'N. 152°01'W.	21487–20392	17Feb79	12	●	0	Denali National Park and Preserve; Ruth, Tokositna, and Kahiltna Glaciers.
77–16	62°38'N. 152°01'W.	30556–20500–B	12Sep79	29	●	5	Denali National Park and Preserve; Ruth, Eldridge, and Muldrow Glaciers.
77–17	61°16'N. 153°09'W.	1033–21022	25Aug75	37	◕	10	Double, Blockade, Capps, Triumvirate, Trimble, and Hayes Glaciers.
77–17	61°16'N. 153°09'W.	21613–20441	23Jun79	49	●	5	Alaska and Aleutian Ranges; Hayes, Trimble, Triumvirate, Capps, Shamrock, Blockade, and Tanaina Glaciers.
77–17	61°16'N. 153°09'W.	30880–20413–B	01Aug80	43	●	0	Landsat 3 RBV image of Capps, Triumvirate, Trimble, and Hayes Glaciers; archived by USGS-GSP.
77–17	61°16'N. 153°09'W.	30880–20413–D	01Aug80	43	◕	10	Landsat 3 RBV image of Double, Blockade, and Shamrock Glaciers; archived by USGS-GSP.
77–18	59°54'N. 154°12'W.	21289–20314	03Aug78	43	◑	20	Laterol and Tuxedni Glaciers.
77–18	59°54'N. 154°12'W.	21613–20443	23Jun79	50	●	5	Aleutian Range; Tuxedni Glacier.
77–19	58°31'N. 155°10'W.	2983–20253	01Oct77	24	◕	10	Katmai National Park and Preserve; Hallo, Hook, and Serpent Tongue Glaciers.
77–19	58°31'N. 155°10'W.	2533–20450	8Jul76	49	◕	10	Katmai National Park and Preserve; Hallo, Hook, and Serpent Tongue Glaciers.
77–20	57°08'N. 156°04'W.	30448–20525	27May79	50	●	0	Aleutian Range; Alaska Peninsula.
78–11	69°17'N. 145°56'W.	5848–19364	14Aug77	31	●	0	Brooks Range, Romanzof Mountains; McCall Glacier.
78–11	69°17'N. 145°56'W.	2570–20462	14Aug76	33	◕	10	Brooks Range, Romanzof Mountains; McCall Glacier.
78–11	69°17'N. 145°56'W.	30485–20540–B	03Jul79	43	◕	10	Landsat 3 RBV image of Romanzof Mountains; McCall Glacier; archived by USGS-GSP.
78–12	67°59'N. 147°46'W.	5848–19371	14Aug77	31	●	0	Brooks Range, Phillip Smith Mountains.
78–12	67°59'N. 147°46'W.	22028–20541	11Aug80	36	●	5	Brooks Range, Phillip Smith Mountains.
78–15	63°59'N. 152°13'W.	1882–20574	03Sep74	32	●	5	Denali National Park and Preserve; Heron, Foraker, and Straightaway Glaciers.
78–16	62°38'N. 153°27'W.	1772–20580	03Sep74	33	●	0	Western Denali National Park and Preserve; Kichatna Mountains.
78–16	62°38'N. 153°27'W.	30557–20554–B	13Sep79	29	◕	10	Landsat 3 RBV image of western Denali National Park and Preserve; archived by USGS-GSP.
78–17	61°16'N. 154°35'W.	1772–20583	03Sep74	34	●	0	Glacier northeast of Lake Clark.
78–19	58°31'N. 156°36'W.	1772–20592	03Sep74	36	◑	30	Katmai National Park and Preserve; McNeal River glaciers.
78–19	58°31'N. 156°36'W.	21488–20462	18Feb79	16	●	0	Katmai National Park and Preserve; McNeal River glaciers.
78–20	57°08'N. 157°30'W.	2534–20511	09Jul76	50	●	0	Alaska Peninsula, Aniakchak Crater, Mount Chiginagak.
78–21	55°45'N. 158°21'W.	2192–20581	02Aug75	47	◕	10	Alaska Peninsula, Mount Veniaminof.
79–11	69°17'N. 147°23'W.	1773–21014	4Sep74	27	●	0	Brooks Range.
79–12	67°59'N. 149°12'W.	1773–21020	4Sep74	28	●	0	Brooks Range.

Table 1.— *Optimum Landsat 1, 2, and 3 Multispectral scanner (MSS) and Return Beam Vidicon (RBV) images of glaciers of Alaska*—Continued

Path-Row	Nominal scene center (lat., long)	Landsat identification number	Date	Solar elevation angle (in degrees)	Code	Cloud cover (in percent)	Remarks
79–20	57°08'N. 158°56'W.	1449–21133	15Oct73	22	◑	20	Alaska Peninsula, Aniakchak Crater.
79–21	55°45'N. 159°47'W.	2427–21091	24Mar76	31	◕	10	Alaska Peninsula, Mount Veniaminof, winter snow obscures the glaciers.
79–21	55°45'N. 159°47'W.	22191–21025	21Jan81	11	●	5	Alaska Peninsula, Mount Veniaminof.
80–11	69°17'N. 148°49'W.	1774–21072	5Sep74	26	●	0	Brooks Range.
80–12	67°59'N. 150°38'W.	1774–21074	5Sep74	28	●	0	Brooks Range.
80–18	59°54'N. 158°30'W.	2950–20441	29Aug77	35	●	0	Wood River Mountains.
80–18	59°54'N. 158°30'W.	30145–21091	28Jul78	45	●	5	Wood River Mountains.
80–21	55°45'N. 161°13'W.	21688–21044	06Sep79	37	●	0	Alaska Peninsula, Povlof Volcano.
81–12	67°59'N. 151°37'W.	1775–21133	6Sep74	27	●	0	Brooks Range.
81–17	61°16'N. 158°26'W.	21347–20570	30Sep78	23	●	0	Wood River Mountains.
81–17	61°16'N. 158°26'W.	30146–21143	29Jul78	—	—	—	Wood River Mountains.
81–18	59°54'N. 159°29'W.	2591–21055	04Sep76	33	◕	10	Wood River Mountains.
81–18	59°54'N. 159°29'W.	2285–21130	03Nov75	13	●	0	Wood River Mountains.
81–21	55°45'N. 162°13'W.	2825–20574	26Apr77	42	●	0	Alaska Peninsula, Povlof Volcano.
81–22	54°22'N. 163°01'W.	2591–21073	04Sep76	37	◑	50	Unimak Island, Shishaldin Volcano.
81–22	54°22'N. 163°01'W.	2825–20581	26Apr77	43	●	5	Unimak Island, Shishaldin Volcano.
82–22	67°59'N. 153°29'W.	22410–21133	20Aug81	30	●	0	Brooks Range, Endicott Mountains.
82–22	54°22'N. 164°53'W.	1056–21331	17Sep72	35	◕	10	Unimak Island, Pogromni and Shishaldin Volcanoes.
83–12	67°59'N. 154°55'W.	2557–21155	01Aug76	38	●	0	Brooks Range, Endicott Mountains.
83–12	67°59'N. 154°55'W.	22015–21224	29Jul80	39	◑	75	Brooks Range, Endicott Mountains.
83–22	54°22'N. 166°19'W.	2413–21240	10Mar76	27	●	0	Northern part of Unalaska Island; Makushin Volcano, winter snow obscures glaciers.
83–23	52°58'N. 167°04'W.	2413–21243	10Mar76	28	●	0	Southern part of Unalaska Island and Umnak Island, Umnak Volcano, winter snow obscures glaciers.
84–12	67°59'N. 156°22'W.	22412–21245	30Aug81	29	●	0	Brooks Range, Phillip Smith Mountains.
84–23	52°58'N. 168°30'W.	2954–21090	02Sep77	38	◑	30	Southern part of Unalaska Island and Umnak Island; glaciers on Okmok Volcano and Mounts Recheshnoi and Vsevidof.
85–23	52°58'N. 169°56'W.	2307–21374	25Nov75	13	●	0	Southwestern part of Umnak Island with glaciers on Mounts Recheshnoi and Vsevidof.
87–24	51°34'N. 173°21'W.	2975–21252	23Sep77	32	●	5	Atka Island; glacier on Kovin Volcano.
88–14	65°20'N. 165°13'W.	1710–21565	03Jul74	46	●	0	Seward Peninsula.
88–14	65°20'N. 165°13'W.	2886–21315	26Jun77	45	●	0	Seward Peninsula.
89–12	67°59'N. 163°32'W.	22417–21533	04Sep81	28	●	0	Brooks Range.
89–12	67°59'N. 163°32'W.	1387–22090	14Aug73	—	—	—	Brooks Range.

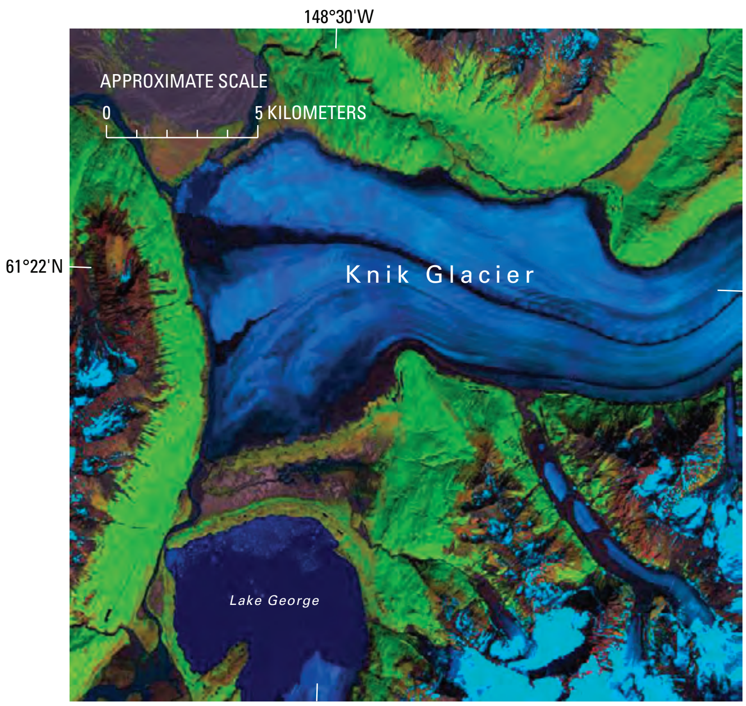


Figure 6.—Landsat 7 Enhanced Thematic Mapper Plus (ETM+) false-color composite image of the terminus region of Knik Glacier and adjacent Lake George, east of Anchorage in the Chugach Mountains. With this band combination, snow appears light blue, glaciers appear darker blue, and healthy vegetation is bright green. The Landsat image (L7068017009921250; bands 5, 4, 2) is from the USGS, EROS Data Center, Sioux Falls, S. Dak.

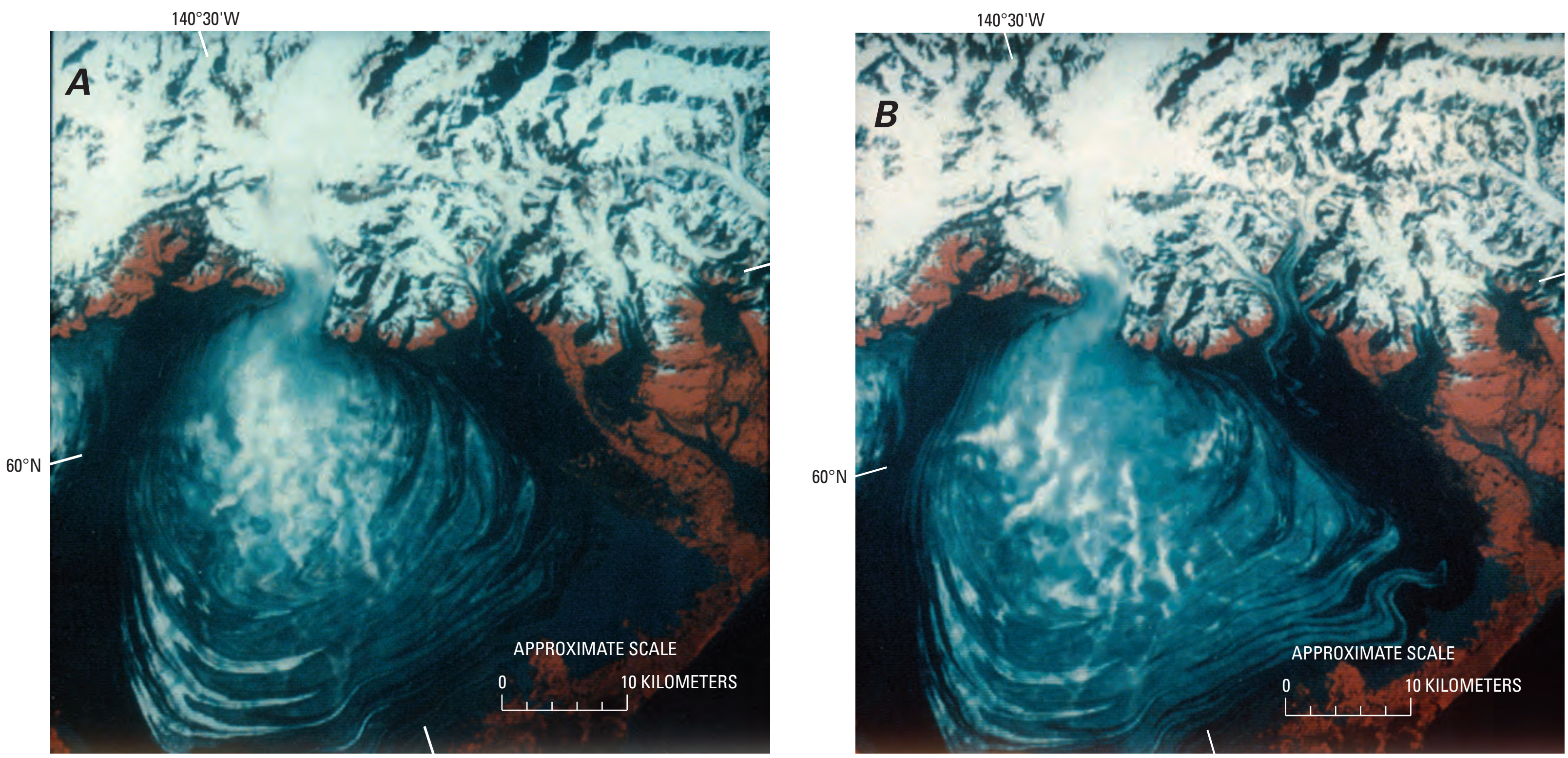
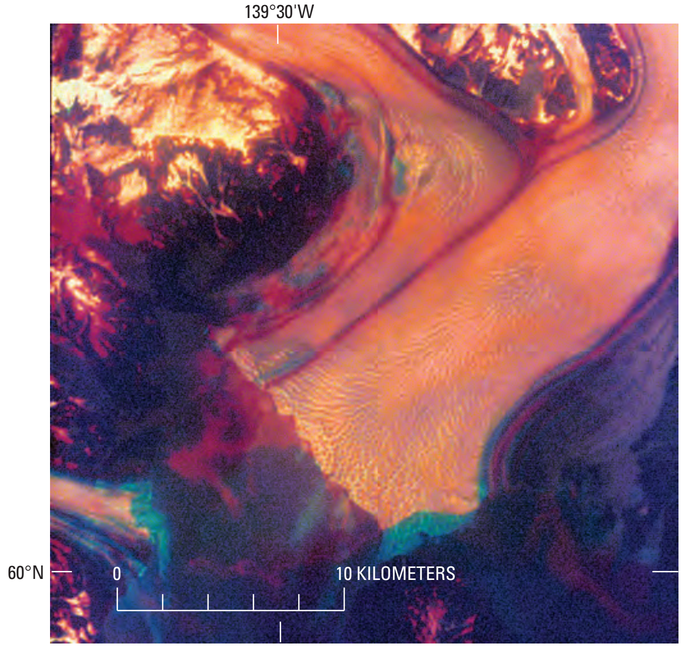


Figure 7.—Pair of Landsat 5 MSS subscene false-color composite images showing changes in the piedmont lobe of Malaspina Glacier resulting from a 1986 surge of the eastern side of the glacier. The images were acquired on 11 September 1986 (A) and 29 August 1987 (B). Between the dates of the two images, folded loop moraines on the eastern side of the glacier were displaced as much as 5 km. The Landsat images (50924–19513; 11 September 1986; Path 62, Row 18; and 51276–19572; 29 August 1987; Path 62, Row 18) are from the USGS, EROS Data Center, Sioux Falls, S. Dak.

Glacier Names and Place-Names in Alaska

The names of Alaska's glaciers and other place-names have diverse origins (appendix C), including at least four European languages and numerous dialects of the languages of the indigenous peoples of Alaska. Beginning in the 18th century, when Russian, English, Spanish, and French explorers and merchants began interacting with the indigenous peoples, they recorded many of the names of geographic features, frequently transliterating or translating them into European languages. Additionally, the Europeans provided new place-names for many geographic features, many of which are still in use.

Figure 8.—*A Landsat MSS "temporal-change composite image" showing differences occurring between 1985 and 1986 in the termini of Hubbard (center) and Turner (lower left) Glaciers and the Valerie Glacier, a tributary to the Hubbard Glacier. All are located in the upper end of Disenchantment Bay. This image was produced by digital addition of two geographically registered Landsat MSS images and determination of differences in brightness values for individual pixels. Differences, including the 1986 advance of the terminus to block Russell Fiord (lower right), are shown in green. Unpublished 1986 analysis by Bruce F. Molnia and Matthew Schwaller.*



U.S. involvement in the naming of Alaska's geographic features predates its purchase of Alaska in 1867 from Russia. U.S. whalers hunting in the Arctic Ocean applied names to many northern geographic features. Additionally, official pre-purchase expeditions, such as the 1854–55 U.S. Navy (USN) North Pacific Exploring Expedition, provided new geographic-feature names. In order to track and authenticate Alaskan place-names, a formal system of legitimizing named features evolved in the 19th century, leading to Marcus Baker's *Geographic Dictionary of Alaska* (Baker, 1902), which contained 2,000 identified names. A second edition four years later contained about 9,300 names and 3,300 cross references and was released as USGS Bulletin 299 (Baker, 1906).

In 1967, the most recent version of a USGS Alaskan geographic dictionary—*Dictionary of Alaska Place Names*—was released as USGS Professional Paper 567 (Orth, 1967). Containing more than 20,000 names, it was reprinted with minor revisions in 1971 (Orth, 1971). In 1991, The Denali Press (Schorr, 1991) released a compendium of about 1,300 additional place names—*Alaska Place Names*—based on BGN decisions made between January 1966 and December 1990. More than 25 new glacier names were included.

Today, most BGN databases have been computerized. The *Alaska Dictionary Database* and the USGS *Geographic Names Information System* (GNIS) serve as the central repositories for approved Alaskan place-names. "The Geographic Names Information System (GNIS) is the Federal standard for geographic nomenclature. The U.S. Geological Survey developed the GNIS for the U.S. Board on Geographic Names as the official repository of domestic geographic names data." The USGS GNIS is available on the Internet at the following URL: http://geonames.usgs.gov/. The *Alaska Dictionary Database* is currently available to the general public only through Orth (1967). Even though more than 600 glacier names have been officially approved as of March 1998 (appendix C), the great majority of Alaska's glaciers, perhaps as many as 99 percent of extant glaciers, are still unnamed.

Many names that were given to glaciers by early expeditions and USGS field parties were never formally adopted. Neither of the glacier names that Schwatka uses for the two glaciers depicted in his 1885 book, *Baird Glacier* and *Saussure Glacier* (Schwatka, 1885, p. 73, 77), for example, were adopted as official names. Both are shown without names on the latest USGS map of the area. Similarly, the names of some glaciers have changed several times. For instance, the LeConte Glacier, named in 1887 by the U.S. Navy for University of California geologist Joseph LeConte, was previously called *Hutli Glacier* and *Thunder Glacier*. Similarly, Taku Glacier originally was called *Schulze Glacier* and *Foster Glacier*.

Early Observations of Alaska and its Glaciers

Traditional Knowledge

Alaska's indigenous peoples were cognizant of the presence of glaciers. In many areas, local peoples, such as the Tlingit, lived near glaciers and developed a history and culture that took into account the influence that glaciers played in their daily activities. For example, the famous anthropologist de Laguna (1972) gives several accounts of native villages being destroyed by the advance of glaciers. Similarly, after John Muir visited Glacier Bay in 1879, he wrote that the Indians who guided him during his exploration would not go near the face of the tidewater glaciers. They told him that ice rising out of the water had capsized canoes and drowned their occupants. This account is the earliest reported description of submarine calving from the termini of glaciers by a scientist (Muir, 1895) (see also Vancouver, 1798).

Limited Early Descriptions of Glaciers

Only a very few early explorers, mostly from expeditions carried out during the second half of the 19th century, mentioned glaciers in their reports or provided technical information about the extent and distribution of Alaska's glaciers. Several factors can be offered to explain this situation: (1) most of the early explorers had no personal knowledge or understanding of glaciers or the concept of glacierization, and (2) most were searching for a "Northwest Passage" or for expanding economic trading spheres for their countries and were not focused on descriptions of geographical features.

An additional factor may be the vocabulary commonly used in Europe during the period of early exploration. An 1855 discussion of glaciers by Wilhelm Wittich states that "The term glacier is frequently considered as being synonymous with that of snow-mountain, and both terms are sometimes used without discrimination" (Wittich, 1869). However, even without using the correct terminology, explorers did describe glaciers. For example, although Vancouver (1798) never used the word glacier, he did use phrases such as "an immense body of compact perpendicular ice, extending from shore to shore..." to describe Brady Glacier in Taylor Bay and "From the shores of this basin a compact body of ice extending some distance nearly all round" (Vancouver, 1798, p. 416–417) to describe Taku Glacier. Obviously, Vancouver had an understanding of glaciers, even if not of modern glaciological terminology.

What follows is a summary of the accomplishments of selected explorers who conducted 18th through 20th century sea and land expeditions that provided descriptions of the glaciers of Alaska or contributed to Alaska's geographic information. Qualitative information provided by these explorers can be used to extend the record of historic changes in Alaska's glaciers.

18th and 19th Century Explorations and Observations of Alaska and its Glaciers

The 18th and 19th centuries saw a number of European expeditions to Alaska. Some were focused on exploration, some on exploitation, some on adventure, and some on scientific investigation. Together, these explorers, scientists, and adventurers provided descriptions of glaciers or contributed to Alaska's geographic information. Appendix D provides a chronological list of many of those explorers and expeditions, their nationality, and date(s) of exploration. For a number of locations, this mostly qualitative information can be used to draw conclusions about the location and size and even the processes active at selected Alaska glaciers. Much of the information for appendix D was compiled from Davidson (1901, 1904), Baker (1902, 1906), Hulley (1953), Sherwood (1965), Orth (1967), Henry (1984), and Molnia and Post (1995). Following is a brief summary of selected explorers/expeditions who visited Alaska during the 18th, 19th, and early 20th centuries and their contributions to our earliest knowledge of glaciers in Alaska.

Vitus Bering

The first documented European expedition to explore Alaska, conducted in 1741 for Russia, consisted of two ships, the *St. Peter*, captained by Vitus Bering, with Sven Waxell as second-in-command and Georg W. Steller as naturalist, and the *St. Paul*, captained by Alexie Chirikof. Soon after leaving Kamchatka, the ships lost contact with each other and remained separated for the remainder of their respective voyages. The *St. Peter* sailed as far east as the vicinity of the St. Elias Mountains, sighting land on the western side of Yakutat Bay and Mount St. Elias in mid-July 1741. Although the *St. Peter* sailed within a few kilometers of the largest glaciers in continental North America, no written information exists about any glaciers from any of the expedition's members.

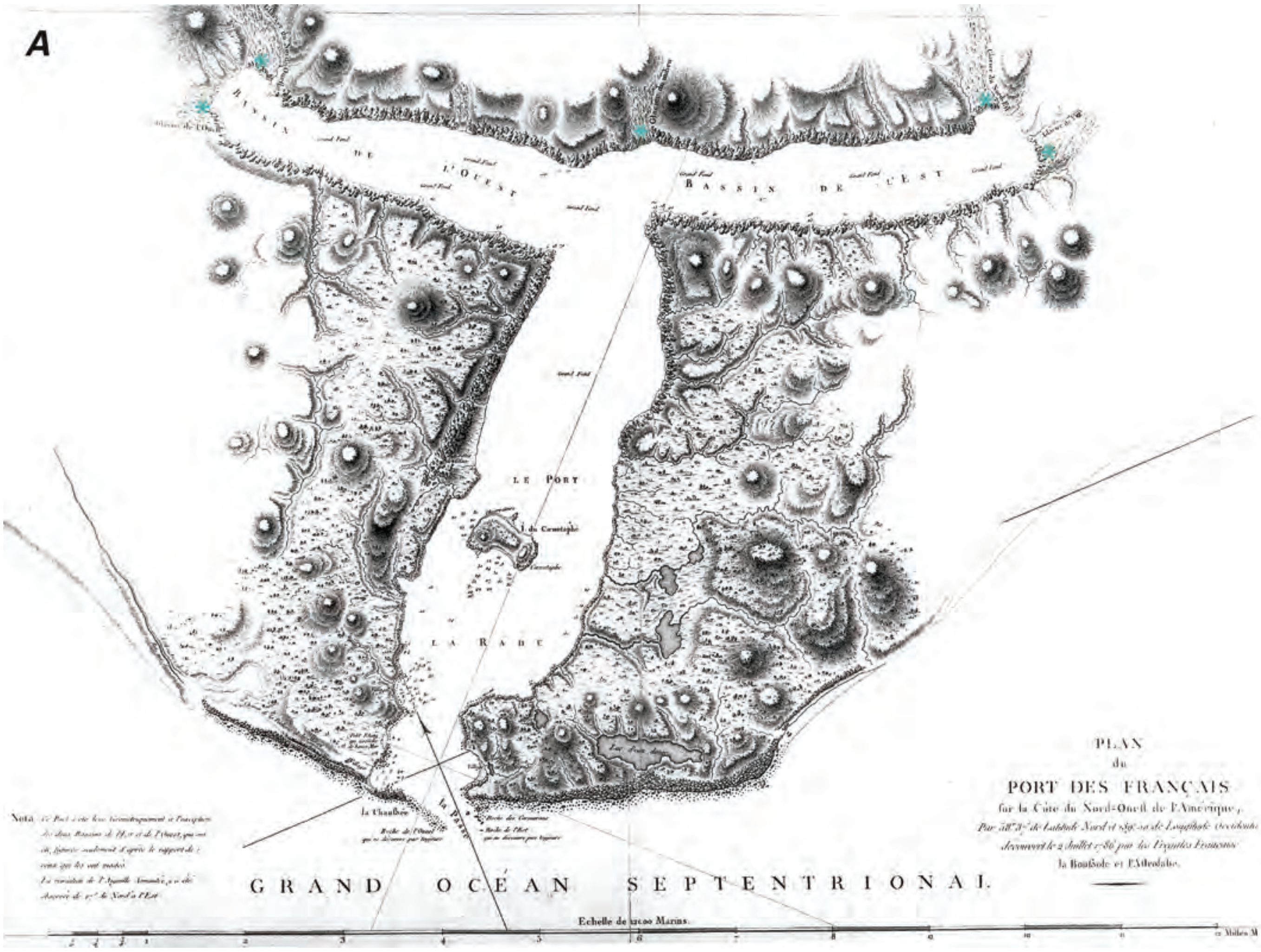
On 20 July 1741, Steller and members of the crew landed on Kayak Island (Waxell, 1952). Attempting to return to Kamchatka, Captain Bering sailed along the Aleutian Islands before most of the crew fell ill with scurvy, and the ship suffered permanent damage. On 5 November 1741, to prevent its sinking, the *St. Peter* was run aground on an island off the coast of Russia, now called Bering Island. Although Captain Bering died without reaching home, his expedition produced the first information and descriptions of the Pacific Ocean coast of Alaska. Captain Chirikof sailed as far east as the Alexander Archipelago, perhaps to what is now known as Sitka on the western coast of Baranov Island, before safely returning to Russia.

James Cook

Beginning in May 1778, Captain James Cook, in command of the HMS *Resolution*, and Captain Charles Clerke, in command of the HMS *Discovery*, sailed westward along the North American shoreline of the Pacific Ocean looking for a passage to the Atlantic Ocean. After naming Mount Edgecumbe (on Baranof Island), Cook observed snow-covered Mount Fairweather (in Glacier Bay National Park and Preserve). Cook later explored Prince William Sound and Cook Inlet from 12 May through 25 June 1778. The expedition then proceeded through the Bering Strait into the Arctic Ocean, where it was turned back by pack ice on 28 August 1778. Many sketches of coastal features, including the St. Elias Mountains and the Chugach Mountains, were made by William Bligh, sailing master of HMS *Resolution,* but there are no known descriptions of glaciers from that voyage.

Jean François de Galaup de La Pérouse

In July 1786, Jean François de Galaup de La Pérouse led two ships, the *Boussole* and the *Astrolabe*, in an expedition to the coast of the St. Elias Mountains. In Lituya Bay, a T-shaped fiord with numerous glaciers at its head, he set up a scientific observatory on Cenotaph Island. He clearly had knowledge of glaciers because his log describes their locations and characteristics (La Pérouse, 1798–99). His map of Lituya Bay (fig. 9*A*) accurately depicts water depths within the bay and the location of five glaciers at the upper ends of the bay. La Pérouse's narrative describes how several members of the expedition attempted to climb one of the glaciers at the head of the western arm of the bay. He stated that "With unspeakable fatigue they advanced 2 leagues, being obliged at extreme risk of life to leap over clefts of great depth; but they could only perceive one continued mass of ice and snow, of



which the summit of Mount Fairweather must have been the termination" (La Pérouse, 1798–99, p. 374). Drawings by expedition members Lieutenant de frégate Blondela and Gaspard Duche de Vancy show Cascade Glacier at the head of Lituya Bay. The details of La Pérouse's descriptions and map provide a qualitative source of data to estimate changes in the positions of glacier termini in Lituya Bay (figs. 9*B*, 9*C*) and sediment accumulation for a period that now exceeds 200 years (Jordan, 1962; Molnia, 1979).

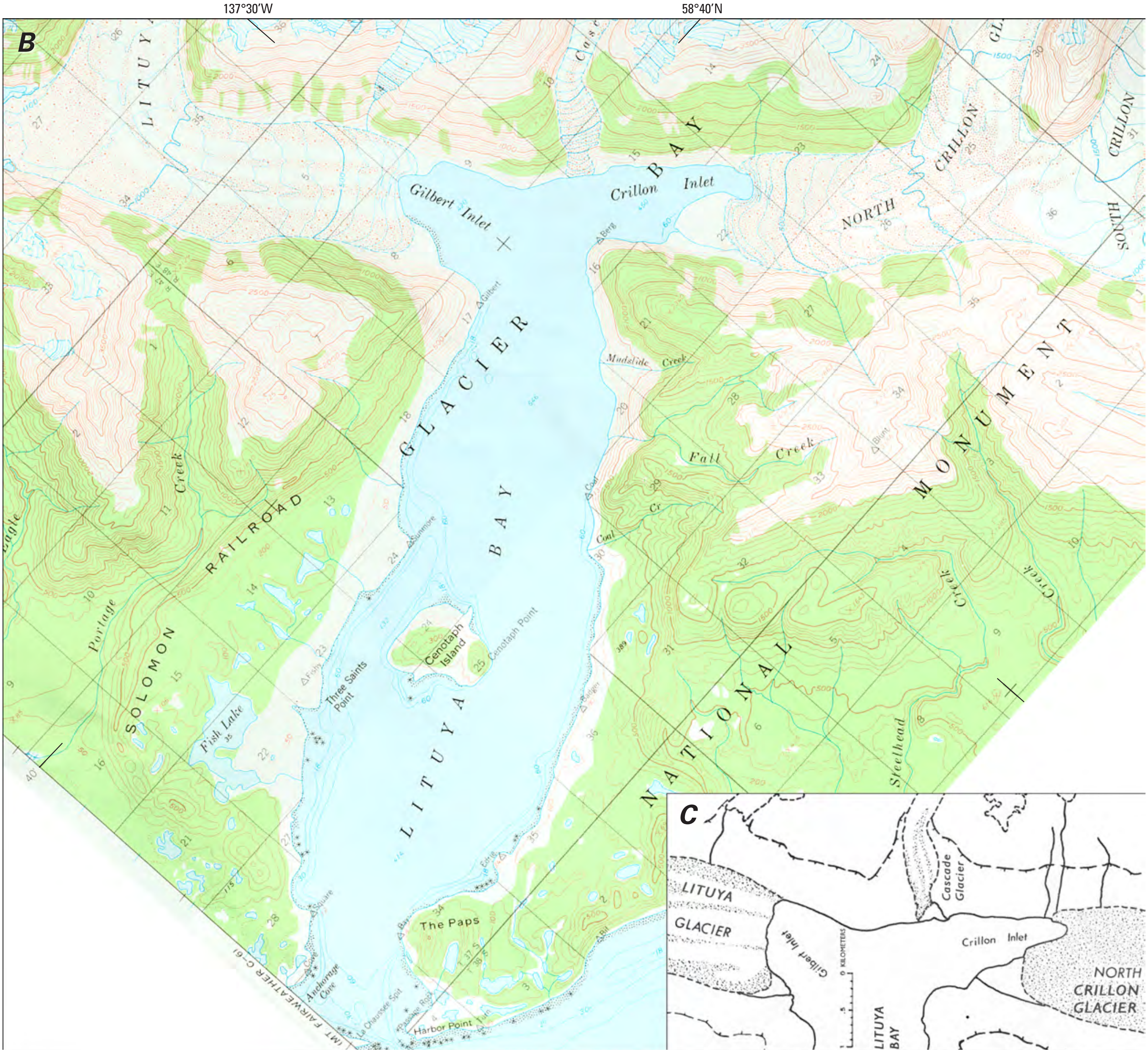
▲ ***Figure 9.****—Three maps of Lituya Bay: 1797, 1961, and 1972.* **A**, *La Pérouse's 1797 map;* ► **B**, *Part of the USGS (1961) 1:63,360-scale topographic map (appendix B) of the same area. (Mt. Fairweather, C–5, Alaska; compiled photogrammetrically from vertical aerial photographs acquired in 1948 and 1958, field annotated in 1961).* ► **C**, *1972 sketch map by Austin Post, U.S. Geological Survey. The La Pérouse map shows the presence of five named glaciers (green asterisks) at the head of the bay. The USGS and Post maps show only three. In the interval of time between the three maps, the pairs of glaciers at the heads of each arm of the bay have coalesced and each has advanced more than 3 km. By 1972, however, Cascade Glacier had retreated to a stable position on the beach (table 3). Compare with figures 136 and 137 to see continuing changes.*

Alexandro Malaspina

In 1791, a Spanish scientific expedition reached Alaska with the purpose of collecting natural history materials and information, preparing maps, and investigating the political state of Spanish possessions in the New World (Beddall, 1979). The expedition, which carried three naturalists, consisted of two ships, the *Descubierta* and the *Atrevida*, under the leadership of Alexandro Malaspina. On 2 June 1791, they reached Sitka and then proceeded north to Yakutat Bay which they explored in detail and named Disenchantment Bay (Bahia del Desengano). While they were in Yakutat Bay, a description of a glacier, now known as the Malaspina Glacier, was prepared. The expedition also studied Icy Bay and Prince William Sound.

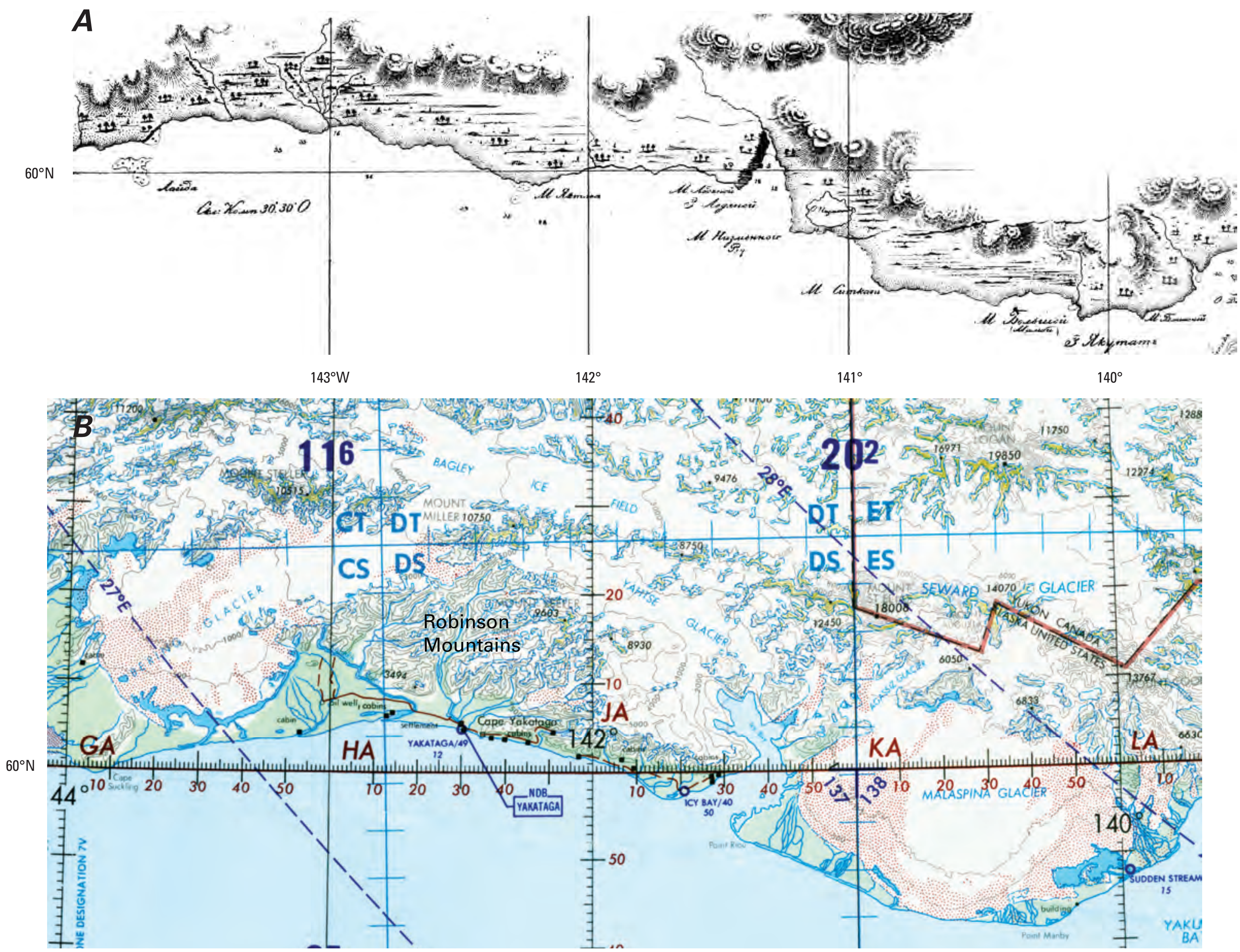
George Vancouver

In 1793, Captain George Vancouver of the British Navy, commanding the sloop HMS *Discovery*, explored the southeastern corner of Alaska from the vicinity of Portland Inlet north to the vicinity of Cape Caamano at the northern end of Clarence and Sumner Straits. Captain Vancouver named the cape



after Don Jacinto Caamano, a Spaniard commissioned by the Viceroy of Mexico in 1792 to explore the southeastern Alaskan coast. In 1794, Vancouver returned to Alaska, exploring the coast from Chirikof Island, west of Kodiak, to Kodiak, to Cook Inlet, to Prince William Sound, to the mouth of Glacier Bay, and south to Port Conclusion on the east coast of Baranof Island. During this expedition, Lieutenant James Whitbey frequently went ashore in a small launch and made detailed investigations of many coastal features.

During Captain Vancouver's 1794 exploration of College Fiord in Prince William Sound, a correlation was made between the frightening thunderous roars that were frequently heard and the falling of blocks of frozen snow off the faces of "snow cliffs." This instance is the first recorded observation of glacier calving in Alaska. Captain Vancouver described Icy Bay (Vancouver,



1798). Many sketches of coastal features, including Mount St. Elias and Icy Bay, were made by Thomas Heddington, a midshipman.

Edward Belcher

In 1837, Sir Edward Belcher, aboard HMS *Sulphur*, journeyed to Alaska in order to fix the geographic coordinates and determine the height of Mount St. Elias (Belcher, 1843). In the vicinity of Cape Suckling, the expedition made what is probably the first observation of the surge of an Alaskan glacier. Belcher described a surface composed of rectangular prisms of severely shattered ice lightly mantled with morainic debris in the area of Bering Glacier's present terminus. Years later, Belcher (1862) had become more familiar with glaciers and icebergs but still did not understand what he had observed in 1837 or its dynamics. After severe thought over a period of many years, he presented an explanation for and a description of the icebergs that he saw near Icy Bay and tried to relate them to the pyramids observed in 1837. He stated that "the apparently descending ice, from the mountains to the base, was in irregular broken masses, which tumbled in confusion. The motion was clearly continuous" (Belcher, 1862, p. 186–187).

Figure 10.*—Maps of the Gulf of Alaska coastal area from Yakutat Bay on the east to the Cape Suckling area on the west.* **A***, Teben'kov's 1849 map shows the margin of the Malaspina Glacier as a snow-covered plateau surrounded by forest and marsh. The "Icy Bay" shown west of long 141°W. is not the present Icy Bay. In the intervening years the embayment was filled. To the west of Icy Bay, the Robinson Mountains are shown as snow-covered.* **B***, The same area portrayed on the 1975 U.S. Air Force Operational Navigation Chart (ONC) D–11.*

George Simpson

In 1841, George Simpson, Governor of the Hudson Bay Company, visited many of the settlements in Russian America, observing the local geography as well as their economic situations. In September 1841, he sailed through Stephens Passage, where he observed "The valleys were lined with glaciers down to the water's edge; and the pieces that had broken off during the season had filled the channels and straits with fields and masses of ice, through which the vessel could scarcely force her way" (Simpson, 1847, v. 1, p. 213).

Mikhail Dimitrievich Teben'kov

Between 1848 and 1850, a series of charts and maps appeared that were prepared by cartographers Kosima Trentiev and M.M. Kadin for Admiral Mikhail Dimitrievich Teben'kov, Director of the Russian American Company and Governor of the Russian American colonies. These charts and maps, published as the *Atlas of the Northwest Coast of America* (Teben'kov, 1852), clearly show the location of many coastal features, including glaciers. The observations of more than 50 pilots and Russian explorers (appendix D) were consolidated into these charts and maps (fig. 10).

William P. Blake

In 1863, the Russian Navy invited Professor William P. Blake of Yale University to accompany Commander Vladimir Bassarguine on the corvette *Rynda* on an exploration expedition to Russian America. After arriving at Sitka, Blake accompanied a party for the first exploration of the Stikine River valley. Blake described "four large glaciers and several smaller ones" (Blake, 1867, p. 96) within 60 to 70 miles of the mouth of the river. His observations were published as early as July 1863 in California newspapers and, in 1867, as *Glaciers of Alaska, Russian America* (Blake, 1867), the first summary of Alaska's glaciers. His 1868 map and report to Secretary of State William Seward (Blake, 1868) includes several sketches of glacier terminus morphology and descriptions of individual glacial moraines. The map shows the terminus position of four glaciers, including Popof Glacier (fig. 11).

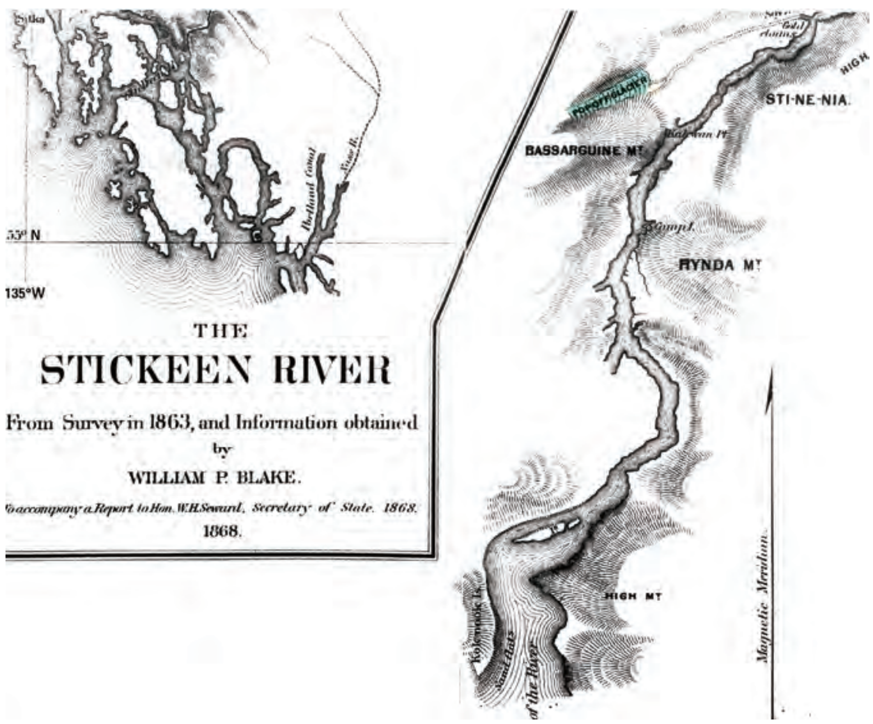
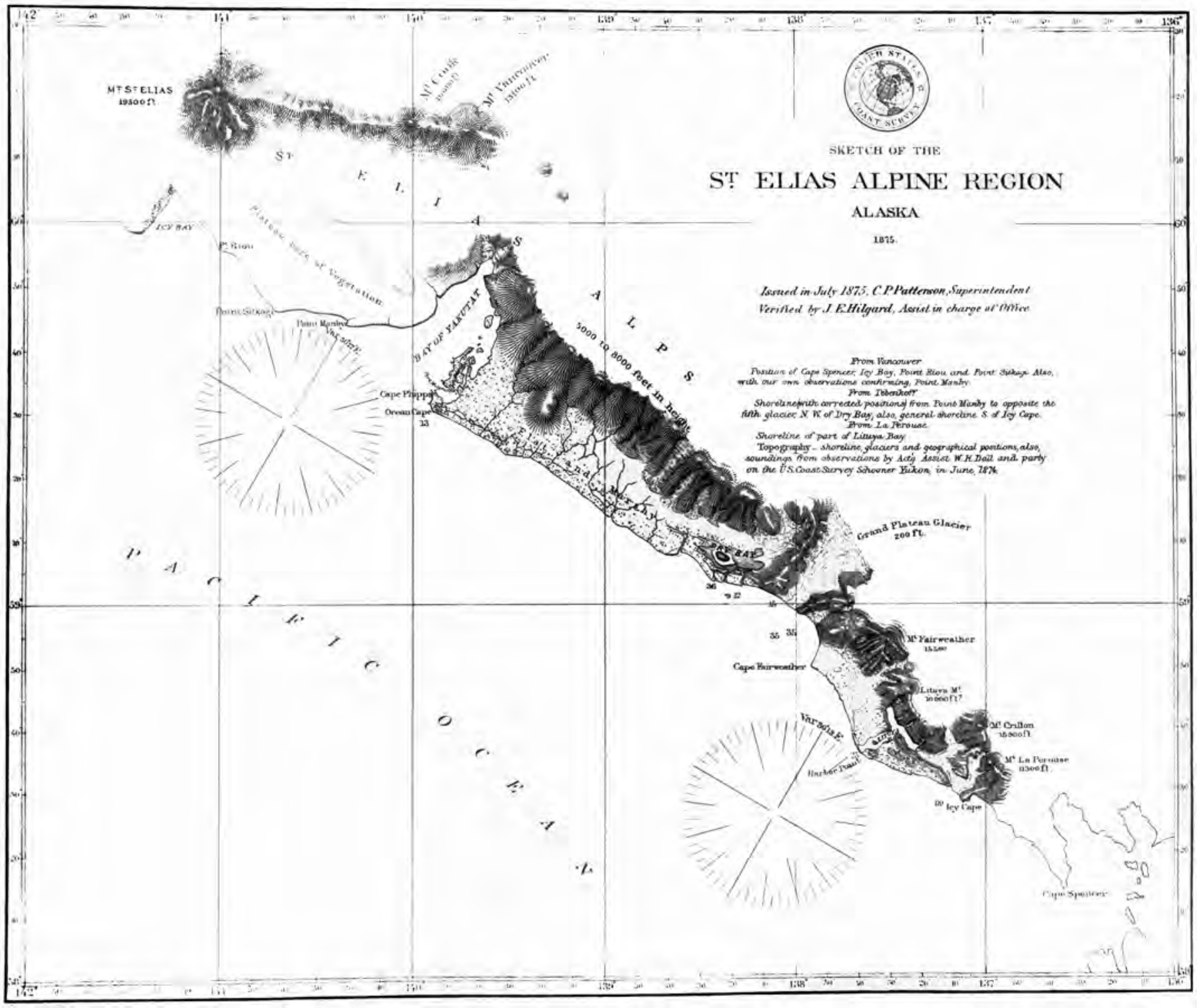


***Figure 11.**—Part of Blake's 1868 map of the Stikine (Stickeen) River area showing the terminus of Popoff [Popof] Glacier. Farther upstream, off this section of the map, three other glaciers are depicted, all located on what is now the Canadian side of the border. Blake uses the terms "moraine" and "old moraine" to describe sedimentary deposits in front of two of the Canadian glaciers.*

William H. Dall

Beginning in 1865, William H. Dall began a lifelong investigation of the resources of Alaska, including its glaciers. His reports mention the effects of past and present glaciation and the geology of the region. In his 1870 description of the resources and geography of Alaska, Dall (1870), notes several glaciers of the Coast Mountains, including the Davidson Glacier and those near the Taku River, and mentions Icy Bay, named "for the glaciers which surround it" (Dall, 1870, p. 252). On 21 April 1883, Dall presented a summary of his observations about the glaciation of Alaska to the Philosophical Society of Washington (Dall, 1884). In the interior of Alaska, he observed ice lenses in permafrost and took time to clearly differentiate between ice of glacial origin and permafrost ice. Dall described the distribution of glaciers as "confined to the region of the Alaska range and the ranges parallel with it south of the Yukon Valley, but particularly to the coast mountains bordering on the Gulf of Alaska and the Alexander Archipelago, of which the St. Elias Alps form the most conspicuous uplift" (Dall, 1884, p. 35). Dall recognized "that the extent of Alaskan glaciers is generally diminished from its former state, and is probably still diminishing" (Dall, 1884, p. 35).

Figure 12.*—Sketch map of the Saint Elias Alpine Region [sic, mountains] produced by the U.S. Coast Survey in 1875. Shown and named is Grand Plateau Glacier. Shown but not named are La Perouse and the Crillon Glaciers and three glaciers north of Dry Bay. The Malaspina Glacier is shown as a flat area in front of a mountain chain that includes Mount Saint Elias, Mount Cook, and Mount Vancouver. In front of the Malaspina Glacier is a "Plateau bare of Vegetation."*



George Davidson

Following the purchase of Alaska from Russia in 1867, George Davidson was directed by the Superintendent of the United States Coast Survey [USCS, later the U.S. Coast and Geodetic Survey (USC&GS), and now the National Ocean Survey (NOS)] to “gather whatever information I could of the resources of that terra incognita” (Lewis, 1954, p. 42). This directive began investigations of the coastline and continental margin of Alaska that continue to the present. These types of investigations produced figure 12, an 1875 *Sketch of the St. Elias Alpine Region* (United States Coast Survey, 1878), combining topography and shoreline glacier positions compiled during an 1874 survey directed by Dall with data and observations from the charts of Vancouver, La Pérouse, and Teben’kov. The sketch map shows the La Perouse and Grand Plateau Glaciers and describes the area covered by the Malaspina Glacier as a “plateau bare of vegetation” (United States Coast Survey, 1878, pl. 22).

Davidson maintained a keen and continuing interest in Alaska into the 20th century. In 1901, he published a detailed examination of Bering’s 1741 voyage (Davidson, 1901). More importantly, in 1904, Davidson completed his summary of *The Glaciers of Alaska That Are Shown on Russian Charts or Mentioned in Older Narratives* (Davidson, 1904). This summary contains 11 plates depicting the early mapped glacier positions, one of which is shown in figure 13.

Charles Erskine Scott Wood

In 1877, Lieutenant Charles Erskine Scott Wood journeyed to Alaska in an attempt to climb Mount St. Elias. His indigenous guides refused to undertake

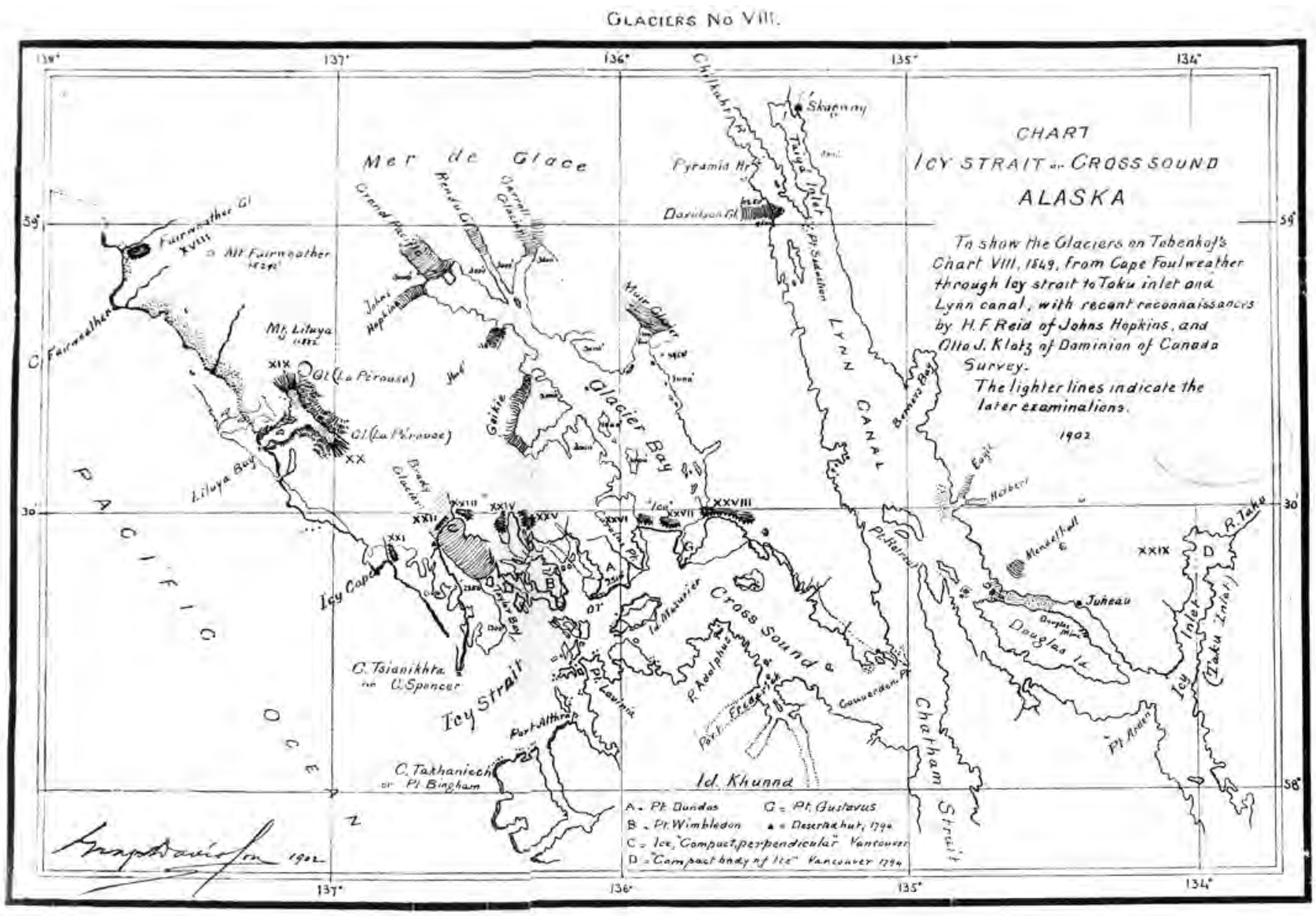


Figure 13.—Map showing the glaciers of the Icy Strait-Cross Sound region compiled in 1902 by George Davidson from data published by the Russian-American Company and other 19th century sources (Davidson, 1904, Plate VIII). Comparing this map to earlier maps, shows very clearly that the delineation of landforms in general and glaciers in particular was becoming much more accurate.

an ocean canoe trip and led him to the Mount Fairweather area instead. From there, Wood saw Glacier Bay in the distance from the divide (Wood, 1882).

John Muir

In 1879, John Muir, a naturalist and travel writer, visited Alaska for the first time. He was accompanied by Samuel Hall Young, a Presbyterian missionary. Together, they performed the first detailed investigation of Glacier Bay and Muir Glacier. Muir returned in 1881 (Muir, 1893, 1895) and 1899 (Muir, 1902) and noted many changes in the bay and its glaciers. He also explored numerous glaciers in other parts of southern Alaska.

U.S. Military Expeditions

In 1883, a U. S. Army expedition led by Lieutenant Frederick Schwatka (1885) explored the northern part of the Alaska panhandle in the vicinity of the Chilkoot Pass while on its way north to the headwaters of the Yukon River. The expedition transported a camera and exposed glass photographic plates, capturing images of several glaciers north of Skagway. These photographs are likely the earliest of Alaskan glaciers. Schwatka described and mapped an “immense glacier” at the head of the Nourse River and “the southern terminal spur of a large glacier” between the Nourse and the Dayay Rivers. He named these the Baird and Saussure Glaciers (fig. 14) and prepared lithographs of each (Schwatka, 1885).

In 1885, Lieutenant Henry T. Allen of the Second U. S. Cavalry led a 1,500-mile (2,414-km) expedition to the Copper, Tanana, Koyukuk, and Yukon Rivers to make a reconnaissance of the Copper and Tanana River valleys of Alaska (Allen, 1887). His report contains lithographs of the termini of the Childs and Miles Glaciers (fig. 15) based on his photographs and narrative, which describe Childs and Miles Glaciers and several other glaciers in the Copper River Valley.

George Frederick Wright

In 1886, G. Frederick Wright, a professor at Oberlin Theological Seminary and an Assistant of the USGS, conducted a month-long investigation of Muir Glacier and Glacier Bay (Wright, 1887, 1889). Among his findings is an estimate of the annual sediment budget of the Muir Glacier. Wright also made observations on the glaciers of the Stikine River and many other parts of the Coast Mountains (fig. 16). Wright’s *The Ice Age in North America and its Bearings upon the Antiquity of Man* (Wright, 1889) contains a map

***Figure 14.**—1883 lithograph produced from one of the first photographs taken of an Alaskan glacier. Although it is labeled “Finger of Saussure Glaciers,” this name was never adopted. The glacier, which is underfit in its valley, appears to have a retreating terminus. It is probably an unnamed glacier on the east side of Mount Hoffman, Coast Mountains. Lithograph from Schwatka (1885). Photograph by Charles A. Homan, U.S. Engineers.*

of southeastern Alaska that systematically depicts the location of known Alaskan glaciers between Dixon Entrance [54°30'N.] and Mount St. Elias [60°20'N.] (fig. 17). Wright quoted H.W. Elliot as stating that "counting great and small, there can not be less than five thousand glaciers between Dixon's Entrance and the extremity of the Alaskan Peninsula" (Wright, 1889, p. 30).

New York Times Expedition

In 1886, a *New York Times* expedition led by Frederick Schwatka attempted to reach Mount St. Elias. Schwatka was accompanied by William Libbey, Jr., of the College of New Jersey and Lieutenant Heywood W. Seton Karr, a former British Army officer and mountaineer. Seton Karr applied the name "Bering Glacier" to an "ice-plain" that he observed west of Icy Bay (Seton Karr, 1887). Libbey (1886) named the Guyot and Aggasiz Glaciers and also recognized that the majority of the glaciers that he saw were retreating. "Today we find in the glaciers which gleam on the mountain sides of these channels only the relics of their former greatness. The history of the great Muir Glacier at the head of Glacier Bay is but silent witness of the fact that these ice masses are rapidly retreating to their mountain fastnesses, for it has retreated many miles towards its sources since it was first discovered" (Libbey, 1886, p. 281–282). This expedition was responsible for providing the first written description of the complex glacier systems now known as the Bering, Guyot, and Malaspina Glaciers.

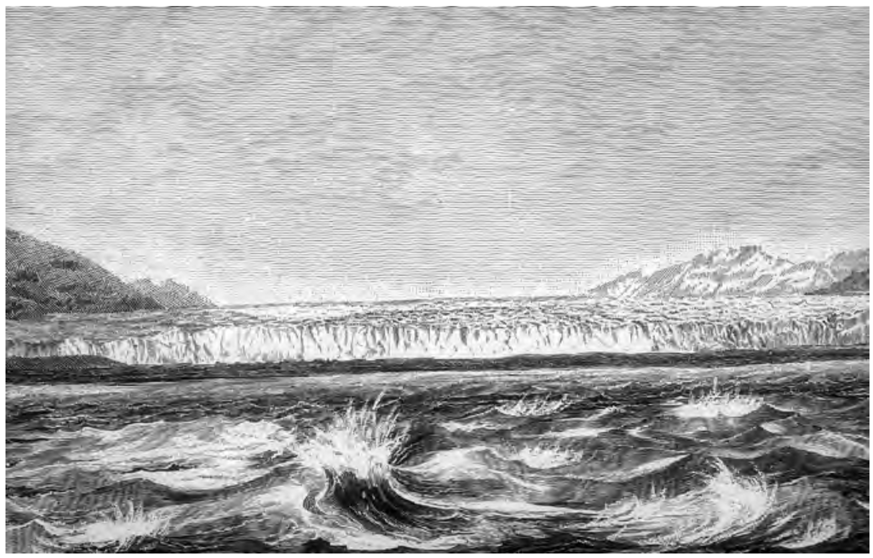


Figure 15.*—1887 lithograph produced from one of the few surviving photographs taken by Lt. Allen's Copper River Expedition of 1885 (Allen, 1887). Shown is the terminus of Miles Glacier.*

Figure 16.*—1886 photograph by W.H. Partridge of the terminus of Norris Glacier, Coast Mountains. This image was published in Wright (1889).*

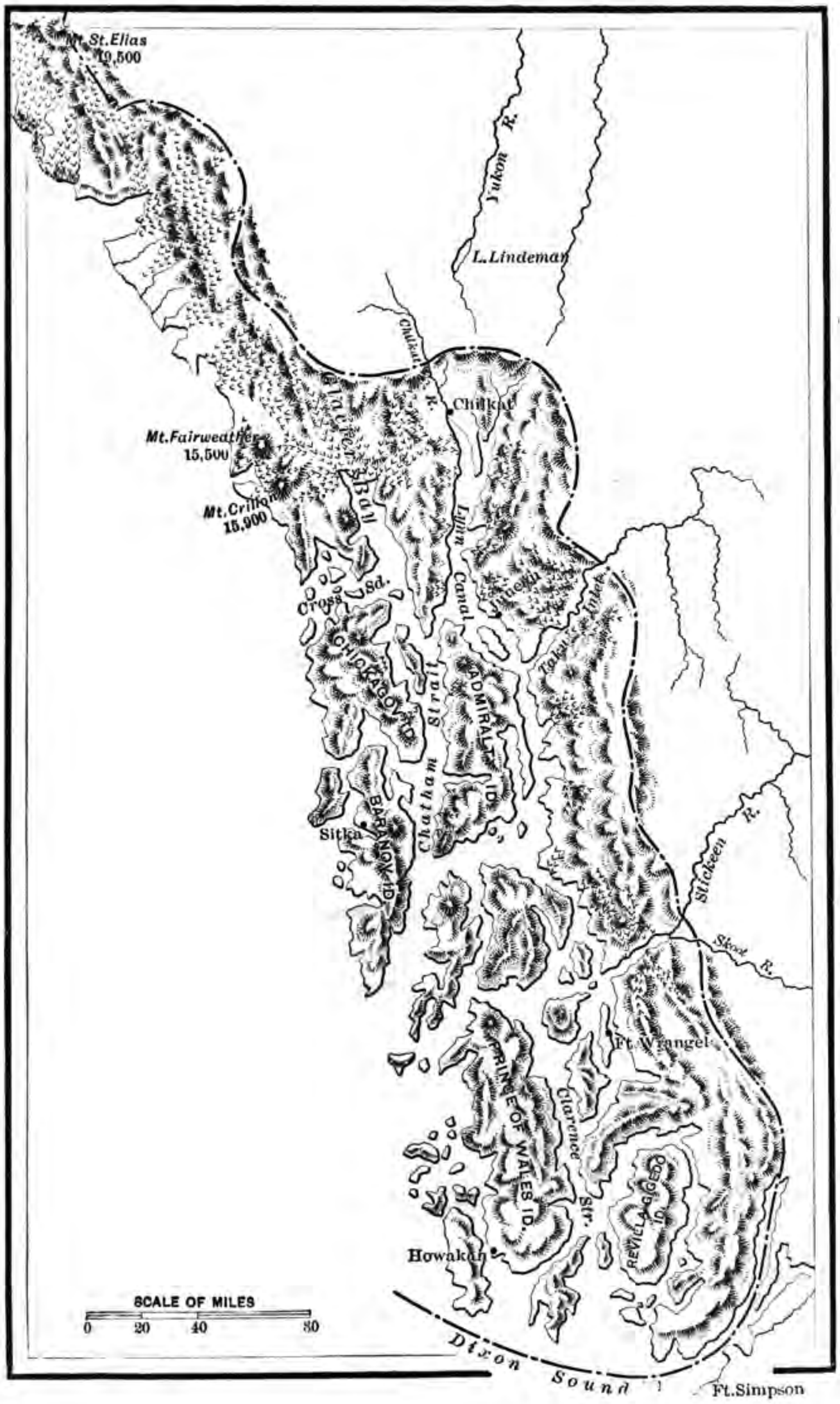


Figure 17.—*Wright's 1889 sketch map of southeastern Alaska showing the location of glaciers in the region [⌞ symbols] (Wright, 1889, p. 26). This sketch is the earliest attempt at a systematic mapping of the glaciers of southeastern Alaska.*

► ***Figure 18.***—*Israel C. Russell's 1891 "Sketch Map of the Mount St. Elias Region" (Russell, 1893, Plate IV). By 1891, the "Icy Bay" shown on figure 10 had all but disappeared, and the Malaspina Glacier and Guyot Glacier were united into one continuous ice mass.*

Israel C. Russell

Israel C. Russell, a USGS geologist, led two expeditions in 1890 (Russell, 1891, 1892) and 1891 (Russell 1893, 1894) to climb Mount St. Elias and to explore the geology and topography of Yakutat Bay (fig. 18), Malaspina Glacier, and Icy Bay. The expeditions were jointly funded by the USGS and the National Geographic Society (NGS). [Editors' note: I.C. Russell was the first recipient of a research grant from the NGS. The NGS's Committee for Research and Exploration has since (as of 2004) made more than 7,500 such awards.] The observations made on the expeditions resulted in many publications, including maps and a description of the glaciers of Mount St. Elias (Russell, 1891, 1892). A large area was mapped, Mount Logan was discovered, and the heights of Mount St. Elias and several other peaks were determined. The

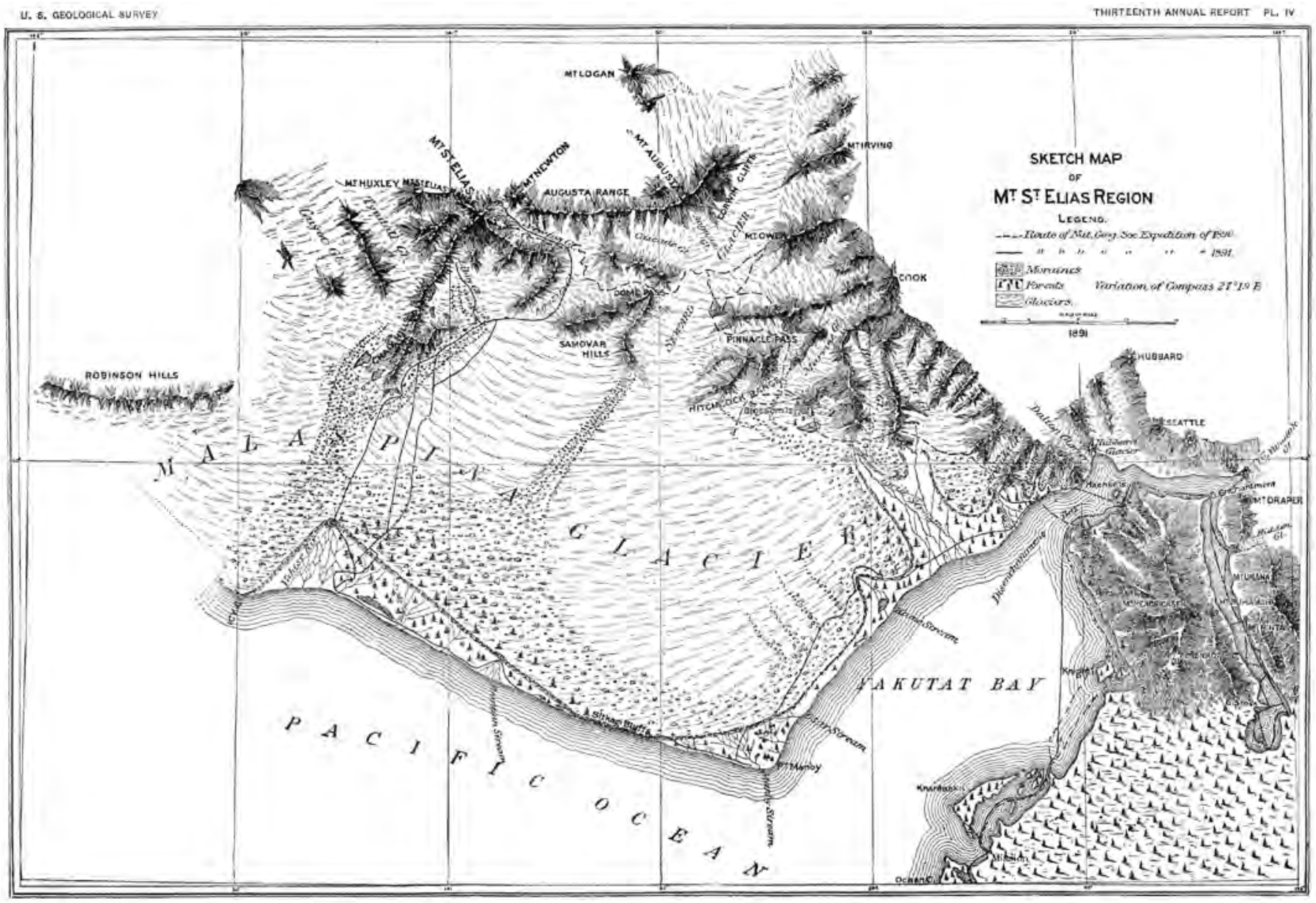


Figure 19.—**A**, *1891 Israel C. Russell photograph of a USGS field party crossing the Malaspina Glacier, St. Elias Mountains, during their unsuccessful attempt to climb Mount St. Elias. Samovar Hills is in the middle background. Photograph Russell 520 from the USGS Photographic Library, Denver, Colo.* **B**, *Israel C. Russell and members of his survey team in the St. Elias Mountains. Israel C. Russell was the first recipient of a field-research grant from the National Geographic Society in 1890 (USGS Photographic Library photograph Russell 568).*

height of Mount St. Elias, thought to be 18,008 ft, was calculated to be 18,100 ±100 ft. The ascent failed owing to severe weather. Russell Fiord, later named for him, was also explored in detail. Russell's expeditions produced more than 150 photographs (fig. 19), including the earliest photographs of the positions of the termini of the Turner and Hubbard Glaciers. Many of these photographs were published in 1892 and in 1893 (Russell, 1892, 1893), and some were used by other investigators, such as Tarr and Martin (1914), to assist them in determining change in glaciers.

Henry Fielding Reid

Henry Fielding Reid was affiliated with the Case School of Applied Science in Cleveland (now Case Western Reserve University) and with Johns Hopkins University in Baltimore. In 1890 and 1892, he conducted two expeditions to Glacier Bay to study Muir Glacier. He made numerous photographs and described how to document the location of a glacier's terminus:

> (1) All photographs at the end of a glacier are useful; particularly if the magnetic bearings of the camera, and the approximate distance from the glacier are given. (2) Select two stations, one on each side of the valley, commanding a view of the glacier's end. Photograph the end from these two stations... Mark the station, describe them carefully... so that they can easily be found by later observers... This will be the beginning of a systematic record of the glacier. From these photographs it will be possible to make a map of the glacier's end if we know: the distance between the stations; the angle at each station between the other and some points in the photograph and the focal length of the lens (Reid, 1895, p. 286–287).

In a pair of publications (Reid 1892, 1896), he described the morphology of the bay, its geology, glaciers, and glacial deposits, changes between his two visits, moulins, Glacier Bay's tides, and its water chemistry. H.P. Cushing of Western Reserve University (Cleveland), a member of the first Reid expedition, published the first geological map of the region in 1895 (Cushing, 1896). A preliminary version showing the geology of the Muir Glacier Basin was included in Reid (1892). During the same time period, other photographers came to Glacier Bay and also recorded the position of the terminus of Muir Glacier (fig. 20).

Starting in 1895, Reid began to compile summaries of the global variations of glaciers, including glaciers of Alaska.

> The great interest which the physical study of living glaciers has to the geologist is the light it may throw on the causes producing, and the conditions prevailing during the Ice Age. One of the habits of living glaciers bearing most directly on the Ice Age is the variation continually occurring in their length, thickness, and velocity of motion... but it is only within about twenty years that anything like systematic work has been done in getting together records which enable us, in some cases, to exhibit roughly the variations in the extent of certain glaciers for three hundred years, during which period there has been quite a number of advances and retreats... (Reid, 1895, p. 278).

On an almost annual basis, he continued to compile and report these changes in a series of articles, frequently titled *Variations in Glaciers*, until the advent of World War I (for example, Reid, 1897, 1898, 1899, 1900, 1904, 1909, 1913a, 1913b, 1915). He last visited Glacier Bay in 1931.

[Editors' note: According to Mark F. Meier (written commun., 2004), Reid was the first scientist to carry out true glaciological studies in Alaska. One of his many significant achievements was the mapping, using planetable-mapping techniques, of the large, heavily crevassed Muir Glacier from its terminus to its head. He also published many "cutting-edge" scientific papers, including an exposition on the "kinematic theory" of glacier flow. Reid

Figure 20.*—1893 photograph by Frank LaRoche (standing) (T.J. Richardson, sitting) of the terminus of Muir Glacier, Saint Elias Mountains. Morse Glacier can be seen in the left background. The photograph is from the National Snow and Ice Data Center (NSIDC), Boulder, Colo.*

was the U.S. representative on the International Commission on Glaciers. He clearly was the most prominent U.S. glaciologist until the emergence of a new generation of glaciologists, such as Robert P. Sharp and others in the post-World War II years. Unfortunately for the science of glaciology, the 1906 Earthquake in San Francisco diverted his attention to the science of seismology, where he published a seminal paper on the "elastic-rebound theory" of earthquakes.]

Alaska-Canada Boundary Surveys

The boundary survey work done by the Americans and Canadians from approximately 1893 to 1920 to delineate the boundary between Canada and Alaska is an invaluable source of glacier photographs.[3] The settlement of the border involved a tremendous amount of hard work and sacrifice on the part of the boundary survey parties. The Anglo-Russian Treaty of 1825 fixed the boundary between British and Russian possessions in 1867; after Canada took over the British possessions in 1870 and 1871, the boundary description given in the treaty continued unchanged. The vague language of the 1825 treaty with regard to the Alaska panhandle led to U.S.–Canadian disagreement over the boundary description in that area. In 1892, the parties agreed to a joint survey of the disputed area by the Alaska Boundary Commission, which was made up of both Americans and Canadians. An unproductive field season in 1893 caused by poor weather was followed by a very successful season in 1894 and then a wrap-up of the work in 1895. In 1899, a Joint High Commission was still unable to settle the boundary dispute, and the differences culminated in the 1903 Alaska Boundary Tribunal. The six-member tribunal voted in favor of the United States, resulting in the *Atlas of Award,* which was published in 1904. Joint surveys by the United States and Canada, under the auspices of the International Boundary Commission, then followed from 1904 through 1928 to demarcate the boundary as indicated in the *Atlas*.

The surveys were performed by using a 5-year-old photo-topographic method developed for mountain work. A series of photographs were taken from a triangulated camera station covering a full 360 degrees. Camera stations established high in the Coast Mountains afforded clear views of the mountains, valleys, and glaciers farther inland. The result was a superb set of photographs of glaciers in the Coast Mountains dating from the 1890s. Several people are credited with much of the glacier photography: A.J. Brabazon, J.A. Flemer, James L. Gibbons, James G. Gibbons, Otto Klotz, William Ogilvie, J.J. McArthur, and A.C. Talbot. Otto Klotz, a Canadian, was one of the first to recognize that photography could be a useful tool for surveying and documenting the position of glaciers and for determining changes in glacier position with time. In 1894, he conducted a photo-topographic survey of the terminus of Baird Glacier (Klotz, 1895). He also realized that "Probably nowhere on the earth are better opportunities afforded for the study of living and dead glaciers than on the north-west continental shore of America" (Klotz, 1899, p. 534). He instructed future investigators to leave "readily recognizable marks near the ice-front...for the determination of smaller fluctuations of the glaciers" and to develop consistency in future photographic surveys so that the "study of the motion of glaciers will then be reduced to an exact science" (Klotz, 1899, p. 534).

National Geographic Society Expeditions

Starting in the 1890s, the NGS served as a focal point both for organizing and funding studies of Alaskan glaciers and for reporting their results in its magazine. In addition to Russell's descriptions of Mount St. Elias, the

[3] The editors appreciate the scholarly contribution to this section by C Suzanne Brown, formerly with the USGS, in using her extensive knowledge of the history of these surveys.

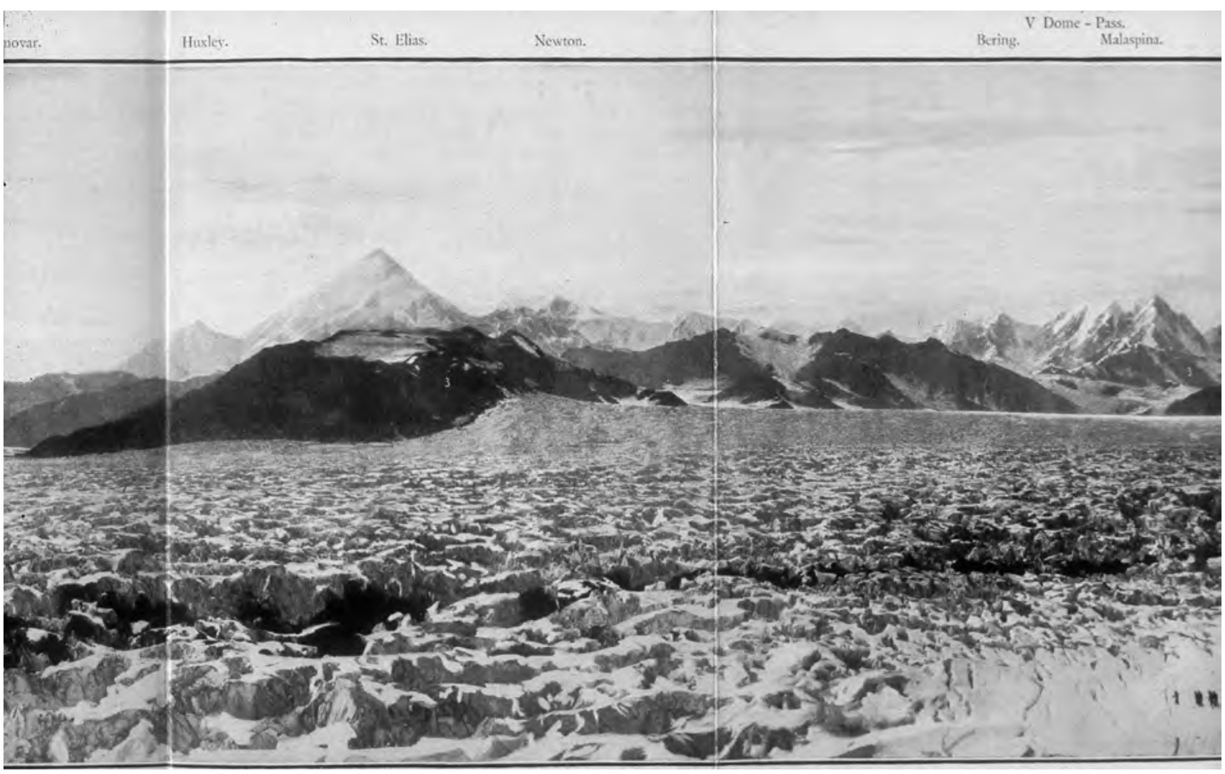
Malaspina Glacier, and Yakutat Bay (Russell, 1891, 1892, 1893), the NGS presented the results of the Frederick Schwatka and C.W. Hayes explorations of the Copper River and the area north of the St. Elias Mountains (Hayes, 1892; Schwatka, 1885); H.F. Reid's descriptions of Glacier Bay and Muir Glacier (Reid, 1892); G.K. Gilbert's summary of the glaciers of Alaska (Gilbert, 1903); Henry Gannett's description of Alaskan glaciers, including those in Prince William Sound (Gannett, 1899); E.R. Skidmore's descriptions of the glaciers of the Stikine River area and the exploration of Alaska and its glaciers (Skidmore, 1894, 1896, 1899); C.L. Andrews, Fremont Morse, and G.K. Gilbert's studies of Muir Glacier during the first decade of the 20th century (Andrews and Gilbert, 1903; Morse, 1908); W. C. Mendenhall's exploration of the glaciers of the Wrangell Mountains (Mendenhall, 1903a, b); studies of the glaciers of the Mount McKinley region by W.A. Dickey, A.H. Brooks, and Robert Muldrow (Dickey, 1897; Brooks and Reaburn, 1903; Muldrow, 1901); W.H. Osgood's descriptions of the glaciers of the Lake Clark region (Osgood, 1904); and Ferdinand Westdahl's photographs of glaciers in the Aleutian Islands (Westdahl, 1903); A.H. Brooks' studies of the geography of Alaska (Brooks, 1902, 1904, 1906a, b, 1911, 1914); and the work by Ralph Tarr and Lawrence Martin for the NGS (Martin, 1911; Tarr and Martin, 1910, 1914).

Duke of Abruzzi

In 1897, Prince Luigi Amedeo Di Savoia, Duke of Abruzzi, successfully led an expedition to the summit of Mount St. Elias and named many of the glacial features that were seen during the ascent. His narrator, Filippo de Filippi (1899), provided a description of a "huge glacier" observable from the summit. Not realizing that this glacier was part of the already named Bering Glacier, the Duke named the new discovery Columbus Glacier after Christopher Columbus: "This glacier, of even greater extent than the Seward, forms a vast snow-level showing no fissures on its surface" (de Filippi, 1899, p. 158).

One of the most significant products of the expedition were a number of foldout panoramic photographs of the surrounding region (fig. 21). Aside from those made by Israel C. Russell, these photographs were among the

Figure 21.*—Part of a 1897 panoramic photograph of "The Chain of Saint Elias and [Mount] Augusta seen from the Eastern Side of Seward Glacier, near its Outflow into Malaspina Glacier," made by members of the first successful expedition to the summit of Mount St. Elias led by the Prince Luigi Amedeo Di Savoia, Duke of Abruzzi. Photograph from de Filippi (1899).*



first photographs of the St. Elias Mountains ever made and the first of the large valley glaciers located at the base of Mount Logan.

Postcards

Toward the end of the 19th century and the early years of the 20th, a new industry developed: printing picture postcards of Alaska, many of which featured glacier termini. Many postcard photographs included enough of the geography around the glacier termini to qualitatively determine the location of the glacier at the time the photograph was exposed. Copyright dates in the captions and postmarks on the cards permit some accuracy in determining the date of the photograph. The glaciers of Glacier Bay, and Miles, Childs, Hubbard, Mendenhall, and Taku Glaciers (fig. 22) were frequently depicted.

Harriman Alaska Expedition

The Harriman Alaska Expedition of 1899, privately funded by Edward Henry Harriman, a wealthy financier and railroad executive, "was originally planned as a summer cruise for the pleasure and recreation of my family and a few friends. ...Our comfort and safety required a large vessel and crew. ...We decided, therefore, ...to include some guests who...would gather useful information and distribute it for the benefit of others" (Harriman, 1902, p. xxi-xxiii). So was born one of the most prolific multidisciplinary scientific explorations of Alaska. Twelve separate volumes of scientific observations were published as a result of the Harriman-funded investigations. Harriman chartered the steamer *George W. Elder* and invited about two dozen distinguished scientists to participate. Scientific disciplines covered by the expedition included ethnology, zoology, botany, geography, and geology. The expedition sailed from Seattle on 31 May 1899, covered more than 9,000 miles (14,500 km), and visited more than 50 locations. Glacierized areas studied included Lynn Canal, Davidson Glacier, Glacier Bay, La Perouse Glacier, Lituya Bay, Yakutat Bay (fig. 23), and Prince William Sound. The expedition returned to Seattle on 30 July 1899. The five geologists aboard the *George W. Elder* were William H. Dall, John Muir, Benjamin K. Emerson of Amherst College, Charles Palache of Harvard University, and Grove Karl Gilbert of the USGS. Edward S. Curtis, the expedition's official photographer, (who was later known for his photographs of Native Americans), took 1,000 photographs. Volumes 1 and 3 of the Harriman Alaska Expedition, which summarize the geological, glaciological, and glacial findings of the expedition, were published by Burroughs and others (1902) and Gilbert

Figure 22.—*Late 19th/early 20th century postcard of the terminus of Taku Glacier, Coast Mountains. This photograph of the Taku Glacier is one of the earliest in existence.*

Figure 23.—*20 June 1899 photograph of Cascading Glacier, descending from Mount Draper on the south wall of Nunatak Fiord, Saint Elias Mountains. John Muir is pictured at left. Photograph by USGS geologist Grove Karl Gilbert while he was a participant on the Harriman Expedition. Photograph Gilbert 303 from the USGS Photographic Library, Denver, Colo.*

(1904), respectively. As noted by Meier and Post (1980), Gilbert's contributions to the science of glaciology were significant.

Selected 20th Century Explorations and Observations of Alaska's Glaciers

Early USGS Investigations and Photography

Many late 19th and early 20th century USGS geologists carried cameras as a standard part of their field equipment. Although many studies were not primarily focused on glaciers, many of the photographs serve to provide a 50- to 75-yr extension back in time from the Landsat baseline period (1972–81). Between 1898 and 1924, for example, Alfred H. Brooks took more than 1,300 photographs: Tanana Glacier in 1899, the Kigluaik Mountains in 1900, the Tordrillo, Kichatna, and Talkeetna Mountains in 1902, Miles and Childs Glaciers in the Chugach Mountains in 1909 and 1910, Davidson Glacier in 1912, and the glaciers of Glacier Bay and Prince William Sound in 1924.

Similarly, in an Alaska career that spanned more than 35 years (1903–39), Fred H. Moffit took nearly 2,000 photographs: Resurrection Bay and its glaciers and Turnagain Arm with Portage and Twentymile Glaciers in 1904; the glaciers of the Wrangell, Skolai, and Chugach Mountains, including Kluvesna, Kennicott, Childs, Miles, Russell, Frederica, and Valdez Glaciers in 1905; Gulkana Glacier in 1910; Kuskulana, Kennicott, and Chitina Glaciers in 1919; Kennicott Glacier in 1922; the glaciers of Prince William Sound, including McCarty, Chenega, and Columbia Glaciers in 1924; the glaciers of Prince William Sound, including Port Nellie Juan, Taylor, Cottrell, Columbia, Kings, Falling, and Contact Glaciers in 1925; Chitistone, Russell, Frederica, Nizina, and Rohn Glaciers in 1927; Kennicott Glacier in 1928, Muldrow Glacier in

1930; Black Rapids Glacier in 1937; and Black Rapids, Jarvis, and Gerstle Glaciers in 1939. Other USGS geologists who took photographs of glaciers in Alaska included Stephen Capps (1908–36), Ernest Leffingwell (1906–14), Alfred G. Maddren (1906–17), Walter C. Mendenhall (1898–1902), John B. Mertie (1911–42), and Sidney Paige (1905 to about 1908). Many of these photographs, a good number of which are archived in the USGS Photographic Library in Denver, Colo., are used in later sections of this report to visually document historic glacier changes throughout the State of Alaska.

In 1905, 1908, and 1909, the USGS investigated the glaciers of Prince William Sound and the southern part of the Kenai Peninsula. Valdez, Shoup, Columbia, and Meares Glaciers were investigated by U.S. Grant and Sidney Paige in 1905. In 1908, Valdez, Shoup, Columbia, and Barry Glaciers, as well as the glaciers of Port Nellie Juan, Icy Bay, Port Bainbridge, and Thumb Cove of Resurrection Bay were investigated by U.S. Grant and D. F. Higgins. In 1909, Grant and Higgins visited and mapped all of the glaciers of the northern shore of Prince William Sound from Port Valdez westward to and including Blackstone Bay and most of the glaciers of the southern shore of the Kenai Peninsula (Grant and Higgins, 1911a, b, 1913). As a result, “All of the tidewater glaciers and many near tidewater were seen and some notes, photographs, and maps were made of all of the tidewater glaciers and many of the others” (Grant and Higgins, 1913, p. 7). The results contain many maps and plates that can be compared with later USGS and American Geographical Society (AGS) maps to document changes in the position of glacier termini.

Of the more than 235 photographs they took, many were published in the 1913 summary of their observations (Grant and Higgins, 1913). Like so many other of their contemporaries, Grant and Higgins realized the significance of systematic, sequential photography of glaciers. “In any study of the positions of glacier fronts, dated photographs are of prime importance, for they furnish accurate records and can be obtained when there is no time for detailed observation. If the photographs are taken from easily recognized stations which can be occupied in later years their value is still greater” (Grant and Higgins, 1913, p. 10). Realizing that documented photographs “will be of so great value in the study of future fluctuations of these ice streams” (Grant and Higgins, 1913, p. 10), they presented systematic lists of photographs available for each glacier studied. In addition to their photographs made in 1908–09, they included photographs by F.C. Schrader in 1898, G.K. Gilbert and W.C. Mendenhall in 1899, A.C. Spencer in 1900, and Sidney Paige in 1905 (Grant and Higgins, 1913).

Ralph S. Tarr and Lawrence Martin

Ralph S. Tarr of Cornell University and Lawrence Martin of the University of Wisconsin were involved in more than half a dozen expeditions to study the glaciers of southeastern and south-central Alaska, concentrating on the areas of Yakutat Bay, Malaspina Glacier, the Copper River, Cook Inlet, the Alaska Peninsula, Controller Bay, and Prince William Sound. Before his death in 1912, Tarr conducted investigations in 1905 and 1906 for the USGS and in 1909 and 1911 for the NGS. In 1904, Martin also worked with the USGS. His 1905 investigations were funded by the AGS. In 1909, 1910 (Martin, 1911), and 1913, his studies were funded by the NGS. Investigations in 1905, 1909 (Tarr and Martin, 1910), and 1911 were performed together.

The rationale they presented for studying Alaska glaciers is still relevant nearly 100 years later: “Alaska offered the best field in the world for these investigations, its glaciers being the largest in the world except those of the polar regions. There are thousands of them and only a few of them even have been named” (Tarr and Martin, 1914, p. vii).

Alaskan Glacier Studies, completed by Martin after Tarr’s death in 1912 and published in 1914 (Tarr and Martin, 1914) by the NGS, is their *magnum opus*. The 498-page volume is the most comprehensive treatment of Alaska’s glaciers released before the comprehensive research by William O. Field and his colleagues in the 1970s (Field, 1975a). Containing 172 numbered plates, many with multiple photographs, 72 text illustrations, a frontispiece, and 10 folded maps in a rear pocket, *Alaskan Glacier Studies* is among the best illustrated glacier books ever produced. A number of other scientific publications (for example, Bean, 1911) and a unique 1:80,000-scale relief model of the Malaspina Glacier region (Martin, 1909) also resulted from their work.

Tarr and Martin (1914) used several innovative graphic approaches to illustrate the physical appearance and size of many Alaskan glaciers, such as superimposing a map of the greater Boston area on a map of the Malaspina Glacier to show the large area that the glacier covered; superimposing the street plan of the greater Washington, D.C. area on a map of the Columbia Glacier to show the area covered by the glacier; combining a scaled image of the U.S. Capitol (fig. 24) and other well-known buildings with the vertical front of a glacier to show the height of the ice terminus, and showing the Hubbard Glacier with three European Alps glaciers superimposed to document its great area and length (Tarr and Martin, 1914, p. 102).

Several thousand photographs resulted from the expeditions. During expeditions after the 1905 expedition, many of the photographs were made by Oscar D. von Engeln, a professional photographer who became a geologist as a result of his involvement in these expeditions (fig. 25). Later, following Tarr's death, von Engeln became Professor of Geomorphology at Cornell University. In 1910, von Engeln published an article in *National Geographic Magazine* providing tips to maximize success in obtaining photographs in Alaska's glacier-covered areas (von Engeln, 1910).

Early Aerial Photography of Glaciers by the U.S. Government

Between 1907 and 1916, James W. Bagley, a USGS topographer, experimented with the use of panoramic cameras for mapping large areas (Bagley, 1917). He used several such cameras in his topographic surveys of Alaska (fig. 26*A*). Before World War I, Bagley was commissioned by the U.S. Army and assigned the task of developing a multiple-lens camera for mapping surveys from aircraft. This type of multiple-lens camera "is regarded primarily as an instrument which makes use of the principles of plane-table surveying for constructing a map rather than an instrument for picturing the surface of the earth" (Sargent and Moffit, 1929, p. 144). It was this type of camera, referred to as a Bagley T-1 Camera, that would be used for the first systematic aerial photographic survey of Alaska (fig. 26*B*).

Two U.S. Government aerial photographic expeditions in 1926 and 1929 produced the first vertical aerial photographs of Alaska glaciers (fig. 27). According to R.H. Sargent, Chief Topographer for the Alaska Branch of the USGS and the USGS representative on both expeditions, "It is doubtful whether many exploratory expeditions of late years have contributed so much of financial and scientific value as these two aerial surveys" (Sargent, 1930, p. 145). During the fiscal year 1924–25, funds were identified to pay for a 1926 effort to obtain aerial photographs of 10,000 square miles of Alaska. This survey would "test this new method in regions where large areas are particularly adapted to its success and the common methods are difficult to apply because the country is remote and many parts of it are, at present almost inaccessible" (Sargent and Moffit, 1929, p. 144).

In response to a request from the USGS, the Department of the Navy organized the Alaskan Aerial Survey Expedition in 1926. Under the command of Lt. Ben Wyatt, USN, the 112-man expedition consisted of the tender *Gannet*, four open-cockpit Loening Amphibian biplanes, and a 140-ft-[43-m-] long barge completely equipped to perform all necessary photographic and film-processing operations (fig. 28). Sargent was responsible for selecting the specific areas to be flown, preparing flight lines, and inspecting and transmitting film to the USGS in Washington, D.C. Photographs at a scale of approximately

Figure 24.—An example of Tarr and Martin's innovative approach to making information about glaciers understandable to the lay public by depicting part of the terminus of the Childs Glacier with the U.S. Capitol superimposed for scale (Tarr and Martin, 1914, Plate CXLVIII, p. 416).

Figure 25.—Oscar D. von Engeln, photographer on the 1910 NGS Alaska Expedition led by Lawrence Martin, washing a strip of negatives in Yakutat Bay sea water, surrounded by icebergs. Photograph from Cornell University archives. Original photograph in National Geographic Society archives, Washington, D.C. (Bendavid-Val and others, 1999).

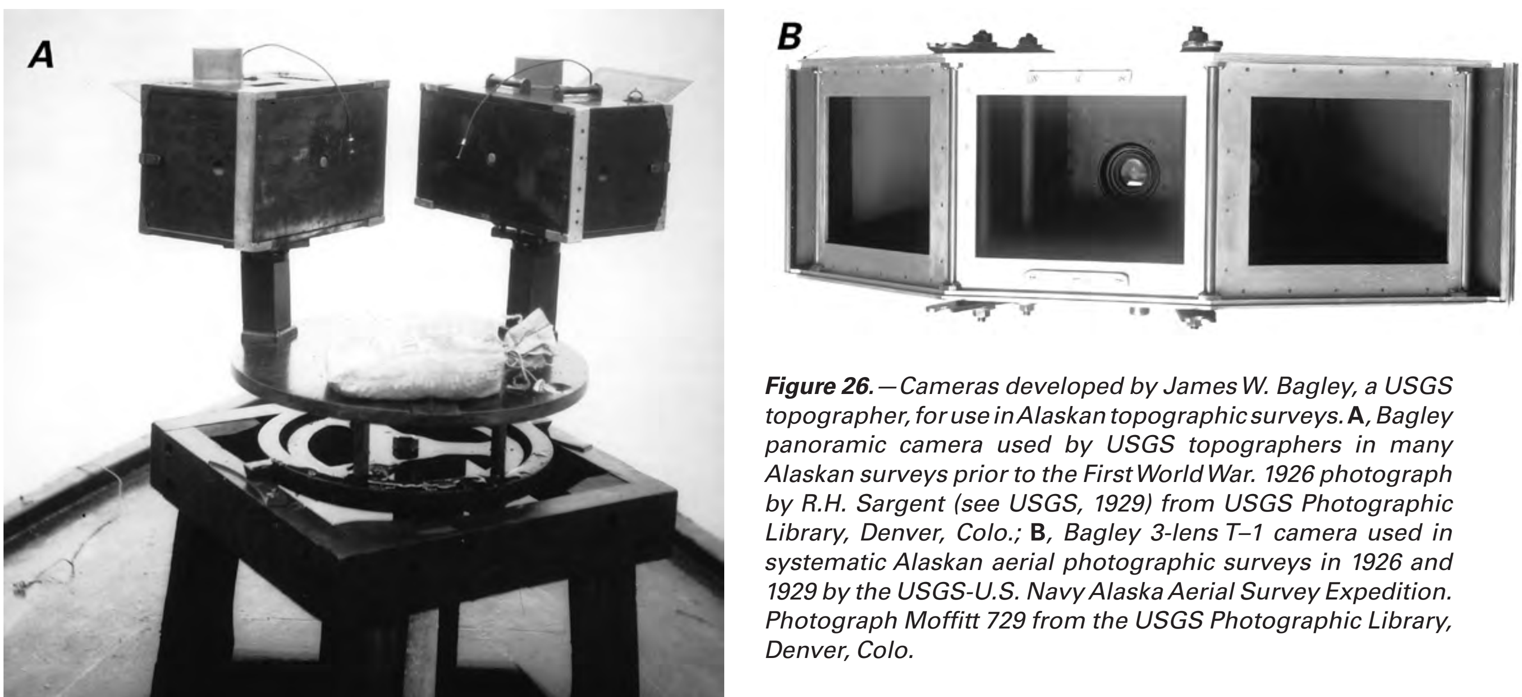


Figure 26.—Cameras developed by James W. Bagley, a USGS topographer, for use in Alaskan topographic surveys. **A**, Bagley panoramic camera used by USGS topographers in many Alaskan surveys prior to the First World War. 1926 photograph by R.H. Sargent (see USGS, 1929) from USGS Photographic Library, Denver, Colo.; **B**, Bagley 3-lens T–1 camera used in systematic Alaskan aerial photographic surveys in 1926 and 1929 by the USGS-U.S. Navy Alaska Aerial Survey Expedition. Photograph Moffitt 729 from the USGS Photographic Library, Denver, Colo.

Figure 27.—Vertical aerial photograph of North Crillon Glacier (darker surface) flowing into an arm of Lituya Bay and South Crillon Glacier (lighter surface) flowing into both Lituya Bay and Crillon Lake, Fairweather Range, Saint Elias Mountains. It is an example of the type of aerial photography produced by the 1926 and 1929 USGS-US Navy Alaska Aerial Survey Expedition using the Bagley T–1 camera. This photograph was taken in 1929 and is Alaska 177 from the USGS Photographic Library, Denver, Colo.

1:20,000 were obtained from an altitude of 10,000 ft [3,050 m] [Editors' note: 6-in (15 cm) focal-length lens] on flight lines of 3.5 miles (5.6 km). In all, 5,760 three-image aerial photographs (a total of 17,280 negatives) were exposed with the Bagley T-1 cameras during the expedition. According to Sargent and Moffit (1929), each triplet includes "a central picture which represents the ground directly under the airplane and two side pictures which represent adjoining areas on each side of the central picture. A set of three pictures thus taken represents an area of about 11 square miles when the plane flies at the preferred elevation of 10,000 ft (3,050 m)" (Sargent and Moffit, 1929, p. 160) (fig. 29). The Bagley T-1 camera was the forerunner of the Trimetrogon camera that was used extensively by the USN in support of the USGS mapping program in Antarctica in 1946–47 (USN *Operation Highjump*) and by the U.S. Air Force in the late 1940s for the USGS mapping program in Alaska.

Among the areas photographed were Admiralty, Annette, Dall, Duke, Etolin, Gravina, Heceta, Kosciusko, Kuiu, Kupreanof, Long, Mitkof, Prince of Wales, Revillagigedo, Sikkwan, Tuxekan, Woronkofski, Wrangell and Zarembo Islands; the Cleveland and Lindenberg Peninsulas; and the area of the Chickamin River. Glaciers are present on Admiralty and Kupreanof Islands and in the headwaters of the Chickamin River.

The 1926 expedition was considered to be so successful that a similar mission was conducted in 1929. Photographing glaciers was one of the highest priorities of this expedition. "It was my purpose to have the fronts of all large glaciers in the region photographed, both by the mapping and the oblique cameras, so as to record the positions of the fronts of the glaciers in 1929. These vertical photographs reveal the phenomenon of glacier flow in a manner never before recorded in the United States. It is believed that there is a wealth of scientific information for the glaciologists in these pictures" (Sargent, 1930, p. 145). The 1929 expedition (fig. 30) produced approximately 7,600 three-image photographs, covering approximately 12,750 mi^2 (33,023 km^2) of Alaska.

An additional 692 oblique aerial photographs were also taken. Film was exposed at an altitude of 10,900 ft (3,325 m) producing a picture of an area more than 6 mi (9.7 km) wide and about 2½ miles [4 km] in the direction of the flight. Additional Alaskan Aerial Survey Expedition missions by the Navy Department acquired photographs of Alaskan glaciers in 1932 and 1934. The 1934 missions photographed Finger Glacier, La Perouse Glacier, Malaspina Glacier, Icy Bay, and Bering Glacier.

Figure 28.—1926 photograph of Alaska Aerial Survey Expedition operations in Juneau Harbor, showing the stern of the tender Gannet; one of the open-cockpit Loening Amphibian biplanes used to obtain aerial photography; and the stern of the 140-ft-long barge used for photographic and film-processing operations. Photograph Alaska 363 from the USGS Photographic Library, Denver, Colo.

Figure 29.—Phototriplet obtained with the Bagley 3-lens T–1 camera on the 1926 Alaska Aerial Survey Expedition (USGS, 1929). This triplet shows a recently deglacierized cirque and valley in the Alexander Archipelago. Photograph Alaska 175 is from the USGS Photographic Library, Denver, Colo.

Figure 30.—1929 oblique aerial photograph by the Alaska Aerial Survey Expedition of Twin Glaciers, Coast Mountains, northeast of Juneau. The photograph was made from the oblique camera in plane 3. Photograph Alaska 188 is from the USGS Photographic Library, Denver, Colo.

Later Vertical Aerial Photography Programs

Between 1941 and the late 1950s, several U.S. Government aerial photographic programs produced systematic vertical aerial coverage of many parts of Alaska. Glaciers of the Gulf of Alaska region were photographed with a 9-lens mapping camera (fig. 31) in 1941 and again in 1959 and with the Trimetrogon camera system in 1948. Glaciers in much of the southeastern part of Alaska were photographed with a single-lens vertical camera in a series of U.S. Air Force photographic missions between 1948 and the middle 1950s, all designated by the prefix "SEA." Since the early 1950s, Federal, State of Alaska agencies, and private companies have conducted many vertical photographic missions of Alaska that included glacierized areas. For example, during the 1993–95 surge of Bering Glacier, the USGS, the Bureau of Land Management, and the Department of the Interior's

Figure 31.—*1959 nine-lens vertical aerial photograph of Fairweather Glacier, St. Elias Mountains. The nine-lens camera, designed by Oliver Reading in the early 1930s, was a state-of-the art aerial camera used by the U.S. Coast and Geodetic Survey for three decades. The nine-lens system was used to minimize internal distortion in the photography. This camera system was used several other times to photograph the glaciers in southern Alaska. Looking closely at the photograph, it is possible to see the central octogon-shaped image, surrounded by eight joined polygons.*

Office of Aircraft Services flew nearly a dozen individual missions to monitor the changes in the terminus region and lower reaches of the glacier.

The most significant aerial photographic program for Alaska began in 1978, when a number of Federal and State of Alaska agencies pooled their resources and initiated an integrated and standardized program, the Alaska High-Altitude Aerial Photography (AHAP) Program to develop a uniform aerial photographic database of Alaska. The purpose of the program was to cover the entire State of Alaska with "a set of unified and coordinated photographs" (Brooks, 1988). By 1986, the last year of data acquisition, 90 percent of Alaska was imaged with both black-and-white and color-infrared vertical aerial photography. The aerial photographs were acquired by a NASA U–2C high-altitude aircraft from 65,000 ft. Black-and-white aerial photography is at a scale of approximately 1:120,000; color-infrared aerial photography is at a scale of approximately 1:65,000. A black-and-white aerial photograph covers an area of about 250 mi^2 (648 km^2); a color-infrared aerial photograph covers an area of about 64 mi^2 (166 km^2) (fig. 32). Many of these photographs are used in the later sections of this report to document glaciers throughout Alaska.[4]

William Osgood Field

William O. Field [5] made his first visit to Glacier Bay in 1926. It was the first of many scientific visits to Alaska that would continue for the next six decades. The primary purpose of the 1926 trip was to see how the glaciers in Glacier Bay had changed since last reported by H.F. Reid in 1890 and 1892, H.P. Cushing in 1891, and G.K. Gilbert in 1899 (Field, 1926). Field recorded the glacier terminus positions throughout Glacier Bay, including the spectacular find that Johns Hopkins Glacier had retreated 6 to 7 miles from where it had last been seen in 1912. In 1931, Field visited glaciers in Prince William Sound to reoccupy photo-survey stations established by Lawrence Martin in 1909, 1910, and 1911, by Grant and Higgins in 1905, 1909, and 1910, and by Gilbert and Gannett during the 1899 Harriman Expedition. In 1935, Field returned to both Glacier Bay and Prince William Sound, the beginning of systematic repeated measurements and photographs of glacier termini in both places. His last field trip to Glacier Bay was in 1982 and to Prince William Sound in 1976, but his son J.O. Field and C S. Brown reoccupied his photo stations in Glacier Bay in 1989, 1994, 1997, and 2000 to continue his legacy. Many of Field's photo stations were revisited in 2003 and 2004 by a joint USGS-U.S. National Park Service (NPS) expedition led by the author. His photographs and observations comprise the largest ground-based photographic data base on the changes in Alaska glaciers in existence. Field also established numerous survey/photographic stations that were reoccupied, often in successive years. The result was numerous publications documenting glacier variations (for example, Field, 1942, 1948; for a complete list, see Field's (2004) appendix B) and a series of maps that systematically depicts changes in the positions of individual glaciers (figs. 33, 34). Field was unique in that he personally knew many of the pioneer scientists/explorers who visited Alaska around the turn of the 20th century. A link to these pioneers and to their early work in glaciology (Field, 2004), Field collected many of their photographs, which, together with all of his photographs and other materials, are housed in the Archives of the Alaska and Polar Regions Department in the Elmer E. Rasmuson

[4] The AHAP aerial photographs are archived at the USGS EDC in Sioux Falls, SD and at the GeoData Center, Geophysical Institute, University of Alaska, Fairbanks, AK (http://www.gi.alaska.edu/services/geodata/). AHAP photographs are archived at the GeoData Center by flight line and frame number (for example, L185F4825). The 3-digit L number could not be found for a few photographs; LXXX is used to indicate missing data.

[5] The editors appreciate the contribution to this section by C Suzanne Brown, formerly with the USGS. Her long professional association with William O. Field, her extensive knowledge of his published and unpublished work on Alaska's glaciers, and her recently published, richly illustrated, oral biography of him (Field, 2004) have been of enormous help.

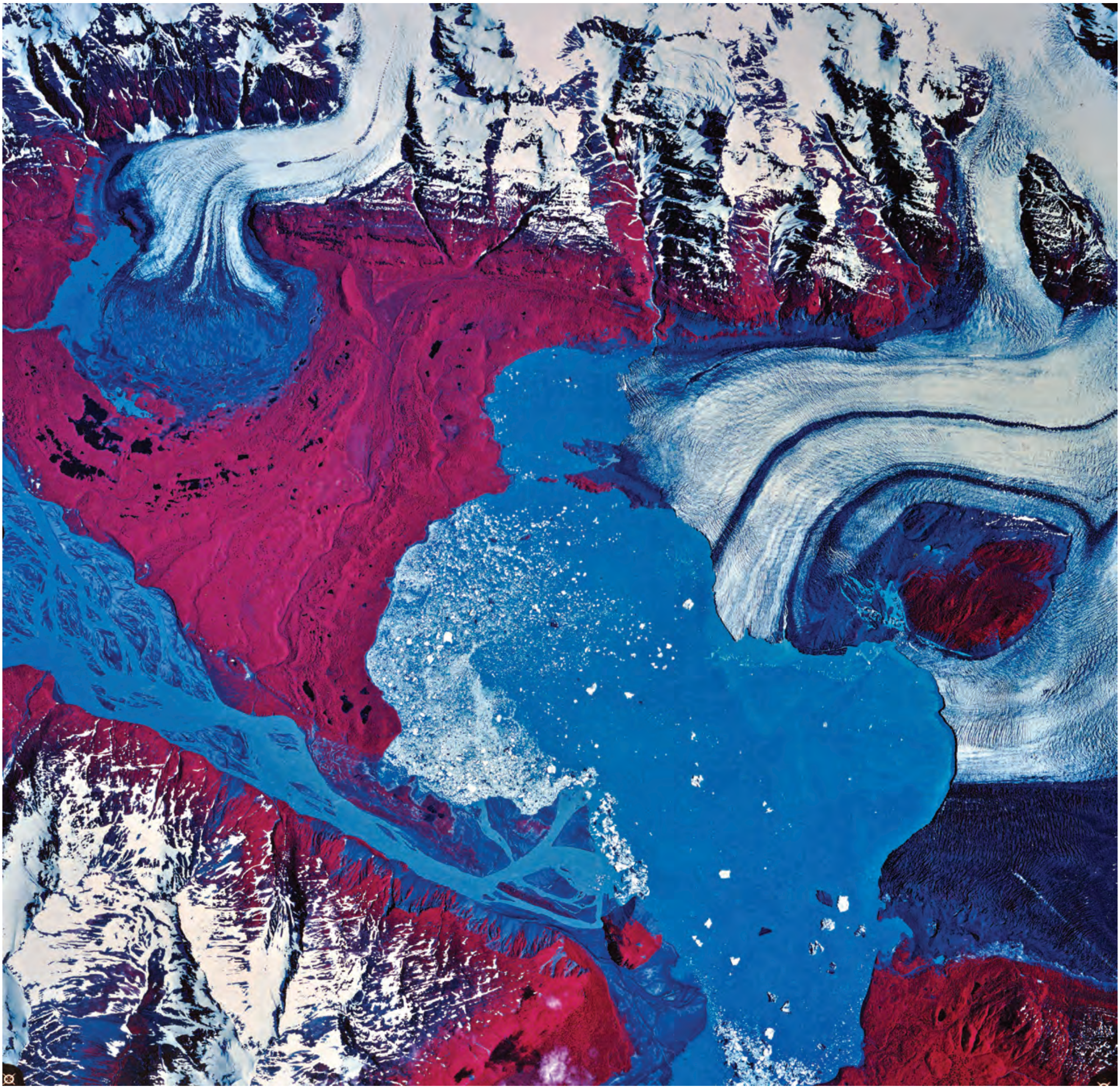


Figure 32.—*NASA high-altitude, false-color infrared vertical aerial photograph (Kodak SO–193 film with a Wratten 12 filter) of Alsek River and part of the terminus of Alsek Glacier, southeast of Yakutat, Alaska. The photograph (1:65,000-scale) was acquired by a National Aeronautics and Space Administration Ames U–2C aircraft on 21 June 1978 from an altitude of 19,800 m, with an RC–10 camera having a 305-mm (12 in) focal length, in support of the interagency Alaska High-Altitude Aerial Photograph Program (AHAP). The spectral range of the film-filter combination is 0.51 to 0.90 μm. Aerial photograph is from the USGS EROS Data Center, Accession No. 578002618 ROLL, frame 4898; or AHAP photograph no. L170F4898 from the GeoData Center, Geophysical Institute, University of Alaska, Fairbanks, Alaska.*

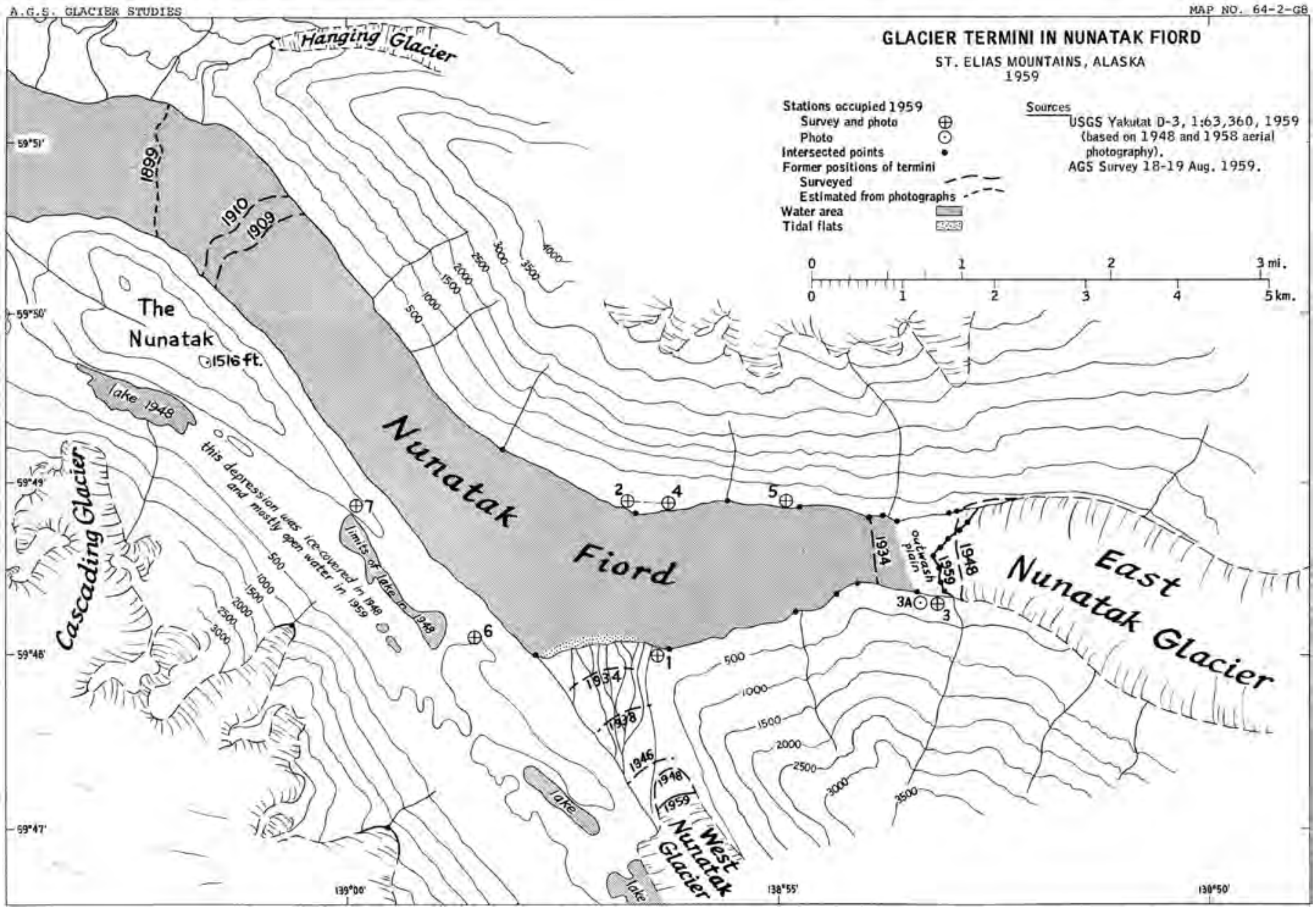
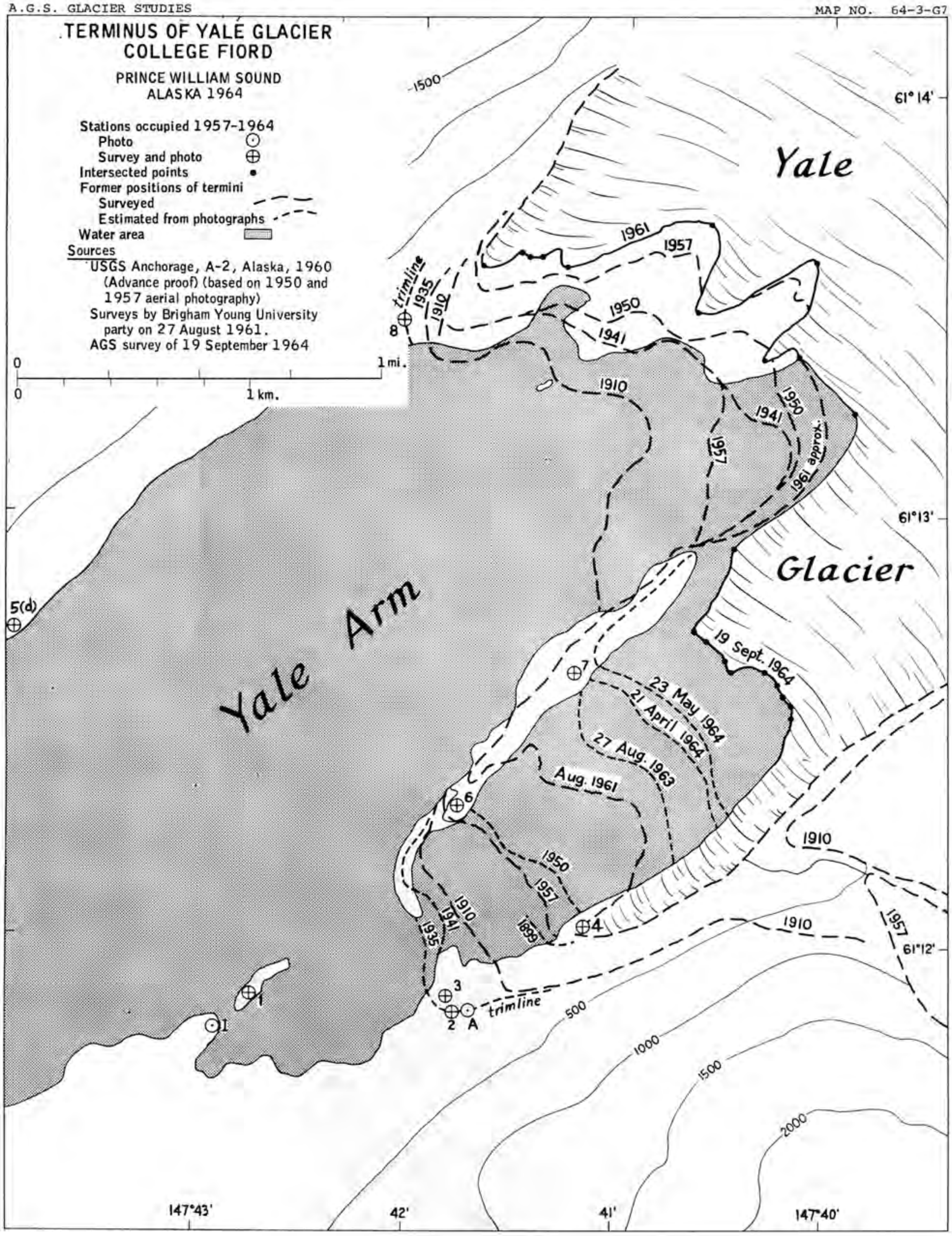


Figure 33.—American Geographic Society Glacier Studies Map 64–2–G8 compiled by W.O. Field in 1959, showing the chronology of changes in the position of glacier termini in Nunatak Fiord, St. Elias Mountains, between 1899 and 1959.

Library at the University of Alaska Fairbanks. He also bequeathed funds to the University of Alaska: (1) to fund the cataloging of his extensive archive of photographs (more than 100,000) and (2) to establish an endowment to support continued research on changes in the glaciers of Glacier Bay National Park and Preserve.

In 1940, Field began working for the American Geographical Society (AGS) in New York City (Morrison, 1995). According to Mel Marcus, “As glaciology developed [in America] in the 1950s culminating in the International Geophysical Year (IGY) in 1957–58, Field’s office was an informal, de facto headquarters for the discipline” (Field, 2004). In 1956, the Technical Panel on Glaciology of the International Geophysical Year (IGY), chaired by Field, recommended that “one of the most useful contributions of the IGY to glaciology would be the preparation of precise maps, on large scales, of selected small glaciers” (American Geographical Society, 1960). The rationale for the project was that “the maps would form a permanent record of the condition of these glaciers so that at a future date they could be resurveyed and compared” (American Geographical Society, 1960). With funding from the National Science Foundation (NSF), Field selected a number of “simple unbranched” valley glaciers ranging from 5 to 8 km in length. Logistical planning was provided by Austin Post. The AGS Glacier Mapping Project ultimately produced 1:10,000-scale maps using photogrammetric and field methods for Lemon Creek, Polychrome, West Gulkana, Worthington, Little Jarvis (fig. 35), *Salmon Creek* (given the official name of Bear Lake Glacier in 1959), Kilbuck (now known as Chikuminuk Glacier, although Kilbuck Glacier is still recognized as an official variation), and McCall Glaciers in Alaska and Blue Glacier in Washington. The map of Little Jarvis Glacier (fig. 35) is an example of an AGS map produced during the IGY. In the 1980s, Lemon Creek and West Gulkana



Glaciers were resurveyed by teams led by Mel Marcus (Marcus and Reynolds, 1988; Marcus and others, 1995). Between 1993 and 1996, all eight Alaska glaciers mapped by the AGS were remapped by Sapiano and others (1998) using airborne surface-elevation, laser-altimeter profiling augmented with global-positioning system (GPS) methods. Elevation, volume, and terminous changes were determined for each glacier. The results of this remapping are presented in later sections of this report. In 1975, Field published *Mountain*

Figure 34.—*American Geographical Society Glacier Studies Map 64–3–G7 compiled by W.O. Field in 1964, showing the chronology of changes in the position of glacier termini in Yale Arm, Prince William Sound, between 1910 and 1964.*

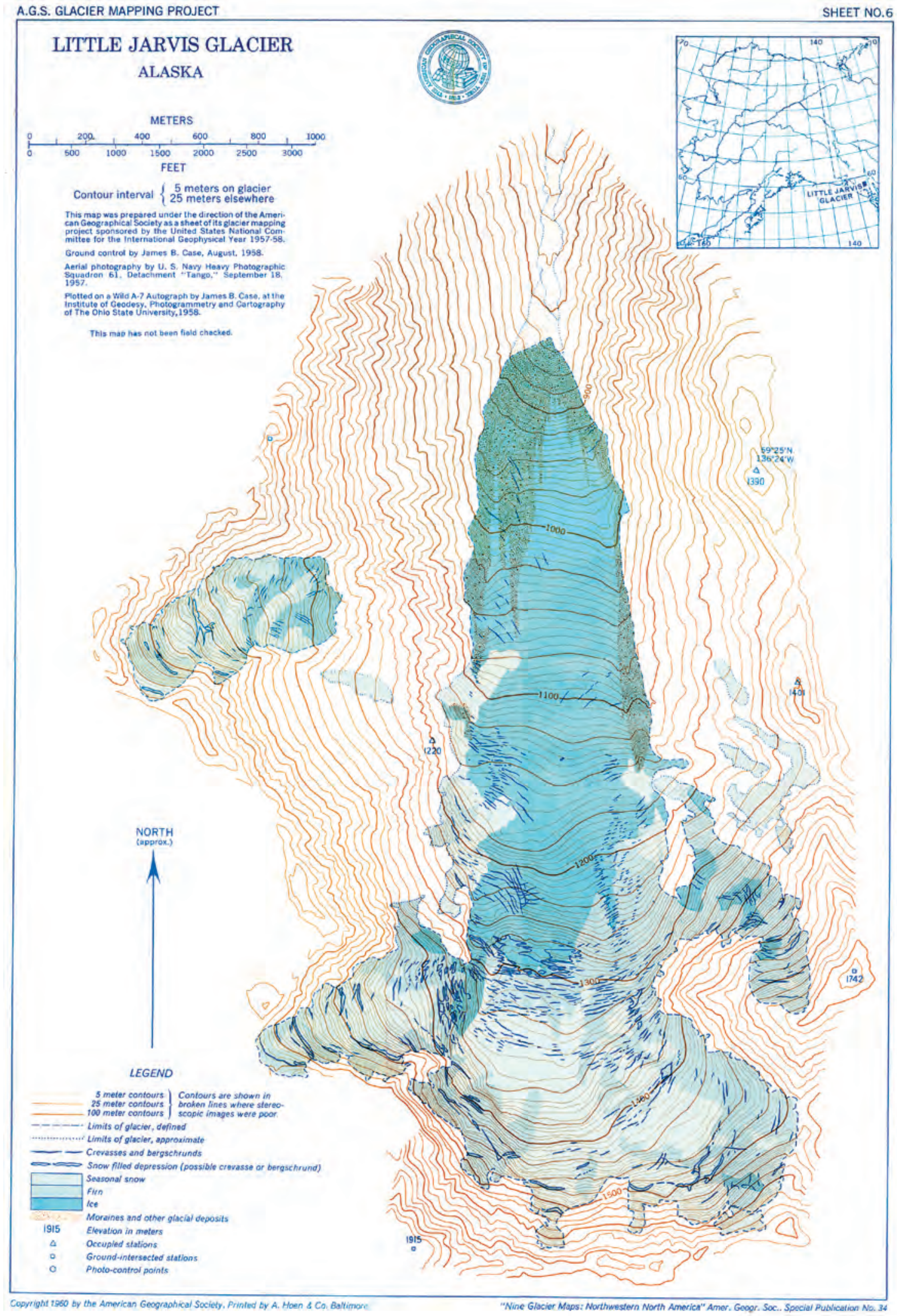


Figure 35.—*Copyrighted map of Little Jarvis Glacier, Alaska, produced by the American Geographical Society (1960) as part of its Glacier Mapping Project 1960, as a contribution to the International Geophysical Year 1957–58. It is based on 18 September 1957 vertical aerial photographs. Used with permission. In addition to the Little Jarvis Glacier, seven other glaciers in Alaska—Lemon Creek, Polychrome, West Gulkana, Worthington, Bear Lake, Chikuminuk, and McCall Glaciers—were mapped as well as Blue Glacier in Washington. All maps were produced at 1:10,000 scale.*

Glaciers of the Northern Hemisphere, a three-volume set complete with an atlas of maps (Field, 1975a). This work is the most comprehensive summary of the glaciers of Alaska and other glaciers of the Northern Hemisphere; the regional maps in the atlas by Field (1975a) are reproduced in each geographic section of this chapter.

Bradford Washburn

In the early 1930s, Bradford Washburn began photographic reconnaissances of Alaska mountains as a prelude to many of his climbing expeditions. His black-and-white photographs are famous for their artistic quality, documentation of glacial and fluvioglacial processes, and historic record of the position of termini and margins of many Alaskan glaciers. Washburn's negatives and prints are archived at the Elmer E. Rasmuson Library, University of Alaska (Fairbanks), and at the Museum of Science (Boston). Many of his photographs are included in this chapter. A comparison of his large-format (23×23 cm) oblique aerial photographs with those taken later by Austin Post and Robert M. Krimmel, two other superb aerial photographers of Alaska's glaciers, visually document many changes. Many of his photographs include some of the earliest aerial observations of glaciers in the Fairweather Range, St. Elias Mountains, Chugach Mountains, and Alaska Range. In 1933 and 1934, Washburn photographed the glaciers of the Fairweather Range between Finger Glacier and Malaspina Glacier. In 1937, he photographed Lituya Bay and Fairweather Glacier; in 1938, he photographed the area between Yakutat Bay and Bering Glacier (fig. 36), including the Malaspina Glacier (fig. 37) and the Barnard Glacier (fig. 38) north of the Chitina River. In 1935, much of his aerial photography was north of the Alaskan border in Canada's Yukon Territory, but he did conduct a dog-team survey of Alaska's Art Lewis and Nunatak Glaciers. In 1941, he photographed the Susitna Glacier. Support for these photographic expeditions was provided by the NGS. Washburn returned to Alaska many times thereafter, continuing to photograph glaciers at a number of locations. In 1966, he rephotographed the Malaspina Glacier and conducted a photographic survey of the Mount Hubbard-Mount Kennedy area for the NGS (Washburn, 1971a, b) that was the basis for a superb

Figure 36.—*1938 oblique aerial photograph of the southeastern terminus of Bering Glacier, Chugach Mountains, looking west-northwest. Photograph courtesy of Bradford Washburn, Museum of Science (Boston, Mass.). This image is the earliest known aerial photograph of the Bering Glacier.*

__Figure 37.__—Oblique aerial photograph of contorted medial moraines ("marble-cake") of Malaspina Glacier, Saint Elias Mountains, taken in August 1938. Photograph (negative no. 5742) courtesy of Bradford Washburn, Museum of Science (Boston, Mass.).

__Figure 38.__—Oblique aerial photograph of an array of subparallel medial moraines on the Barnard Glacier and tributary glaciers, Saint Elias Mountains, taken in August 1938. Photograph (negative no. 1355) courtesy of Bradford Washburn, Museum of Science (Boston, Mass.). Compare also with figure 181.

map (Williams and Ferrigno, 2002, fig. 5). A recently published biography of Washburn documents his extensive use of photography in his Alaskan expeditions (Sfraga, 2004).

Austin Post

From 1960 through 1983, Austin Post, first with the University of Washington and later with the USGS, conducted annual photographic missions to document changes in glaciers. Post received his introduction to "organized aerial photography of glaciers in western North America" (Post and LaChapelle, 1971, p. i; 2000, p. xii), from Richard C. Hubley of the University of Washington. In 1955, Hubley conducted a photo reconnaissance of the North Cascade Mountains. During the IGY, Post was involved in planning the logistics of the *AGS Glacier Mapping Project*, which included obtaining black-and-white aerial photography of the glaciers to be mapped.

Beginning in 1960, Post began a systematic aerial photographic effort, the *Program for Aerial Photographic Surveying of Glaciers in Western North America*. The first 3 years of the program were funded by the NSF and administered by the Department of Meteorology and Climatology, University of Washington. The primary focus of the program was the glaciers of southeastern and south-central Alaska. However, glaciers in the Alaska Range, the Alaska Peninsula, and the Wrangell Mountains, as well as glacierized mountain ranges of the Western United States and Canada, were also photographed. After the end of the 1963 collection year, the program was nearly terminated. However, the value of photographing Alaskan glaciers annually was confirmed by the numerous photographs (see fig. 229*C*) made in the years immediately following the Great Alaska Earthquake of [27 March] 1964. Post writes that "After the quake, Mark F. Meier, Director of the U.S. Geological Survey's Glaciology Project Office in Tacoma, Washington wanted me to continue the photography and record changes resulting from the shaking. Again, so many interesting things were observed that Mark continued this program the next year, and two years later, after a monumental effort, actually obtained for me a professional position with the Survey" (Post, 1995, p. 19).

During the first decade of the program, Post used aircraft of opportunity, flying with William R. Fairchild and many well-known Alaskan bush pilots. Beginning in the early 1970s, many photo missions were conducted in cooperation with Robert M. Krimmel, USGS glaciologist and pilot; Krimmel frequently piloted the aircraft. Typically, both vertical and oblique photographs were made on each flight. In all, about 100,000 negatives were exposed. Many of these aerial photographs are used in the geographic-area sections of this report to document glacier changes throughout the State of Alaska. Post's aerial photographs are archived at the GeoData Center, Geophysical Institute, University of Alaska, Fairbanks [http://www.gi.alaska.edu/]. The reader is also referred to Post and LaChapelle's (1971, 2000) superbly illustrated book on *Glacier Ice*, an excellent compilation of large-format black-and-white photographs of glaciers in Alaska and other glacierized regions on Earth.

Robert M. Krimmel

Robert M. Krimmel, who has already been mentioned in the previous section as one of the pilots of aircraft used by Austin Post to acquire aerial photographs of glaciers in Alaska, the western United States and western Canada, also has a distinguished two-decade record (1984–90) of acquiring large-format (23×23 cm) black-and-white oblique aerial photographs of glaciers in Alaska, the United States, and Canada. Many of his superb photographs, which he took in 1984, 1986, 1988, and 1990, are reproduced in this chapter.

Ground, Vertical, and Oblique Aerial Photographs by Other USGS Glaciologists

Three other USGS glaciologists have also been active in long-term photographic documentation of Alaska's glaciers: Lawrence C. Mayo (Fairbanks, Alaska), Dennis C. Trabant (Fairbanks, Alaska), and Bruce F. Molnia (Reston, Va). Mayo and Trabant have extensive archives of ground photographs of Alaskan glaciers from several decades of field work in Alaska, especially annual mass-balance studies of Wolverine, Black Rapids, and Gulkana Glaciers, and rapid recession of the Columbia Glacier. In addition, Molnia's multiyear investigations of Bering Glacier have produced a large volume of ground and oblique aerial photography.

For 36 years (beginning in 1968), Molnia photographed and imaged, on the ground and from the air, glaciers of the Coast, St. Elias, and Chugach Mountains (initially using a 35-mm single-lens, reflex camera and later a digital camera). Beginning in 1974, as part of a U.S. Government assessment of the impact of oil and gas activities in the Gulf of Alaska region, he began aerial and ground-based glacier photography that has produced more than 15,000 small-format (35-mm) color photographs. Areas of geographic emphasis include Bering and Malaspina Glaciers, Icy and Glacier Bays, and the Juneau Ice Field. Many of these small-format color, oblique aerial photographs are used in the geographic-area sections of this report. *Alaska's Glaciers* (Molnia, 1982, 1993, 2001), a summary of the distribution and history of investigation of many of Alaska's glaciers, contains small-format color photographs of about 100 Alaskan glaciers. In the late 20th century and early part of the 21st century, Molnia added digital imagery to the documentation of Alaska's glaciers. In 2003, in a partnership between the USGS, Alpha DVD, and the Alaska Geographic Society, *Glaciers: Alaska's Rivers of Ice*, a DVD about glaciers and glacier terminology, was published (Alpha DVD, 2003).