Kenai Mountains

Introduction

The Kenai Mountains (figs. 1, 292, 293), which have maximum elevations approaching 2,000 m, are a 195×35-km mountain range that extends southwest from Turnagain Arm, Portage Pass, and Passage Canal to the southern end of the Kenai Peninsula. Most of the outlet glaciers in the Kenai Mountains originate from two large ice fields, the Sargent and the Harding Icefields, and two smaller unnamed ice fields, one north of the Sargent Icefield between Kings Bay and Portage and the other southwest of the Harding Icefield

Figure 292.—**A**, *Index map of the glacierized Kenai Mountains (index map modified from Field, 1975a), with its four ice fields, two named and two unnamed, and numerous outlet glaciers.* **B**, *see opposite page.*

A

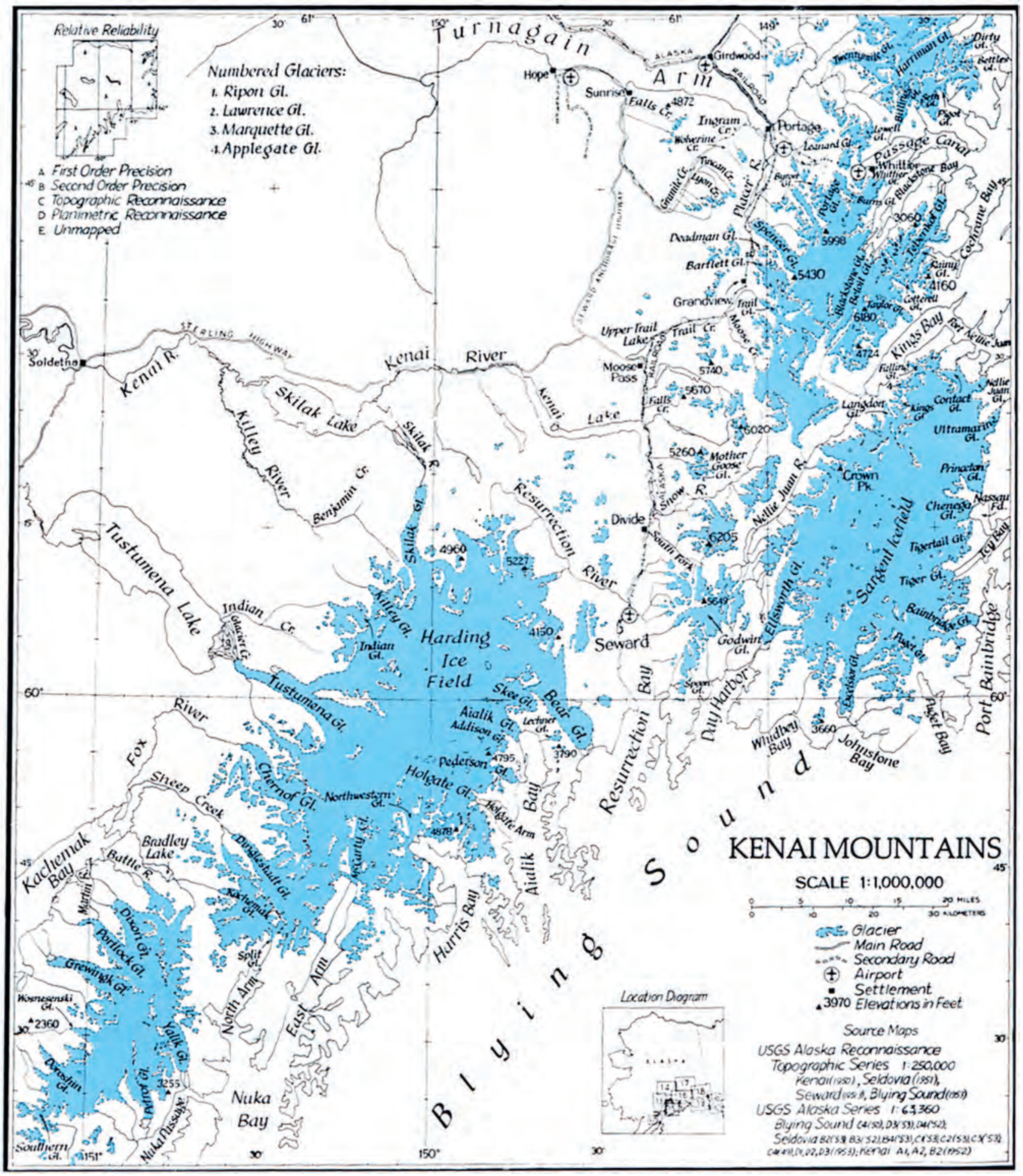
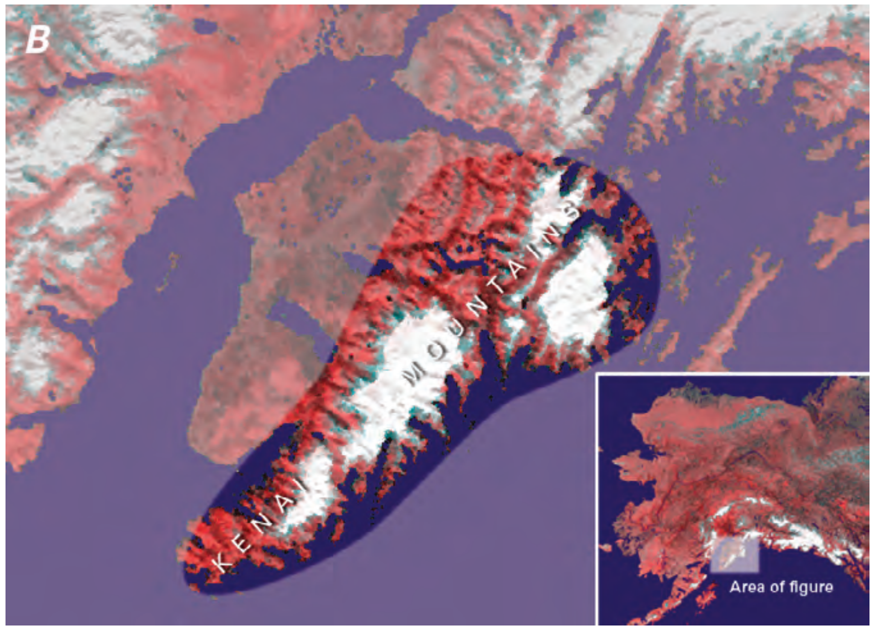


Figure 292.—**B**, *Enlargement of NOAA Advanced Very High Resolution Radiometer (AVHRR) image mosaic of the Kenai Mountains in summer 1995. National Oceanic and Atmospheric Administration image mosaic from Michael Fleming, Alaska Science Center, U.S. Geological Survey, Anchorage, Alaska.*



between Nuka Bay and Kachemak Bay. A number of other generally smaller glaciers descend from other isolated accumulation areas along the crests of many ridges and mountains. The total area of glaciers in the Kenai Mountains is 4,600 km^2 (Post and Meier, 1980, p. 45).

The Sargent and the Harding Icefields have many outlet glaciers that descend toward or into Prince William Sound, Cook Inlet, and the Gulf of Alaska. Many of these outlet glaciers reach to near sea level, and more than a dozen have calving termini, 11 directly into tidewater (fig. 41; tables 2, 3). The region contains several hundred glaciers; almost all of the larger ones have names. Seven have lengths of about 20 km, and 2 exceed 30 km. Unless otherwise noted, lengths and areas given are by Field (1975d) from USGS 1:250,000-scale topographic maps (appendix A), generally compiled from aerial photographic and other surveys performed between 1950 and 1963 and supplemented by the author. Landsat 1–3 MSS images that cover the Kenai Mountains have the following Path/Row numbers: 72/18, 73/17, 73/18, 74/18, 75/17, and 75/18 (fig. 3; table 1).

Wiles and others (1999a) and Barclay and others (1999) performed dendrochronological studies at a number of Kenai Mountain tidewater and former tidewater glaciers. Their work involved both living trees, some more than 680 years old, and a 1,119-year tree-ring-width chronology derived from more than 100 logs recovered from about a dozen glaciers in the western Prince William Sound area. Each of these logs had been sheared or uprooted by a past glacier advance. Their work showed that glacier fluctuations during the "Little Ice Age" were strongly synchronous on decadal time scales at many glaciers (fig. 294). Studies at eight locations indicated that advances occurred during the late 12th through 13th centuries and from the middle 17th to early 18th centuries. Nine glaciers showed evidence of a late 19th century advance. Glaciers studied include Tebenkof, Cotterell, Taylor, Wolverine, Langdon, Kings, Nellie Juan, Ultramarine, Princeton, Excelsior, and Ellsworth Glaciers. They also investigated Billings Glacier in the southern Chugach Mountains.

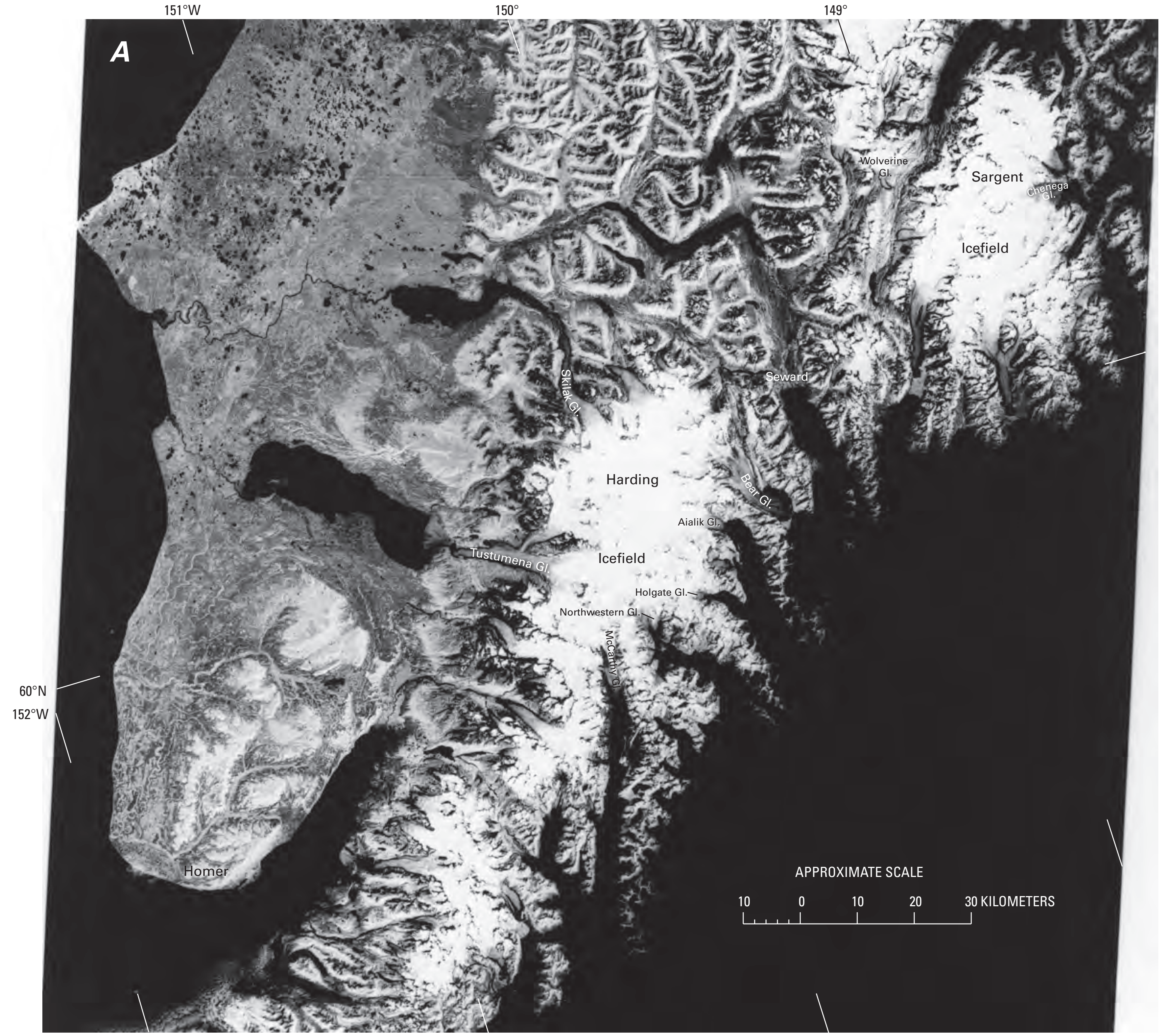


Figure 293.—**A**, *Annotated Landsat 1 MSS image of the Harding and Sargent Icefields and numerous tidewater glaciers on the Kenai Peninsula. McCarthy, Northwestern, Holgate, Aialik, and Chenega Glaciers are all retreating tidewater glaciers at the head of their fjords (Meier and others, 1980) (see fig. 41 and tables 2 and 3). Wolverine Glacier has been studied by the U.S. Geological Survey since 1966 and was nearly stable from 1966 to 1976, but from 1977 to 1982 thickened more than 8 m (Mayo and Trabant, 1984). It has since thinned and retreated. Landsat image and caption courtesy of Robert M. Krimmel, U.S. Geological Survey. Landsat 1 image (1390–20452, band 7; 17 August 1973; Path 74, Row 18) is from the U.S. Geological Survey, EROS Data Center, Sioux Falls, S. Dak.* **B**, *see opposite page.*

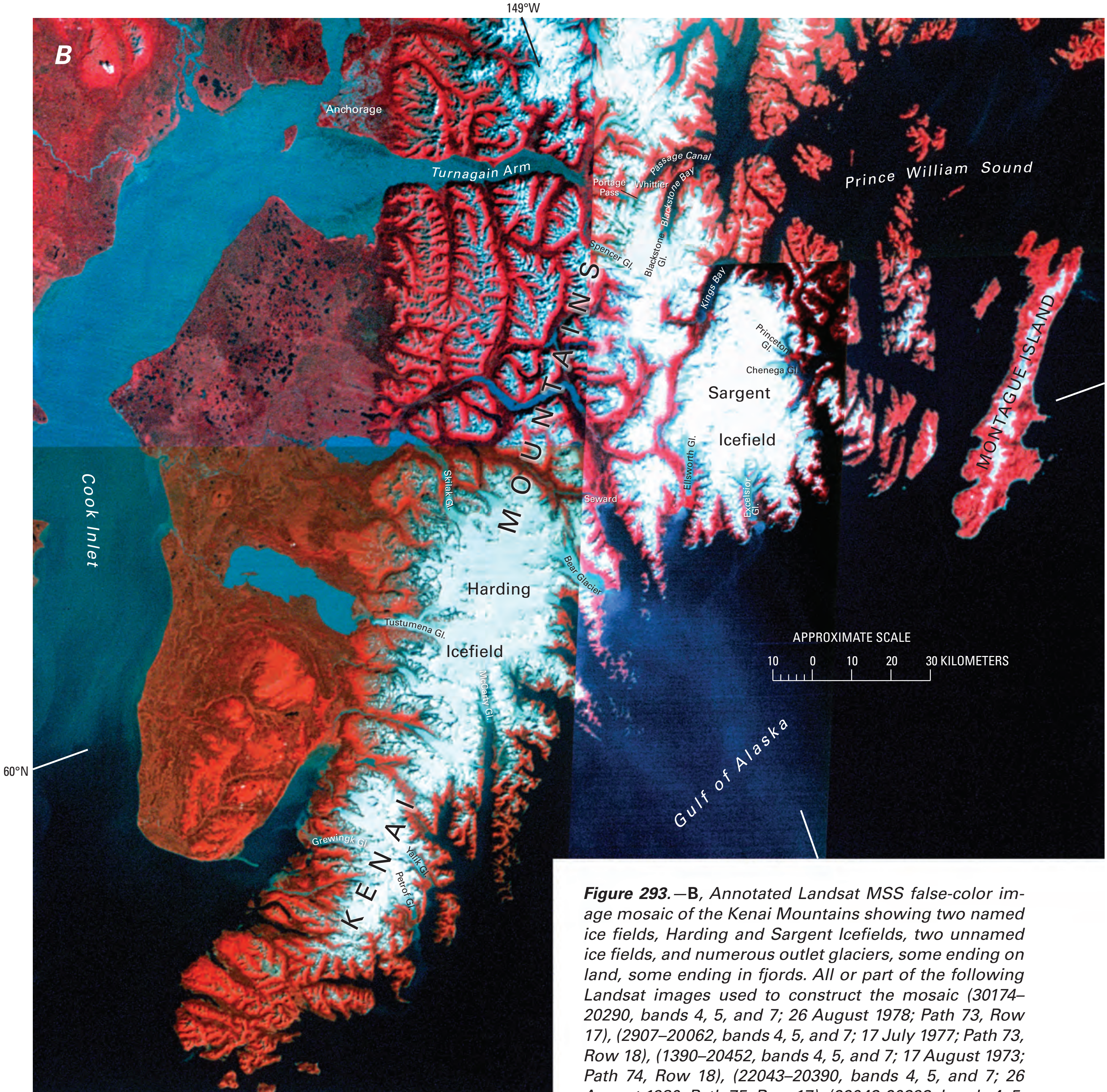


Figure 293.—**B**, *Annotated Landsat MSS false-color image mosaic of the Kenai Mountains showing two named ice fields, Harding and Sargent Icefields, two unnamed ice fields, and numerous outlet glaciers, some ending on land, some ending in fjords. All or part of the following Landsat images used to construct the mosaic (30174–20290, bands 4, 5, and 7; 26 August 1978; Path 73, Row 17), (2907–20062, bands 4, 5, and 7; 17 July 1977; Path 73, Row 18), (1390–20452, bands 4, 5, and 7; 17 August 1973; Path 74, Row 18), (22043–20390, bands 4, 5, and 7; 26 August 1980; Path 75, Row 17), (22043-20393, bands 4, 5, and 7; 26 August 1980; Path 75, Row 18) are from the U.S. Geological Survey, EROS Data Center, Sioux Falls, S.Dak.*

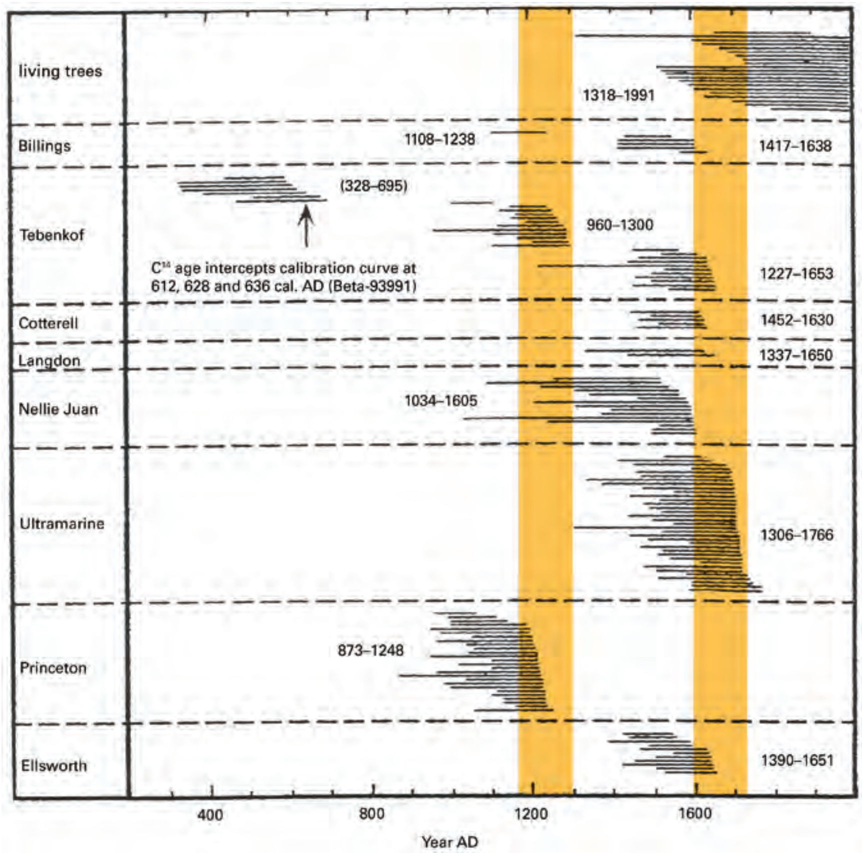


Figure 294.—*Lifespans of cross-dated, glacially overridden subfossil trees collected from areas adjacent to the termini of seven glaciers in the Kenai Mountains and one glacier in the Chugach Mountains, western Prince William Sound. Dates indicate the timespan for each population of logs. General times of glacier advance in the western Prince William Sound area are colored orange. Figure modified from Wiles and others (1999).*

Unnamed Ice Field North of the Sargent Icefield

The northernmost of the Kenai Mountains ice fields, the unnamed ice field north of the Sargent Icefield, covers an area of about 500 km^2 (fig. 295*A*). It consists of a series of connected accumulation areas that support several dozen outlet glaciers. It is bounded on the west by Trail Creek and Placer River and on the east by Kings Bay and Nellie Juan River. Aside from the glaciers of Blackstone Bay—Concordia, Northland, Blackstone, Beloit, Marquette, Lawrence, and Ripon Glaciers—other major named glaciers that drain from this ice field include Portage, Burns, Whittier, Tebenkof, Rainey, Cotterell, Taylor, Claremont, Wolverine, Trail, Bartlett, Spencer, and Skookum Glaciers. Blackstone and Beloit Glaciers have tidewater termini (fig. 41; tables 2, 3). All of these glaciers have retreated significant distances since they were first observed. Wolverine Glacier has been monitored annually since 1966 by USGS glaciologists.

Portage Glacier

During the 1990s, Portage Glacier retreated around a bend in its valley and was no longer visible from a USFS Visitors Center constructed at the position of its late 19th century “Little Ice Age” maximum advance. Prior to 1794, the glacier was at a position several kilometers to the southeast, permitting an ice-free passage (a portage) between Turnagain Arm and Prince William Sound. After 1794, Portage Glacier advanced and, according to Tarr and Martin (1914), reached its most recent maximum position about 1880. [Editors’ note: According to Austin Post (written commun., 2004), the start of the advance of Portage Glacier occurred considerably earlier than the late 18th century. Crossen’s (1990) recent fieldwork confirmed the early advance.] Viereck (1967) dated its maximum forward position at about 1895 on the basis of botanical evidence. A portage was still possible but required an overice journey of more than 7 km (Mendenhall, 1900). During the advance, the terminus bifurcated, and a limb of the much thicker glacier extended about 1.5 km into a side valley flowing toward the head of Passage Canal. Much of the ice was contributed by Burns Glacier, then a tributary of Portage Glacier that merged with it from the east. Retreat and thinning led to the limb's disappearance early in the 20th century. The maximum advance of the western lobe of the glacier is marked by a late 19th century end moraine that serves as the topographic high, damming the western end of Portage Lake. Portage Glacier was near this position when it was first photographed in 1914, but the presence of a small ice-marginal lake may indicate that the terminus has retreated somewhat on its southwestern side. By 1950, the date of the first USGS map of the area (Seward D-5, 1:63,360-scale topographic map) (appendix B), the terminus had retreated about 2.5 km from the moraine for an average rate of about 70 m a^{-1}. By 8 August 2000, the glacier had retreated almost another 2 km, creating a lake about 4 km long (fig. 295*B*) (see also 3 September 1966 oblique aerial photograph by Austin Post, USGS photograph no. 644–58). Burns Glacier maintained contact with Portage Glacier until the early 1980s, when its continued thinning caused it to lose contact.

The maximum advance, which ended in the late 1800s, caused a major change in the basin now occupied by Portage Lake. Before the advance, the sediment-filled basin created a land passage to Prince William Sound. During the advance, the basin sediments were overridden, eroded, and replaced by advancing ice to the limit of the end moraine. Eroded sediment was transported toward Turnagain Arm by Portage Creek. When Portage

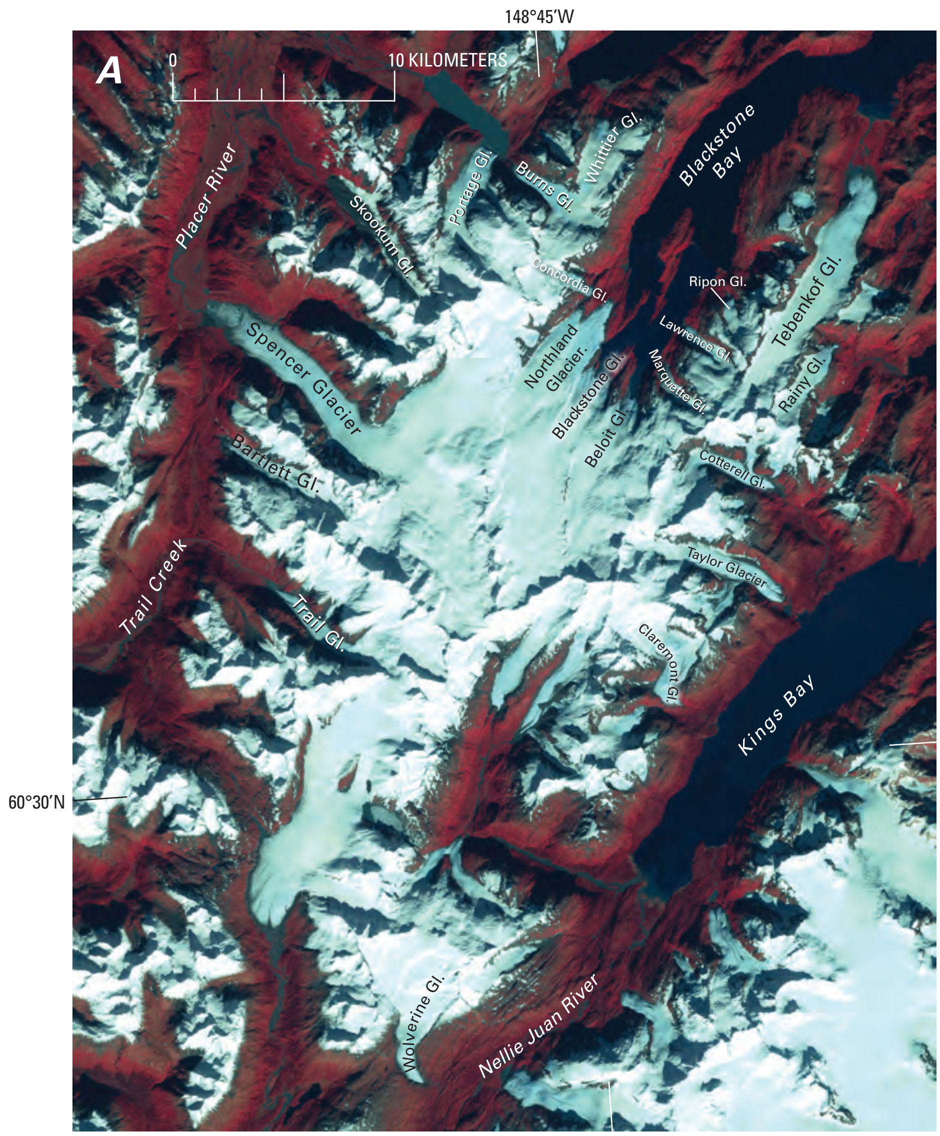


Figure 295.—*A Landsat image and an oblique aerial photograph of an unnamed ice field north of Sargent Icefield, and Portage Glacier one of its major outlet glaciers.* **A**, *Annotated digital enlargement of a Landsat 7 ETM+ image (7067018009926950; 26 September 1999; Path 67, Row 18) from the U.S. Geological Survey, EROS Data Center, Sioux Falls, S. Dak. Burns Glacier, the tributary that joined Portage Glacier from the east is closest to its terminus.* **B**, *see following page.*

Figure 295.—**B**, *8 August 2000 southwest-looking oblique aerial photograph showing Portage Glacier and the entire length of the lake formed by its retreat. Also barely visible are fuel storage tanks at Whittier in the lower right corner of the photograph. Photograph by Bruce F. Molnia, U.S. Geological Survey.*

Glacier subsequently retreated, the basin did not refill with sediment but remained relatively sediment free. R.A.M. Schmidt (reported by Field, 1975d) determined that the basin had a maximum depth of 181 m at a location about 300 m in front of the 1964 terminus position.

Whittier Glacier

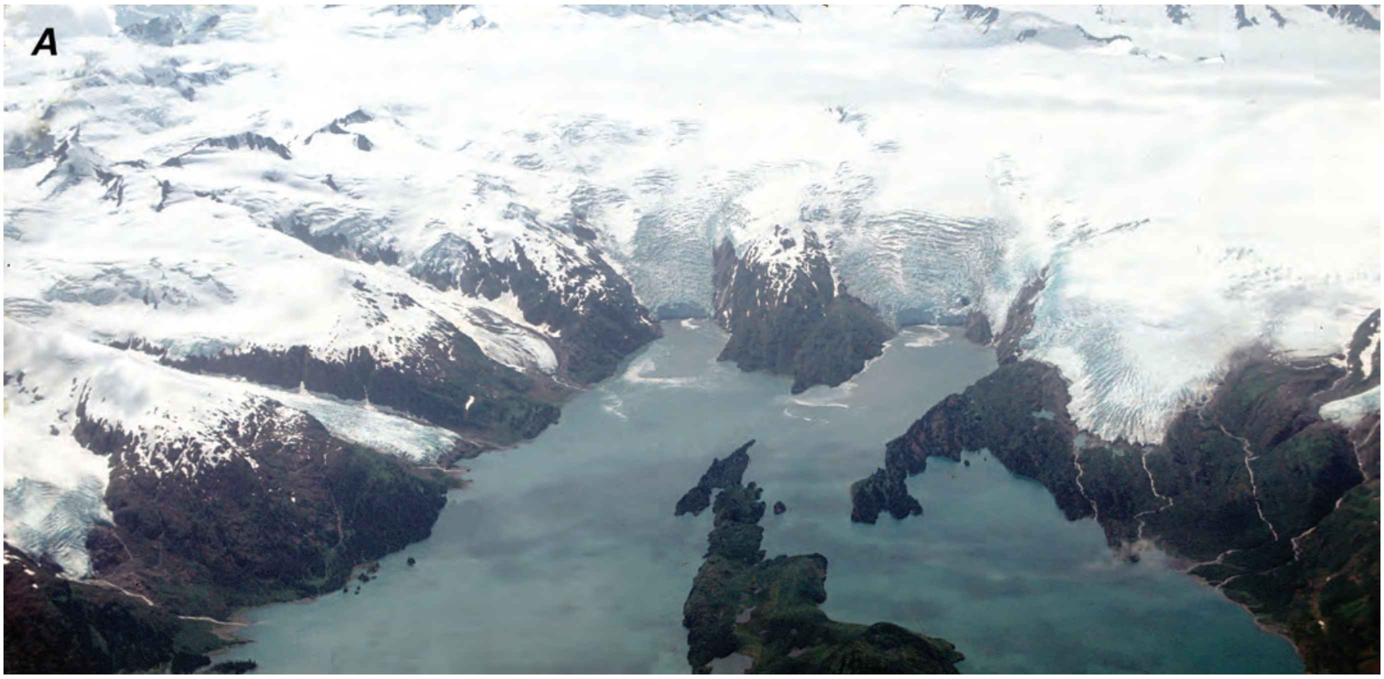
Whittier Glacier was investigated by Barnes (1943), who reported that, between 1913 and 1939, the terminus of Whittier Glacier had retreated "several hundred feet" and that the elevation of the terminus had increased from 180 to about 300 m. The terminus was in this position when it was mapped in 1950 (USGS, 1950) (Seward topographic quadrangle maps, appendix B) and when it was photographed by Post in 1964 (Field, 1975d). When the author flew over the glacier in 2000 and again in 2002, it showed evidence of recent thinning and retreat.

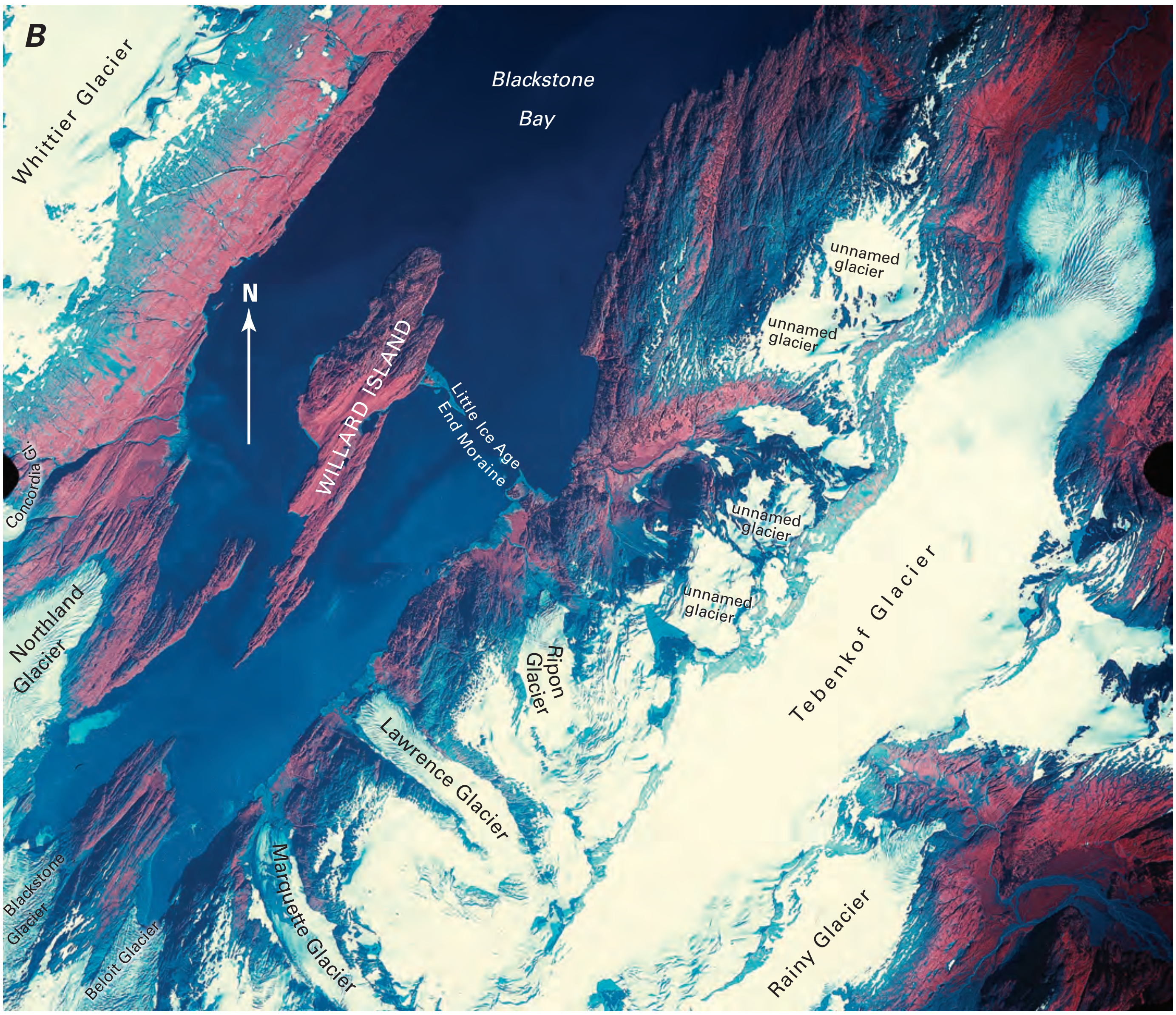
Glaciers of Blackstone Bay

Blackstone Bay (fig. 296) and Blackstone Glacier were named in l899 for a miner who lost his life on the glacier in l896 (Mendenhall, 1900). The glaciers of the bay were first mapped by Grant and Higgins (1913, fig. 5) on 5 July 1909. Nearly a dozen glaciers descend to near sea level; Blackstone and Beloit Glaciers, both located at the head of the bay, reach tidewater. Blackstone Glacier had a length of 12.1 km, an area of 32 km^2, an accumulation area of 29 km^2, an ablation area of 2 km^2, a width at its face of 0.5 km, and an AAR of 0.92 (Viens, 1995) (table 2). Beloit Glacier had a length of 10.1 km, an area of 25 km^2, an accumulation area of 24 km^2, an ablation area of 1 km^2, a width at its terminus of 0.44 km, and an AAR of 0.95 (Viens, 1995) (table 2). Although both glaciers were still tidewater glaciers when the author visited them in September 2000 and observed them from the air on 3 September 2002 and in 2004, they showed exposed bedrock along their margins and evidence of recent thinning.

As in nearby College Fiord [Editors' note: Fjord is used throughout the text in its geological, glaciological, and geomorphological sense as it applies to the glaciated and glacierized coast of Alaska (Jackson, 1997, p. 237). Its anglicized variant, fiord, is used in geographic place-names of Alaska and is used in the identical sense as fjord.], many of the glaciers here were named for colleges. Northland, Ripon, Lawrence, Marquette, and Beloit Glaciers were all named in 1910 by Martin (1913) for schools in Wisconsin. Northland Glacier, named for Northland College in Ashland, Wisc., is about 9 km long and previously reached tidewater, probably in the middle 19th century.

► *Figure 296.*—*Two aerial photographs of Blackstone Bay.* **A**, *8 August 1981 south-looking oblique aerial photograph showing the southern half of Blackstone Bay including Willard Island. Most of the glaciers that drain into or near the bay can be seen (left to right): Ripon, Lawrence, Marquette, Beloit, Blackstone, Northland, and Concordia. All are retreating and thinning. Photograph by Bruce F. Molnia, U.S. Geological Survey.* **B**, *12 August 1984 AHAP false-color vertical photograph (L113F7087) of the upper two-thirds of Blackstone Bay, including Willard Island and its "Little Ice Age" end moraine. All of the glaciers that drain into or near the bay can be seen. These include Tebenkof Glacier, which flows into the north end of the bay; Ripon, Lawrence, Marquette, Beloit, Blackstone, Northland, and Concordia Glaciers and four unnamed glaciers on the northeast side of the bay. Also visible are Rainy and Whittier Glaciers, located in basins to the east and west. All of the valley glaciers shown on this image, located in the southeastern part of the unnamed ice field north of the Sargent Icefield, show evidence of thinning and retreat. AHAP photograph from the GeoData Center, Geophysical Institute, University of Alaska, Fairbanks, Alaska.*


A


B
Whittier Glacier
Blackstone
Bay
N
WILLARD ISLAND
Little Ice Age
End Moraine
unnamed
glacier
unnamed
glacier
unnamed
glacier
unnamed
glacier
Concordia Gl
Northland
Glacier
Ripon
Glacier
Tebenkof Glacier
Lawrence Glacier
Marquette Glacier
Blackstone
Glacier
Beloit Glacier
Rainy Glacier

Lawrence Glacier (fig. 297), named for Lawrence College in Appleton, Wisc., is about 4 km long. As have all the valley glaciers on the eastern side of Blackstone Bay, it has thinned and retreated during the 20th century. Between the author's visits in 1978 and 2000, Lawrence Glacier retreated more than 100 m and thinned as much as 40 m.

A conspicuous submarine terminal moraine, part of which is exposed under most tidal conditions, connects Willard Island in the middle of Blackstone Bay with its eastern shore. Grant and Higgins (1913), who first studied the bay in 1909, suggested that the moraine predates the early 18th century.

Tebenkof Glacier (fig. 298), which drains into Blackstone Bay near its mouth and was named for the last Governor General of Russian America, is 13 km long and has an area of about 28 km^2 (Field, 1975d, p. 527; Tarr and Martin, 1914, pl. CXII, ff p. 352.) Until the 19th century, it had a small piedmont lobe and probably had a terminus ending in the tidewater (see map by Wiles and others, 1999a). Today, it is fronted by several large ice-marginal lakes and a large glacial outwash plain. Through the early 21st century, Tebenkof Glacier retreated more than 3.0 km and thinned by several hundred meters. As do all the other glaciers in Blackstone Bay, it continues to retreat and thin.

Wiles and others (1999a), found evidence that Tebenkof Glacier has advanced several times during the past 1,500 years (fig. 294). Seven logs that grew between A.D. 328 and A.D. 695 were found about 1.5 km in front of the 1992 ice margin, suggesting an early glacier advance at approximately A.D. 700 (approximately 1300 years B.P.). Twelve logs that grew between A.D. 960 and A.D. 1300, were found between 0.7 and about 1.5 km in front of the 1992 ice margin, suggesting a second glacier advance beginning between A.D. 1289 and A.D. 1300 (approximately 700 years B.P.). Another group of 11 logs represent trees felled by the advancing glacier between A.D 1633 and A.D. 1653 and suggest a third advance approximately 350 years B.P. Wiles and others' (1999a) analysis of recent moraines suggested that ice retreat from this approximately 350-year-old maximum position of the glacier began before 1891. They stated (Wiles and others,1999a, p. 167) that "the 1891 maximum was the greatest extent of Tebenkof Glacier since at least A.D. 1189." They also documented an 1891 to 1992 retreat of 2.7 km, with 1 km of retreat between 1983 and 1992.

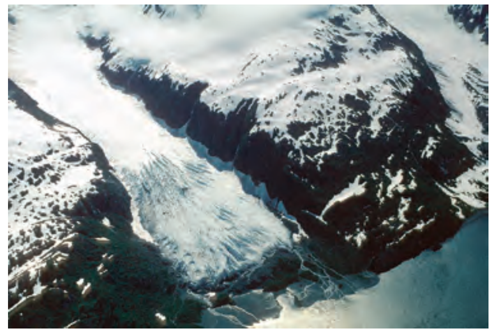


Figure 297.*—15 July 2000 southeast-looking oblique aerial photograph of the terminus of the Lawrence Glacier showing retreat of the terminus and thinning of the margin. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.*

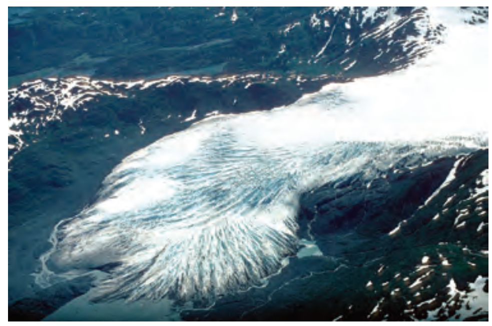


Figure 298.*—15 July 2000 south-looking oblique aerial photograph of the terminus of Tebenkof Glacier showing ice-marginal lakes formed by terminus retreat and the expanding outwash plain. Former positions of its terminus are marked by lakes, trimlines, and moraines. Since 1891, the glacier has thinned by more than 100 m, and parts of its terminus have retreated by more than 3 km. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.*

Glaciers of the Western Side and South of Kings Bay

Kings Bay is the western extension of the bay called Port Nellie Juan. Taylor Glacier (fig. 299) (see also 13 August 1982 AHAP photograph L115F1490) has a length of 8 km and an area of 23 km^2 (Field, 1975d, p. 527) and has been retreating since it was first observed in the latter part of the 19th century. About 1870, it had a tidewater terminus; in 1887, when it was first mapped by Applegate, its terminus failed to reach tidewater (Grant and Higgins, 1913). About 25 year later, when Grant and Higgins (1913) mapped it on 8 and 9 August 1909, its terminus again reached tidewater. The 1909 terminus position was about 400 m behind a trimline, probably related to the 1870 maximum (Field, 1975d) (AGS Glacier Studies Map No. 64–4–G6; Field, 1965). By 1924, Taylor Glacier had retreated another 200 m, and its terminus was adjacent to the inland side of a tidewater-influenced lake. When it was photographed in 1966, it had retreated another 600 m and barely made contact with the back edge of the lake basin. During the Landsat baseline period, retreat and thinning continued at an even more rapid rate. When the author observed the glacier from the air in July and August 2000, it had retreated about 2.2 km from its late 19th century position.

Cotterell Glacier, now 4 km long [8 km long, 18 km^2 in area, according to Field (1975d, p. 527)], is another glacier that has experienced a significant amount of recent retreat. Aerial photographs taken in 1966, 1977, and 2000

Figure 299.—3 September 1966 oblique aerial photograph of much of Taylor Glacier. Also visible is the adjacent Cotterell Glacier. USGS photograph no. 664–62 by Austin Post, U.S. Geological Survey.

show that the glacier has retreated more than 1.5 km and thinned by more than 50 m during that period of time.

Wiles and others (1999a) found five transported logs that represent trees felled between A.D. 1611 and A.D. 1630, suggesting an advance of the glacier approximately 370 to 390 years B.P. (fig. 294). Their analysis of recent moraines suggested that the "Little Ice Age" maximum position—3.1 km inland from Kings Bay—was reached in 1891.

Claremont Glacier, 6 km long, was named in 1910 by U.S. Grant, who intended to name it for Robert Fulton's steamboat *Clarmont*, but he misspelled the name. When Grant and Higgins (1913) first observed Claremont Glacier in 1909, it was located about 300 m behind a moraine that marked its late 19th century position. Subsequent retreat has caused the glacier to separate into two retreating tributaries, as a 3 September 1966 oblique aerial photograph (fig. 300*A*) shows. The southern tributary is now located 2.5 km behind the 1909 moraine; the northern one is 3.5 km behind it. When the author observed them from the air on 15 July 2000 (fig. 300*B*), both tributary glaciers showed evidence of continued retreat and thinning; the southern tributary showed significantly more retreat than the northern tributary.

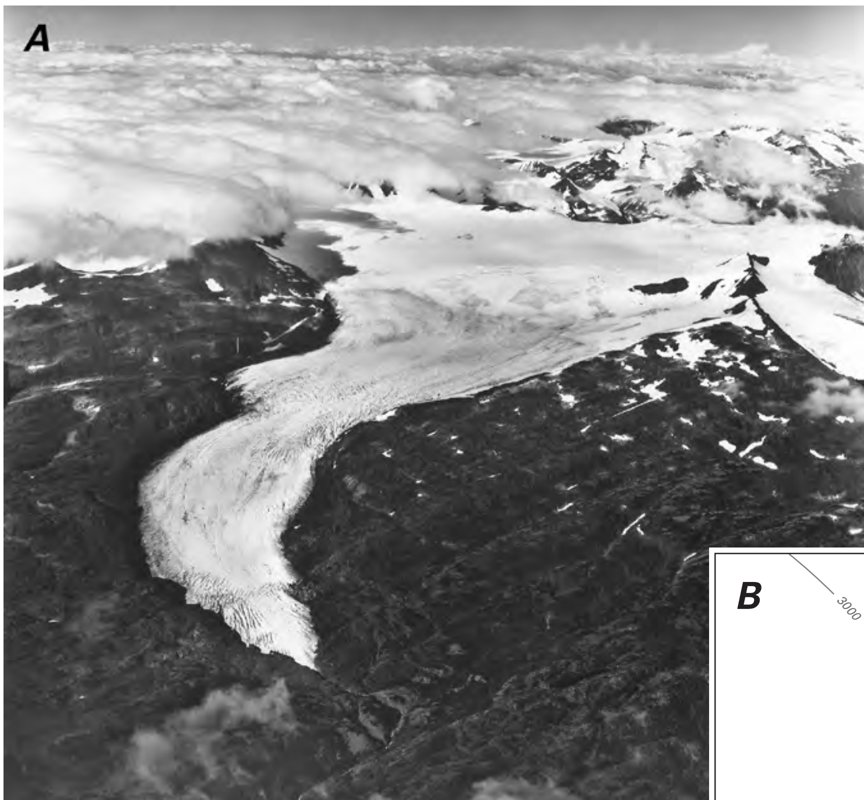
Figure 300.—Two aerial photographs showing changes of the Claremont Glacier between 1966 and 2000. **A**, 3 September 1966 oblique aerial photograph of the terminus of Claremont Glacier showing the two separated former tributaries of the glacier. At the end of the 19th century, they were connected and reached close to the location of the large right-angle bend in the river, near the mouth of the valley. USGS photograph no. 664–63 by Austin Post, U.S. Geological Survey. **B**, 15 July 2000 northwest-looking oblique aerial photograph of Claremont Glacier showing the two retreating, formerly joined tributaries. The northern lobe shows only a small amount of retreat, but the southern lobe appears to have lost an icefall to melting and has retreated about 800 m. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of B is available online.

Glaciers of Upper Kings River

Several large unnamed glaciers serve as the source of the upper Kings River. All, including the two largest, show multiple signs of thinning and retreat. During the last quarter of the 20th century, each retreated about 500 m.

Wolverine Glacier

Wolverine Glacier, as shown on a 3 September 1966 oblique aerial photograph (fig. 301*A*) (see also 14 August 1984 AHAP photograph L116F0251), has retreated nearly 3 km since the early 18th century (Wiles and others, 1999a). Three moraines dated at A.D. 1713, A.D. 1777, and A.D. 1807, located between 2 and 3 km downvalley from the glacier's terminus in the year 2000, document Wolverine Glacier's "Little Ice Age" maximum position and the location of two recessional moraines (fig. 301*B*). Wolverine Glacier is one of three long-term glacier-monitoring sites operated by the USGS. The other two are Gulkana Glacier in the Alaska Range and South Cascade Glacier in the State of Washington. Climate, weather, glacier-motion, mass-balance, terminus position, and streamflow data are recorded at the three monitoring sites to develop a better understanding of glacier-related hydrologic processes. Wolverine Glacier, which has a terminus elevation of about 400 m, has been studied by the USGS since 1966 (Tangborn and others, 1977) and was nearly stable from 1966 to 1976 but thickened more than 8 m from 1977 to 1982 (Mayo and Trabant, 1984; Mayo and others, 1985). It has since thinned more than 20 m. In the 29 years of measurements from 1966 to 1995, negative mass balances have occurred in 19 of those years. The annual range has varied from a low of -2.37 m in



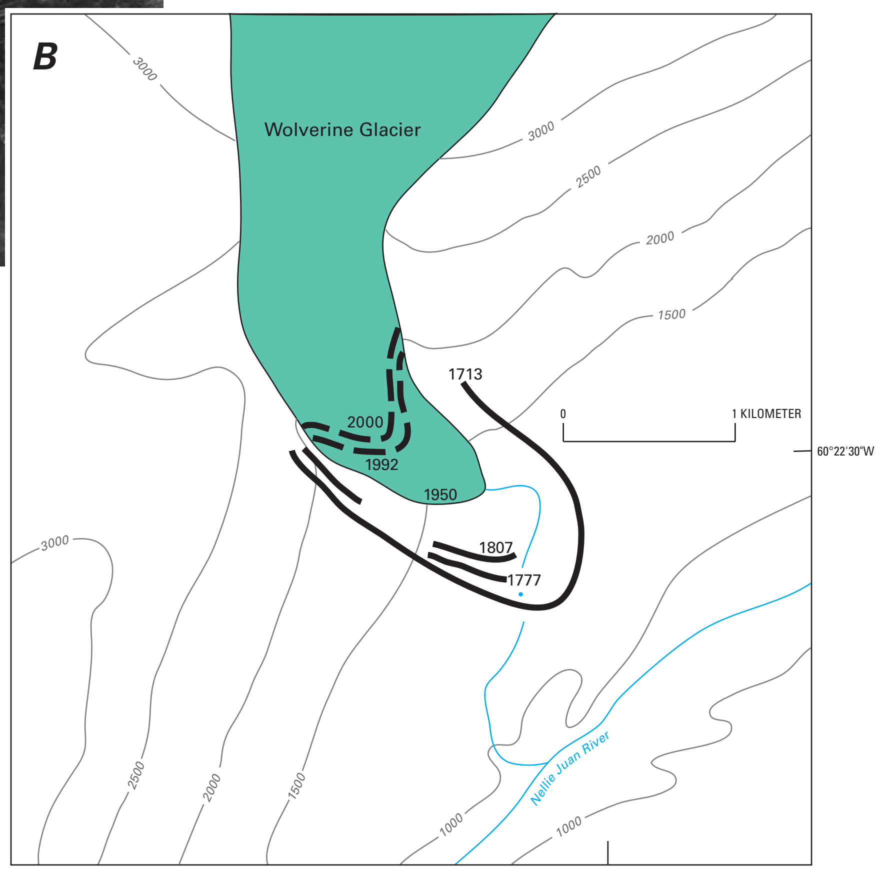


Figure 301.—*Oblique aerial photograph and sketch map of Wolverine Glacier.* **A**, *3 September 1966 oblique aerial photograph showing Wolverine Glacier. USGS photograph no. 664–65 by Austin Post, U.S. Geological Survey.* **B**, *Sketch map showing retreat of Wolverine Glacier between 1713 and 2000.*

1991 to a high of +2.33 m in 1980. Mass balance has been positive every winter, ranging from a high of 4.21 m in 1977 to a low of 0.84 m in 1972. Mass balance has been negative every summer, ranging from a low of -4.23 m in 1981 to a high of -1.34 m in 1973 (Meier and others, 1971; Trabant and March, 1999). Between the 1950s and the middle 1990s, on an annual basis, Wolverine Glacier thinned by 0.519 m, had a volume decrease of 0.00957 km^3, and had its length shortened by 6 m a^{-1}. Between the middle 1990s and 1999, on an annual basis, the glacier thinned by 1.025 m and had a volume decrease of 0.0188 km^3 (K.A. Echelmeyer and others, University of Alaska Fairbanks, written commun., March 2001). A 30-year record of surface mass balance and shorter records of motion and surface altitude were recently published by the USGS (Mayo and others, 2004).

The Wolverine climate station is located at an altitude of 990 m on the crest of a tundra-covered glacial moraine along the western boundary of the basin. The station is slightly lower than the glacier's average ELA and about 500 m from the western edge of the glacier. The average annual air temperature at the recorder site is about -1°C, and the average annual precipitation gage total is about 1,100 mm. Snow is the dominant form of precipitation and usually accumulates on the glacier from September through mid-June. Daily average temperatures range from a low of -25°C to a high of +15°C. Daily precipitation totals range from a low of 0 to a high of approximately 110 mm (Kennedy, 1995; Mayo and others, 1992).

Glaciers of Snow River

Several unnamed glaciers on the western side of the ice field serve as the source of the Snow River. The largest is about 13 km long and has an area of about 75 km^2. When it was photographed in 1941 and again in 1950 (Field, 1975d), it was "at or close to" its "Little Ice Age" maximum position. Since then, it has retreated more than 0.5 km.

Trail Glacier

Trail Glacier, previously named *Notch Creek Glacier*, was first studied during the construction of the Alaska Railroad, near the beginning of the 20th century (Tarr and Martin, 1914). The part of the glacier photographed by Capps (USGS Photo Library photograph Capps, S.R.12), sometime before 1910, had a large mass of morainic debris covering much of its surface. It was also photographed on 21 September 1911 by the USGS (Martin and others, 1915), but its terminus was obscured by trees. Wentworth and Ray (1936) reported that it had retreated about 1.2 km by 1931. By 1957, it had retreated another 500 m (Field, 1975d). When the author observed it from the air in 2000, the glacier was estimated to have retreated at least another 750 m.

Glaciers of Placer River

Bartlett, Spencer, Deadman, and Skookum Glaciers and several unnamed glaciers, all located on the northwestern part of the ice field north of the Sargent Icefield, all drain into the Placer River. At the beginning of the 20th century, the terminus of Bartlett Glacier was located on the floor of the Placer River valley (21 September 1911 USGS photograph presented by Martin and others, 1915, pl. IXB). Because the terminus covered the only feasible railroad route through the valley, a 2-km-long looping elevated trestle had to be constructed to bypass it. By 1931, the glacier had retreated between 150 and 300 m from its maximum position (Wentworth and Ray, 1936). In the early 1940s, the glacier had retreated enough that the track could be lain over the preferred route, so the trestle was dismantled. Retreat has continued at a slow rate, so that, at the beginning of the 21st century, the terminus was a little more than 1 km from its maximum position.

A similar railroad construction problem was encountered at Spencer Glacier (20 September 1911 photograph presented by Martin and others, 1915, pl. VIII; 12 August 1984 AHAP photograph L113F7084). At the beginning of the 20th century, the terminus of Spencer Glacier (19 km long and 82 km^2 in area) (Field, 1975d, p. 528) was within 60 m of its 19th century "Little Ice Age" maximum terminal moraine (Viereck, 1967), a position that the glacier reached about 1880. When track was laid on the surface of this moraine, drainage channels were blasted and constructed in the glacier ice and on the adjacent outwash plain to prevent washouts (Tarr and Martin, 1914). By 1931, the glacier had retreated about 640 m (Wentworth and Ray, 1936). By 1964, retreat totaled about 1.2 km (Field, 1975d). When the author observed it from the air in 2000, he estimated that the glacier had retreated at least another 800 m.

Sargent Icefield

More than 25 outlet glaciers descend from the central accumulation area of the 60×40-km Sargent Icefield (fig. 302). Many of the glaciers draining the

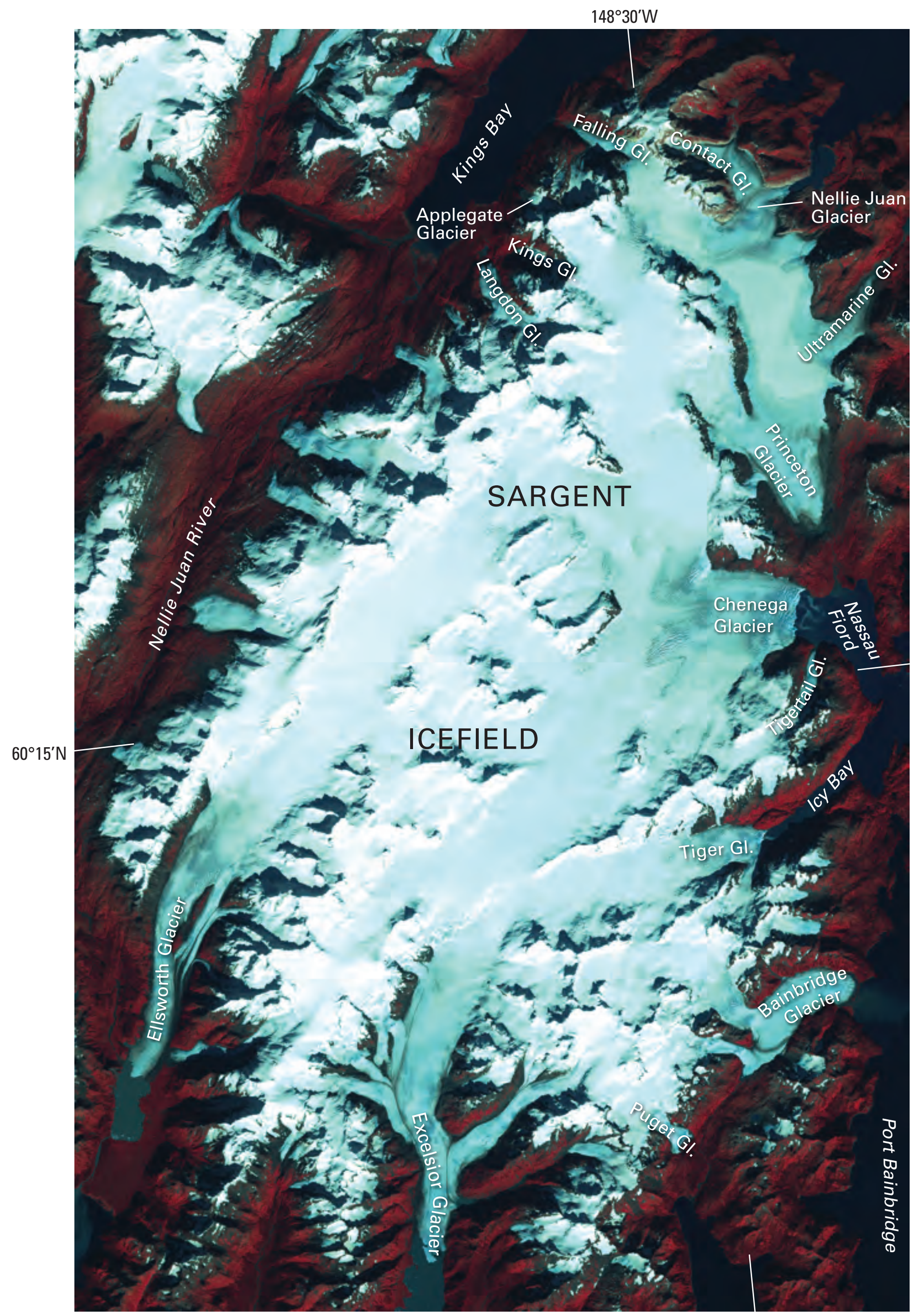


Figure 302.*—Digital enlargement of a Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) false-color composite image showing the Sargent Icefield. Landsat 7 ETM+ image (7067018009926950; 26 September 1999; Path 67, Row 18) from the U.S. Geological Survey, EROS Data Center, Sioux Falls, S.Dak.*

northern, eastern, and southern margins of the ice field end at or near sea level in Kings Bay, Port Nellie Juan, Nassau Fiord, Icy Bay, Port Bainbridge, Puget Bay, Johnstone Bay, and Whidbey Bay. Glaciers flowing from the western side of the ice field all end on land and drain into the Nellie Juan River. Only a few of these have official names. The largest glaciers draining the ice field are 27-km-long Ellsworth and 24-km-long Excelsior Glaciers (Field, 1975d, p. 529–530) and the 24.1-km-long Chenega Glacier (Viens, 1995) (table 2). Three glaciers—Nellie Juan, Chenega, and Tiger—have tidewater termini. All the outlet glaciers of the Sargent Icefield show significant evidence of retreat and thinning.

Glaciers on the Eastern Side of Kings Bay

Several named and unnamed glaciers drain into the southeastern side of Kings Bay, the western extension of Port Nellie Juan. The largest, Falling Glacier (11 km long, 35 km^2 in area, according to Field, 1975d, p. 528) was first observed and its terminus position mapped on 8 and 9 August 1908 by Grant and Higgins (1913). At that time, "a small tongue from the ice just reached the sea" (Grant and Higgins, 191, p. 46). Based on vegetative evidence, Viereck (1967) dated the formation of its "Little Ice Age" maximum terminal moraine at about 1875 to 1885. As late as 1950, although part of the terminus was adjacent to the end moraine and may have been in contact with Kings Bay, the margins of the glacier were in retreat (Field, 1975d). By 1982, the terminus had retreated more than 1 km from its 1950 position. Since then, the glacier has retreated at least 600 m and thinned significantly (fig. 303). When they were photographed from the air in 1966 and again on 15 July 2000, Applegate, Kings, and Langdon Glaciers and an unnamed glacier, all located near the head of the fjord, showed evidence of continuing thinning and retreat (fig. 304).

According to Wiles and others (1999a), Kings Glacier was a former tributary to Langdon Glacier, and together they produced a "Little Ice Age" maximum moraine located about 2.3 km downvalley from their individual late 20th century positions. Two logs found about 1.8 km in front of the 1992 ice margin were from trees overridden in A.D. 1624 and A.D. 1650, suggesting a

Figure 303.—Three photographs, dating from 1924 to 2000, showing changes in the terminus of Falling Glacier. **A**, *1924 photograph by Fred Moffit of the lower reaches of Falling Glacier from the west side of Kings Bay. At the time of this photograph, the central part of the glacier's terminus still reached tidewater. USGS Photo Library photograph Moffit 1014.* **B**, *3 September 1966 southeast-looking oblique aerial photograph of the terminus of Falling Glacier, which is located about 350 m from the shore of Kings Bay. The glacier has thinned appreciably along its western margin. USGS photograph no. 664–71 by Austin Post, U.S. Geological Survey.* **C**, *15 July 2000 east-looking oblique aerial photograph of the lower third of Falling Glacier showing its retreating terminus and newly formed ice-marginal lake. Total retreat from its early 20th century position approaches 3.5 km. Photograph by Bruce F. Molnia, U.S. Geological Survey. Larger versions of* A *and* C *are available online.*

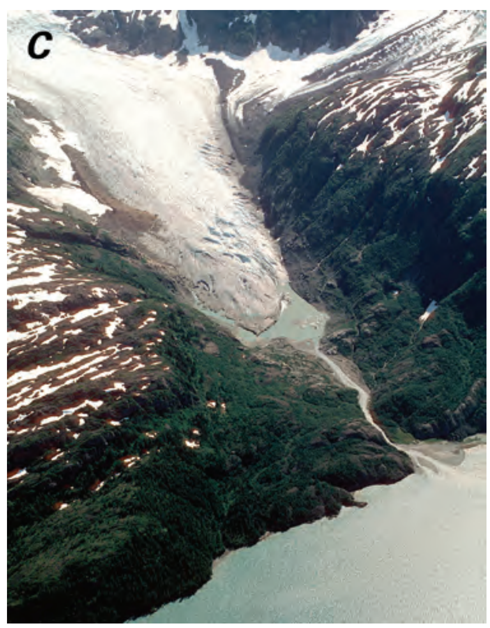


Figure 304.—3 September 1966 oblique aerial photograph looking southeast shows the termini of Applegate Glacier (left) and Langdon Glacier (right). Both show evidence of significant recent thinning and retreat. Langdon Glacier has several elevated medial moraines, whereas Applegate Glacier has a very large elevated lateral moraine on its southeast side. USGS photograph no. 664–72 by Austin Post, U.S. Geological Survey.

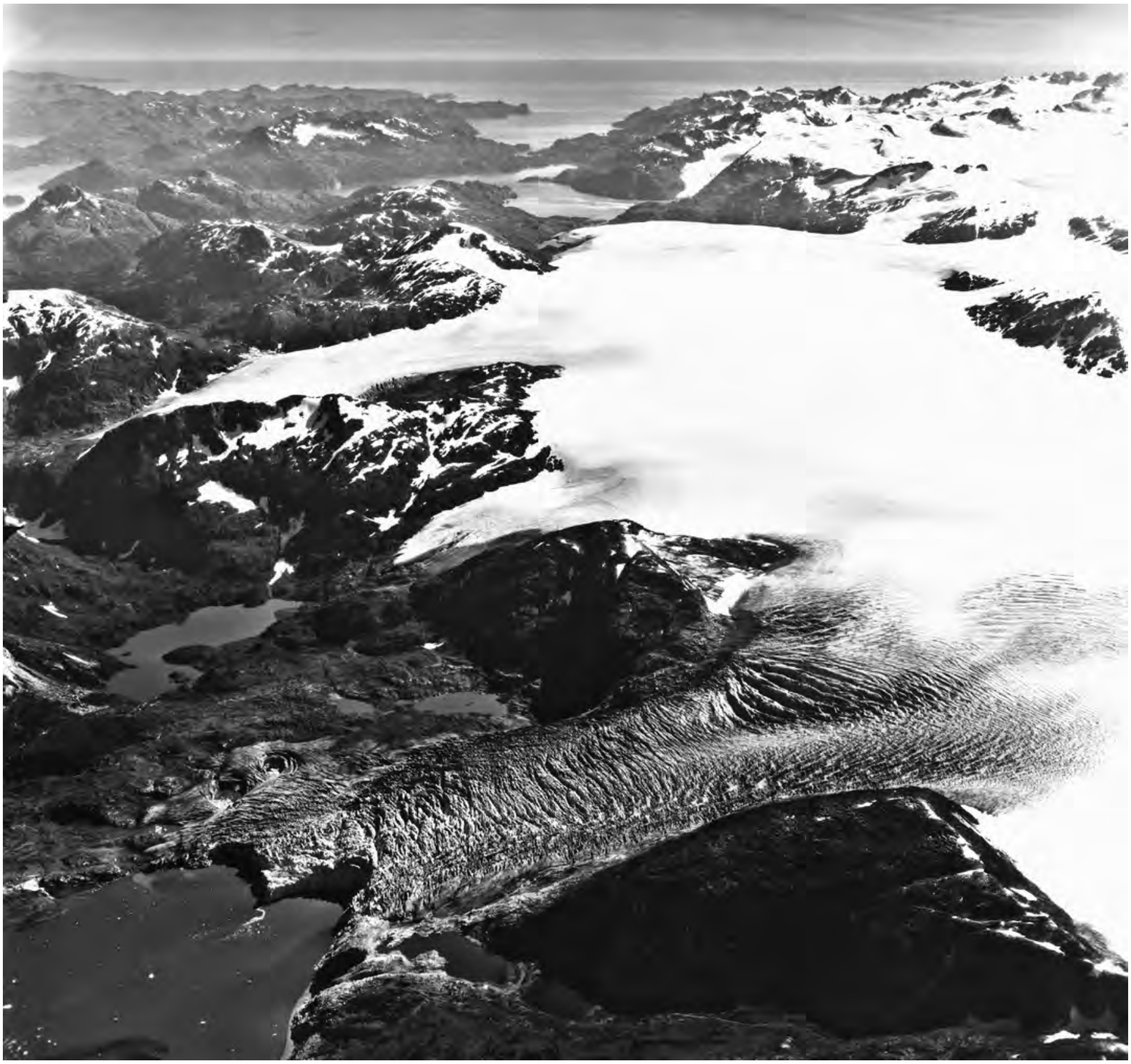
significant advance approximately 350 years B.P. Between 1889 and the end of the 20th century, Langdon Glacier retreated more than 2 km. However, Wiles and others (1999a) reported that, in 1992, the glacier was advancing and overriding alders that were estimated to be 10 to 20 years old. The author observed no evidence of a continued advance from the air in 2000.

Glaciers of Port Nellie Juan

The glaciers of Port Nellie Juan were first mapped on 8 and 9 August 1908 by Grant and Higgins (1913). Deepwater Bay, Derickson Bay, and Blue Fiord are embayments at the head of Port Nellie Juan. The westernmost of the three named glaciers is Contact Glacier (fig. 302), located about 2 km from the head of Deepwater Bay. When it was observed in 2000, the terminus of Contact Glacier showed multiple evidence of continuing rapid thinning and retreat. Between 1909 and 2000, the terminus of Contact Glacier retreated about 1 km.

Adjacent Nellie Juan Glacier has changed as dramatically as any glacier in the Sargent Icefield. Viereck (1967) stated that Nellie Juan Glacier had reached its late “Little Ice Age” maximum position between 1860 and 1880. Wiles and others (1999a) identified an advance of the glacier that felled trees between A.D. 1594 and A.D. 1605. They stated that Nellie Juan Glacier had reached its “Little Ice Age” maximum by 1842 and oscillated at this position until general retreat began around 1893. By 1908, retreat was minimal, ranging from 30 to 150 m (Grant and Higgins, 1913). When Moffit photographed the terminus position in 1924, little had changed; one area had actually advanced beyond the 1908 position. By 1935, the glacier had retreated 470 m on its eastern side and 580 m on its western side (Field, 1937) and had deposited a large moraine that blocked much of the head of Derickson Bay. By 3 September 1966, the glacier had retreated another 950 to 1500 m (fig. 305). A tidal river flowing through the 1935 moraine connected the ice-marginal basin, which expanded in area as the glacier continued to retreat, with Derickson Bay. When the author observed it from the air in 2000, the glacier was about 3 km from its 1935 position. It had a length of about 14.5 km, an area of 56 km^2, an accumulation area of 51 km^2, an ablation area of 5 km^2, a width at

Figure 305.*—3 September 1966 oblique aerial photograph showing the terminus and most of the accumulation area of Nellie Juan Glacier. Fresh bedrock and trimlines near the terminus document ongoing thinning and retreat. USGS photograph no. 664–75 by Austin Post, U.S. Geological Survey.*



its face of 0.5 km, and an AAR of 0.91 (Viens, 1995) (table 2). The terminus is now located in a vegetation-free granite fjord.

Wiles and others (1999a) described a sequence of logs dated between A.D. 1692 and A.D. 1715 that represent trees killed by an advance of 8-km-long Ultramarine Glacier. Other stumps were overridden about A.D. 1766 (fig. 294). Viereck (1967) determined that Ultramarine Glacier, which had a length of 9 km and an area of 30 km^2 (Field, 1975d, p. 529), sat at its "Little Ice Age" maximum position from about 1880 to 1890. Wiles and others (1999a) dated the stabilization of the glacier's terminus at 1889. By 1908, when Grant and Higgins (1913) observed the glacier, it had retreated about 400 m; it retreated another 300 m through 1935 and another 300 m through 1964 (Field, 1975d). Because the end moraine is nearly 3 km from the present margin, the glacier retreated nearly 2 km between 1964 and 2000. In 2000, the terminus of Ultramarine Glacier was surrounded by an apron of morainic-debris-covered stagnant ice and was located at the head of a 2.25-km-long proglacial lake about 4 km from Blue Fiord. The terminus was surrounded by a halo of fresh vegetation-free deglacierized bedrock.

Glaciers of Icy Bay

The glaciers of Icy Bay and Nassau Fiord, its northwestern arm, were mapped on 5 August 1908 by Grant and Higgins (1913). Chenega, Princeton, and Tiger Glaciers are the three largest glaciers. Chenega Glacier (fig. 306), a tidewater glacier and the largest of the three, has a length of 24.1 km and an area of 369 km^2 (AGS Glacier Studies Map. No. 64–4–G5; Field, 1965) (see also 1924 photograph by Fred Moffit, USGS Photo Library Moffit 974; 3 September 1966 oblique aerial photograph by Austin Post, USGS Photograph no. 664–79). Chenega Glacier has an accumulation area of 346 km^2, an ablation area of 23 km^2, a width at its terminus of 0.2 km, and an AAR of 0.94 (Viens, 1995) (table 2). From vegetative evidence, Viereck (1967) determined that Chenega Glacier sat at its "Little Ice Age" maximum position during the second half of the 19th century (about 1857–72). At that time, Chenaga, Princeton, and Tigertail Glaciers were joined and reached to the head of Nassau Fiord. Wiles and others (1999a) described several dozen detrital logs from around the perimeter of Princeton Glacier that confirm that the glacier was advancing towards its "Little Ice Age" maximum position before A.D. 1250 (fig. 294).

By 1908, when it was observed by Grant and Higgins (1913), Chenega Glacier had retreated about 5.5 km and had separated from Tigertail and Princeton Glaciers. Since 1908, Chenega Glacier's terminus has stayed within 1 km of this position (fig. 307). When the author observed the glacier from the air in 2000, freshly exposed bedrock and evidence of minor thinning suggested that it had recently retreated several hundred meters.

Figure 306.*—15 July 2000 southwest-looking oblique aerial photograph of the terminus of Chenega Glacier. Tigertail Glacier can be seen on the left side of the photograph. An apron of freshly exposed bedrock documents recent thinning of the glacier. Several calving embayments mark the front of the glacier. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.*

When Grant and Higgins (1913) viewed Princeton Glacier in August 1908, it had a massive moraine along its front, but its western side reached tidewater. Between 1908 and 1950, Princeton Glacier retreated about 1.5 km from shore and thinned by at least 60 m. Since then, it has retreated an additional 2.5 km. Similarly, Tigertail Glacier (fig. 306) retreated from the shore in the first decades of the 20th century and now sits a few hundred meters from the fjord. Field (1975d) reported that two small moraines dating from 1950 and 1960 mark brief mid-20th century advances. When the author observed the glacier from the air in 2000, freshly exposed bedrock and evidence of thinning suggested that it is continuing its retreat.

Tiger Glacier (fig. 308) is located at the head of Icy Bay (see 13 August 1984 AHAP photograph L118F1580). The glacier has a length of 11.3 km, an area of 56 km^2, an accumulation area of 50 km^2, an ablation area of 6 km^2, a width at its face of 0.8 km, and an AAR of 0.89 (Viens, 1995) (table 2). Tiger Glacier slowly advanced during the first third of the 20th century. Field (1975d, p. 513) reported that, in 1935, it was "slightly" in advance of its 1908

Figure 307.*—Two photographs showing late 20th century changes in Nassau Fiord between 1966 and 2000.* **A**, *3 September 1966 oblique aerial photograph showing part of the terminus of Chenega Glacier and nearly all of Princeton Glacier. Chenega Glacier is little changed since 1908. Princeton, however, is retreating and thinning significantly. USGS photograph no. 664–78 by Austin Post, U.S. Geological Survey.* **B**, *15 July 2000 northwest-looking oblique aerial photograph of the termini of Chenega and Princeton Glaciers. Although Chenega Glacier shows a retreat of only several hundred meters, the terminus of the retreating and thinning Princeton Glacier has retreated more than 1 km since the 1966 photograph. Photograph by Bruce F. Molnia, U.S. Geological Survey.*

Figure 308.—Two photographs showing the late 20th century position of Tiger Glacier between 1966 and 2000. **A**, 3 September 1966 oblique aerial photograph of the terminus of Tiger Glacier. USGS photograph no. 664–80 by Austin Post, U.S. Geological Survey. **B**, 15 July 2000 southwest-looking oblique aerial photograph of the terminus of Tiger Glacier. Little evidence of change in Tiger Glacier can be seen in this photograph. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of B is available online.

position, but that, by the 1960s (fig. 308*A*), "considerable recession" had occurred. When it was observed on 15 July 2000 (fig. 308*B*), Tiger Glacier's margins were very close to those displayed in a 1908 photograph made by Grant and Higgins (1913). Many small glaciers on the walls of the fjord have almost completely melted away.

Glaciers of Port Bainbridge

At the beginning of the 21st century, the terminus of 16-km-long Bainbridge Glacier (Viens, 1995) (table 2) sat about 300 m from the head of a short western arm of the Port Bainbridge fjord. According to Grant and Higgins (1913), who mapped the position of the glacier on 3 August 1908, the glacier was located on an outwash plain that was covered by normal high tides (3 August 1908 photograph by Grant and Higgins, 1913, pl. XXIXB). They observed fresh push moraines along the glacier's margin, some with fresh tree material incorporated into them. They stated (p. 51), "In 1908, the ice was practically, if not absolutely, at its limit of maximum advance since the growth of the present forest." Viereck (1967) determined that the glacier experienced a small advance about 1934 and overrode its 1908 moraine. The glacier had an area of 56 km^2, an accumulation area of 39 km^2, an ablation area of 17 km^2, and an AAR of 0.70 (Viens, 1995) (table 2); it had retreated several hundred meters by 2000 and had most of its terminus fronted by an arcuate ice-marginal lake. A braided outwash plain was located on the southern side of the glacier's terminus, as a 15 July 2000 oblique aerial photograph taken by the author shows (fig. 309). Small glaciers also exist south of Claw Peak on the western side of Port Bainbridge (13 August 1982 AHAP photograph L118F1582).

Figure 309.—15 July 2000 west-looking oblique aerial photograph of the lower part of Bainbridge Glacier showing its retreating terminus and ice-marginal lake. Total retreat from its early 20th century position is about 300 to 400 m. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.

Glaciers of the Puget Bay Region

Puget Glacier, located about 2.5 km north of the head of the bay, is the only named glacier among the half-dozen or so that drain into Puget Bay (3 September 1966 oblique aerial photograph by Austin Post, USGS photograph no. 664–83). This glacier was depicted on 19th century maps made by the Russian-America Company (Teben'kov, 1852) and was first investigated and mapped on 11 July 1909 by Grant and Higgins (1913). Investigations in 1966 determined that the valley below the glacier contained several moraines dating from before 1750, 1830, 1930, and 1950. The pre-1750 moraine was located about 1 km from the 1966 terminus. The distance between the 1950 moraine and the 1966 moraine was about 90 m. When the author photographed the glacier from the air in 2000, it showed continued thinning around its margins and retreat of its terminus. The 2000 terminus position was 250 to 400 m from its 1966 position.

Glaciers of Johnstone Bay

When Grant and Higgins (1913) sailed past the terminus of 19-km-long Excelsior Glacier (fig. 310) in 1909, it was located on an outwash plain about 1 km from the head of Johnstone Bay. They commented that a very large bare area surrounding the glacier indicated that it had been much larger in the recent past and that it might have had a marine terminus.

Wiles and others (1999a) identified a late 19th century moraine seaward of and close to the 1908 location of the glacier but found no evidence of a marine terminus. By 1950, the distance from the head of Johnstone Bay to the retreating terminus had increased to about 3 km; a large ice-marginal lake occupied the 2 km adjacent to the glacier's margin. By 3 September 1966, the glacier had retreated an additional kilometer (fig. 310*A*). Between 1966 and 1991, the lake lengthened by an additional 2 km, with a maximum length of 5 km. Field (1975d, p. 529) stated that Excelsior Glacier was 24 km long and 170 km^2 in area. When the author photographed it from the air on 15 July 2000, Excelsior Glacier showed continued thinning and retreat of its terminus (fig. 310*B*). The area in 2000 was about 160 km^2, and the terminus position was more than 3.5 km from its 1966 location. Both the 1966 and 2000 aerial photographs show that Excelsior Glacier calves large tabular icebergs.

Figure 310.**—Three aerial photographs of Excelsior Glacier showing changes between 1966 and 2000.* **A, 3 September 1966 oblique aerial photograph showing the terminus and much of the accumulation area of Excelsior Glacier. The fractures that cut across the entire terminus suggest that it was actively calving, retreating, and disintegrating when photographed. USGS photograph no. 664–86 by Austin Post, U.S. Geological Survey.* B *and* C*, see opposite page.*

Excelsior Glacier's southeasternmost unnamed tributary separated from the main glacier and experienced about 4 km of retreat, resulting in a conspicuous ice-free valley on the eastern side of Excelsior Glacier's valley. Thinning and retreat of this former tributary, probably in the 1950s, resulted in a reversal of flow direction, the creation of a distributary glacier, and the formation of a 4-km-long ice-marginal lake, as a 3 September 1966 oblique aerial photograph shows (fig. 310*C*).

Figure 310.—**B***, 15 July 2000 north-looking oblique aerial photograph of most of Excelsior Glacier, its ice-marginal lake, and the head of Johnstone Bay. In the 34 years between photographs, the glacier significantly thinned and retreated as much as 5 km. Note the large tabular icebergs, evidence of continued calving and disintegration. Photograph by Bruce F. Molnia, U.S. Geological Survey.* **C***, 3 September 1966 oblique aerial photograph showing a distributary of the Excelsior Glacier. The pre-1966 retreat of the tributary glacier, probably in the 1940's and 1950's, which was previously joined with the Excelsior Glacier on its eastern margin, resulted in a reversal of flow direction (from tributary to distributary glacier) and the formation of a 4-km-long ice-marginal lake. USGS photograph no. 664–84 by Austin Post, U.S. Geological Survey.*

Glaciers of Day Harbor

Ellsworth Glacier (fig. 311), 27 km long and 137 km² in area (Field, 1975d, p. 530), empties into a moraine-dammed lake above the head of Day Harbor. When Grant and Higgins (1913) visited and mapped it on 12 July 1909, the terminus of Ellsworth Glacier was retreating and was located about 2.5 km from the head of Day Harbor. This location was close to Ellsworth's "Little Ice Age" maximum position, which was reached before 1855 (Wiles and others, 1999a).

Figure 311.—*Two aerial photographs of Ellsworth Glacier showing changes between 1966 and 2000.* **A**, *3 September 1966 oblique aerial photograph showing the lower part of Ellsworth Glacier. The glacier retreated about 3 km from its position on the 1909 sketch map by Grant and Higgins (1913). USGS photograph no. 664–87 by Austin Post, U.S. Geological Survey.* **B**, *15 July 2000 north-looking oblique aerial photograph of most of Ellsworth Glacier. Compared to its 1966 position, the glacier shows significant thinning of its surface and margins and retreat of its terminus, especially on the west side. The 2000 terminus position was from 2.5 to 3 km from the 1966 position. Note the large tabular icebergs produced by calving. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of* B *is available online.*

By 1950, this distance had increased to a maximum of about 5 km; a large U-shaped ice-marginal lake, which began forming after 1918, occupied the 2 km adjacent to the glacier's margin. By 3 September 1966, the glacier had retreated an additional kilometer and had lost more than a third of its width (fig. 311*A*). When the author photographed the glacier from the air on 15 July 2000, it showed significant thinning of its surface and margins and retreat of its terminus, especially on the western side (fig. 311*B*). The 2000 terminus position was from 3.5 to 4.5 km from the 1908 position. Both the 1966 and 2000 aerial photographs document that Ellsworth Glacier, like its eastern neighbor Excelsior Glacier, calves large tabular icebergs into its proglacial lake.

Although not part of the Sargent Icefield, several small glaciers (both named and unnamed) flow into the western side of Day Harbor from Resurrection Peninsula. They are discussed below, in the Glaciers of Resurrection Peninsula section.

Glaciers of Nellie Juan River

More than a dozen unnamed glaciers drain in a westerly direction into the Nellie Juan River and eventually into Kings Bay. All show evidence of retreat and thinning (see two 3 September 1966 oblique aerial photographs by Austin Post, USGS photograph nos. 664–68 and 664–69). Retreat ranges from about 400 m to more than 1 km.

Glaciers of Resurrection Peninsula

Not connected to either the ice field north of the Sargent Icefield or the Sargent Icefield itself are a number of glaciers, mostly unnamed, that drain into Nellie Juan River, Day Harbor, Resurrection Bay, or Resurrection River. Named glaciers include Spoon, Prospect, Porcupine, Godwin, Bear Lake, and Mother Goose Glaciers. According to Field (1975d), the termini of Spoon, Prospect, and Porcupine Glaciers have all retreated, so that their elevations in 1950, as shown on the USGS 1950 Seward A-7 1:63,360-scale topographic map (appendix B), were 60 to 150 m higher than they were on Grant and Higgins (1913) map, which was based on their 1909 observations. All the Resurrection Peninsula glaciers have received minimal attention since their early 20th century studies.

Wentworth and Ray (1936) reported that the surface of Bear Lake Glacier—an IGY AGS glacier—lowered between 45 and 60 m during the 20- to 25-year period before their 1931 visit. When the AGS mapped the 6.3-km-long glacier in 1957 at 1:10,000 scale, it had a large elevated moraine on its southern side. Surface elevation profiling surveys (Sapiano and others, 1998) showed that, between 1957 and 1996, the terminus retreated a total of 515 m (an average retreat of 13 m a^{-1}) and that the elevation of the glacier surface decreased an average of 9.7 m, with a maximum of more than 60 m at an elevation of about 520 m near the terminus. Total volume lost was $6.5\times10^7 m^3$ of ice. Between the 1950s and the middle 1990s, on an annual basis, Bear Lake Glacier thinned by 0.277 m a^{-1}, its volume decreased by 0.00192 $km^3\ a^{-1}$, and its terminus receded by 10 m a^{-1}. From the middle 1990s to 1999, on an annual basis, the glacier thinned by 0.953 m a^{-1} and had its volume decrease by 0.00652192 $km^3\ a^{-1}$ (K.A. Echelmeyer, W.D. Harrison, V.B. Valentine, and S.I. Zirnheld, University of Alaska Fairbanks, written commun., March 2001). The long-term mass balance between 1957 and 1996 averaged -0.30 m a^{-1}.

Harding Icefield

The Harding Icefield (fig. 312) has a maximum length of 80 km, a maximum width of about 50 km (Field, 1975d, p. 497), and an area of about 1,800 km^2. It is the largest of the ice fields in the Kenai Mountains and the largest single ice field located entirely in the United States. The ice field has nearly 40 outlet glaciers, 16 of which have lengths greater than 8 km. Alone,

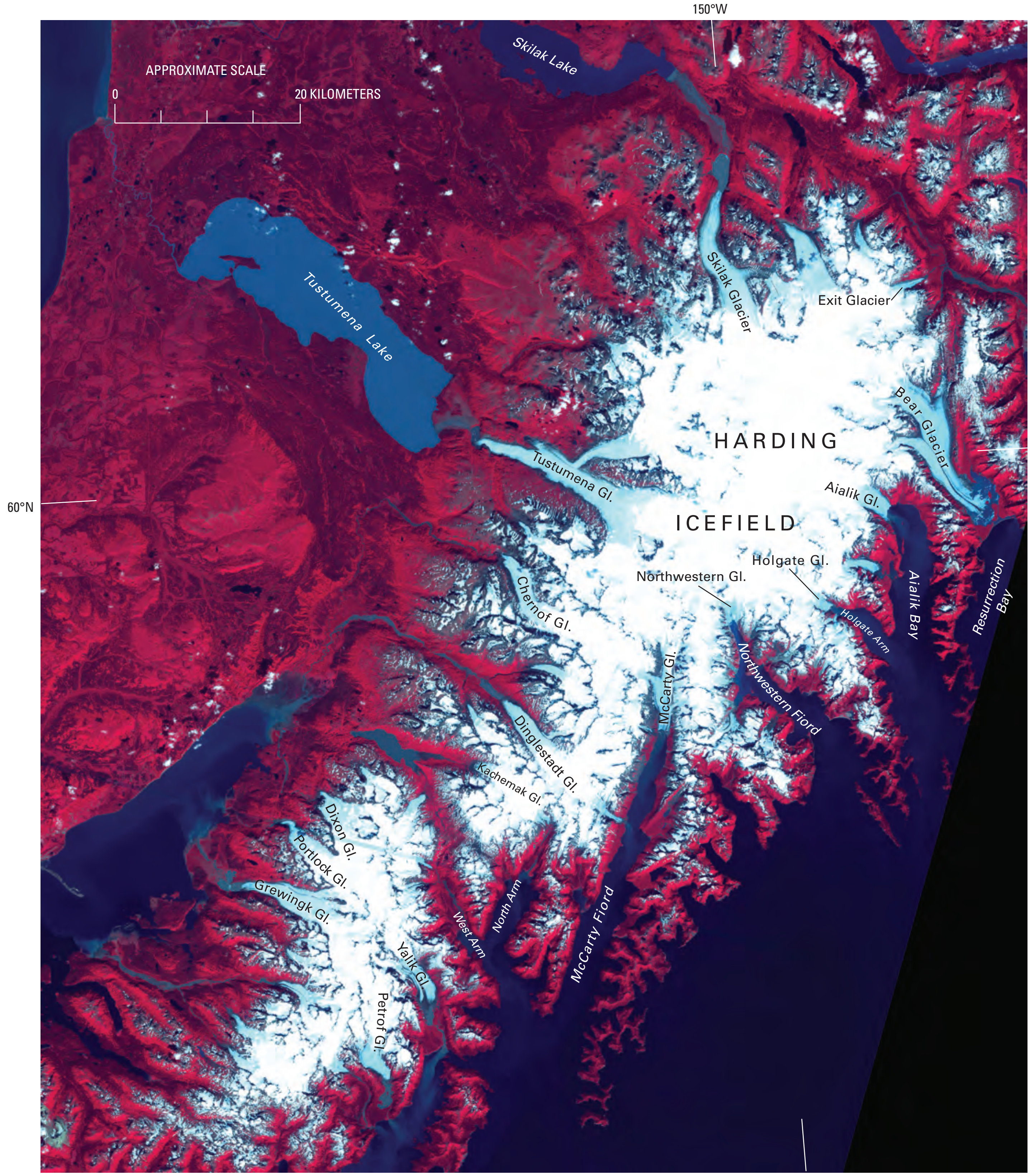


Figure 312.*—Digital enlargement of a Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) image showing the Harding Icefield and the unnamed ice field to the southwest of the Harding Icefield. Landsat 7 ETM+ image (7069018000022250; 9 August 2000; Path 69, Row 18) from the U.S. Geological Survey, EROS Data Center, Sioux Falls, S. Dak.*

these glaciers have an area of about 1,380 km². Four of these glaciers exceed 25 km in length. According to Field (1975d, p. 530–533), Bear Glacier (fig. 313) is 27 km long and has an area of 178 km²; an unnamed glacier is 29 km long and has an area of 183 km²; Tustumena Glacier is 32 km long and has an area of 390 km²; and Skilak Glacier is 34 km long and has an area of 160 km². Meier and Post (1962) estimated the ice field's ELA to be about 600 m and determined that the AAR was 0.68.

Most of the northward-draining glaciers are unnamed and drain into the Resurrection River or Skilak Lake. Southward-draining glaciers generally reach sea level or near to it. Many others—including Aialik Glacier at the head of Aialik Bay, Holgate Glacier in Holgate Arm of Aialik Bay, Northwestern Glacier and two unnamed glaciers in Northwestern Fiord, and McCarty Glacier in McCarty Fiord—have tidewater termini. An unnamed glacier in Holgate Arm had a tidewater terminus in the late 1990s but retreated from tidewater by 2001.

Rice (1987) made planimetric measurements of all of the ice field's glaciers, using 1:63,360-scale topographic maps prepared between 1950 and 1951 (appendix B), and compared them with 1980s aerial photography. He calculated that the ice field had decreased in area as much as 5 percent during the intervening 34 years. The greatest changes were near sea level along the Gulf of Alaska and at the 300- to 600-m elevations on the northern and western sides of the ice field. Many smaller glaciers located at elevations below 1,000 m had disappeared.

Aðalgeirsdóttir and others (1998) obtained airborne surface elevation profiles of 13 Harding Icefield glaciers and the upper accumulation area of the ice field in 1994 and 1996 (table 5). These profiles were compared with 1:63,360-scale topographic maps (appendix B) and the aerial photographs used in their preparation (2 August 1950 and 15 August 1952). They concluded that the ice field has been thinning and shrinking since the 1950s and estimated that it has lost about 34 km³ of ice in the more than 40-year period between being mapped in the early 1950s and profiled in the middle 1990s.

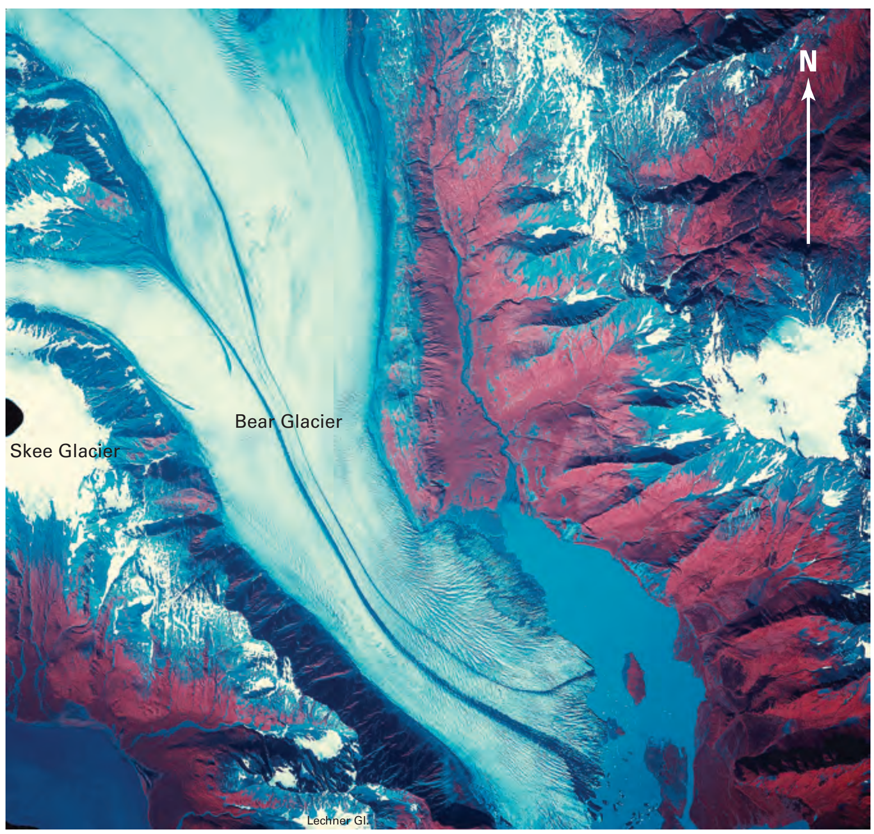


Figure 313.*—14 August 1984 AHAP false-color vertical aerial photograph (L120F0313) of much of Bear Glacier, a Harding Icefield outlet glacier. The glacier has retreated from its position on its outwash plain and is now surrounded by a large ice-marginal lake. During the early 21st century, it retreated 2 km through calving of its floating terminus.*

TABLE 5.—*Changes in outlet glaciers of the Harding Icefield: 1950s to middle 1990s*

Glacier	1950	Mid 1990's[1]					On annual basis[2]		
	Area (km^2)	Terminus change (m)	Area change (km^2)	Ice volume change (km^3)	Average elevation change (m)	Mean annual mass balance (m)	Thickness change ($m\ a^{-1}$)	Volume change ($km^3\ a^{-1}$)	Length change ($m\ a^{-1}$)
Aialik	118	+540	0	–2.6	–11.0	–0.2	–0.25	–0.0295	+13
Bear	228.5	–1550	–8.75	–9.7	–38.4	–0.7	–0.872	–0.195	–36
Chernof	95.3	–750	–1.0	–2.3	–22.6	–0.4	–0.493	–0.0467	–17
Dinglestadt	79.4	–2300	–4.25	–2.7	–32.4	–0.6	–0.717	–0.0554	–50
Exit	42.8	–490	–0.25	–0.1	–2.6	–0.1	–0.063	–0.00267	–12
Holgate	64.3	–260	–0.25	–1.3	–16.3	–0.3	–0.364	–0.0233	–6
Kachemak	54.9	–900	–0.75	–0.9	–16.3	–0.3	–0.375	–0.0205	–21
Little Dinglestadt	31.5	–370	–0.5	–0.6	–18.6	–0.4	–0.4	–0.0125	–9
McCarty	108.6	–690	–1.38	+1.5	+6.2	+0.1	+0.131	+0.141	–16
Northeastern	15.4	–1350	–1.63	–1.4	–97.1	–1.8	–2.087	–0.0304	–30
Northwestern	66.25	–4200	–8.0	–5.0	–80.2	–1.5	–1.746	–0.109	–92
Skilak	217	–3200	–5.63	–0.9	–4.5	–0.1	–0.104	–0.0222	–74
Tustemena	296.7	–690	–1.75	–8.9	–25.1	–0.5	–0.572	–0.169	–17

[1] Aðalgeirsdóttir and others (1998).
[2] K.A. Echelmeyer, W.D. Harrison, V.B. Valentine, and S.I. Zirnfeld, University of Alaska Fairbanks (written commun., March 2001).

This corresponds to an ice field-wide lowering of about 21 m, the equivalent of an average mass balance of –0.4 $m\ a^{-1}$ of water. They also concluded that the rate of change of surface elevation between 1994 and 1996 is significantly greater than the long-term average. The glaciers that they profiled were Aialik, Bear, Exit, Holgate, Skilak, Tustumena, Chernof, Dinglestadt, and Kachemak Glaciers, *Little Dinglestadt Glacier* (informally named by Aðalgeirsdóttir and others, 1998), McCarty Glacier, *Northeastern Glacier*, and Northwestern Glacier.

The northeastern part of the Harding Icefield supports about a dozen glaciers that drain into Resurrection Bay or Resurrection River. Two have names—Exit and Lowell Glaciers. Aðalgeirsdóttir and others (1998) reported retreat of almost 500 m and other changes between the 1950s and middle 1990s of 7-km-long Exit Glacier (table 5). Lowell Glacier's terminus retreated a similar amount.

Glaciers of Lower Resurrection Bay

When the 26-km-long Bear Glacier was mapped on 20 and 21 July 1909, it sat at the head of a tidal-flat outwash plain a maximum of about 300 m from the shore of Resurrection Bay (Grant and Higgins, 1913, fig. 11; two 21 July 1909 photographs—pl. XXXIIA, pl. XXXIB). At that time, the central part of the terminus was much closer to the bay. Grant and Higgins stated (p. 56) that "Along the center of the ice front high tide reaches the glacier." An earlier trimline seaward of the 1909 position was dated by Viereck (1967) as having formed between 1835 and 1845. Trees beyond it were as much as 350 years old. By 1950, the glacier had retreated an additional 400 m, and a small ice-marginal lake had developed along its eastern margin. During the second half of the 20th century, the glacier retreated about 1.5 km.

Aðalgeirsdóttir and others (1998) reported on changes between the 1950s and the middle 1990s of Bear Glacier (table 5). In 2000, the retreating terminus of Bear Glacier was actively calving large numbers of tabular icebergs. By 2004, Bear Glacier had retreated more than 2 km farther.

Glaciers of Aialik Bay

Named glaciers in Aialik Bay include Aialik, Addison, Pedersen, and Holgate Glaciers. The 12.9-km-long Aialik Glacier (Viens, 1995) (table 2; fig. 314) is a tidewater glacier located at the head of Aialik Bay. Between 22–24 July 1909, when Grant and Higgins (1913, pl. XXXIII) first investigated and mapped it, and 1950, the terminus position changed very little. In 1909, Aialik Glacier was a tidewater calving glacier and showed a large area of exposed bedrock along its margin (fig. 314) (21 July 1909 photograph by Grant and Higgins, 1913, pl. XXXIVA). Grant and Higgins stated that the glacier may have retreated as much as 400 m in the decade before 1909. Two gravel bars in Aialik Bay indicate significant recessions in the past (Post, 1980a). Aðalgeirsdóttir and others (1998) reported on changes in Aialik Glacier between the 1950s and the middle 1990s (table 5). The glacier both retreated and advanced in that time period; about 300 m of the 540 m of post-1950s retreat occurred between 1950 and 1964 (Field, 1975d). Aialik Glacier has an area of 70 km^2, an accumulation area of 62 km^2, an ablation area of 8 km^2, and an AAR of 0.88 (Viens, 1995) (table 2); the width of its terminus is 0.6 km. When the author visited on 13 August 2004, it was slowly retreating.

Figure 314.—*15 July 2000 west-looking oblique aerial photograph of the terminus of Aialik Glacier. During the 91 years since it was first photographed, the glacier retreated slightly. When observed by the author on 13 August 2004, the glacier showed signs of recent thinning and retreat. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.*

Pedersen Glacier (fig. 315) has been retreating since before it was first mapped on 22–24 July 1909 by Grant and Higgins (1913). Its 1909 terminus position was from 400 to 500 m behind its most recent maximum position. Even then, part of the terminus was reached by high tide. Grant and Higgins speculated that the glacier may have been at its maximum position as recently as 15 years earlier. By 1950, the glacier had retreated an additional 400 to 1,200 m. A 600- to 800-m-wide tidal embayment fronted part of the glacier. According to Field (1975d, p. 531), Pedersen Glacier has a length of 9 km and an area of 23 km^2. By 1964, another 250 of retreat had occurred. At the start of the 21st century, retreat and thinning were continuing. Aðalgeirsdóttir and others (1998) stated that Pedersen Glacier thinned an average of 5 m between the 1950s and the middle 1990s.

Figure 315.—*15 July 2000 west-looking oblique aerial photograph of the terminus of Pedersen Glacier. During the 91 years since it was first photographed, the glacier has retreated as much as 1.5 km. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.*

Holgate Glacier is a tidewater glacier at the head of Holgate Arm (fig. 316). An unnamed former tributary glacier, located to its southeast, retreated from tidewater before 2001. During the first decade of the 20th century, just before it was mapped on 22–24 July 1909 by Grant and Higgins (1913), the terminus of 8.5-km-long Holgate Glacier retreated about 1.5 km. When they visited it in 1909, the glacier terminus flowed on both sides of a bedrock outcrop that formerly had been a nunatak in the middle of the terminus. By 1950, the southern side of the glacier retreated another 400 m, while the northern side showed no change (Field, 1975d). Aðalgeirsdóttir and others (1998) reported on changes between the 1950s and the 1990s of Holgate Glacier (table 5), which has a length of 12.9 km, an area of 69 km^2, an accumulation area of 63 km^2, an ablation area of 6 km^2, a width at its terminus of 0.6 km, and an AAR of 0.92 (Viens, 1995) (table 2). When the author visited and photographed part of the terminus of Holgate Glacier on 13 August 2004, it had retreated more than 1 km from its 1909 position.

Figure 316.—*15 July 2000 northwest-looking oblique aerial photograph of the terminus of Holgate Glacier. Since 30 May 1964, when it was photographed by the U.S. Coast and Geodetic Survey (photograph no. W9372), Holgate Glacier has retreated as much as 300 m. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.*

Glaciers of Harris Bay

The 12-km-long Northwestern Glacier (fig. 317), which extends from the southeastern side of the Harding Icefield to tidewater in Northwestern Fiord at the head of Harris Bay, was named by U.S. Grant for Northwestern University in Evanston, Ill. The glacier, which had its terminus position mapped for the first time on 23 July 1909 by Grant and Higgins (1913, fig. 12), has been retreating since the beginning of the 20th century, with a total 20th century retreat of about 27 km. A 385-m-high rock knob located in the middle of Northwestern Fiord was completely icecovered in 1909. By 1950, it was a nunatak at the margin of the retreating Northwestern Glacier. Aðalgeirsdóttir and others (1998) reported on its changes between the 1950s and the middle 1990s (table 5). When the author observed the glacier on 15 July 2000 (fig. 317*B*) and visited it on 11 August 2004, he noted that a ridge of bedrock had separated its terminus into two adjacent ice tongues. Much of the margin of the eastern tongue was located above tidewater. Exposed bedrock along the margins of both tongues documents recent thinning. Northwestern Glacier has a length of 12.1 km, an area of 60 km^2, an accumulation area of 54 km^2, an ablation area of 6.0 km^2, a width at its terminus of 0.9 km, and an AAR of 0.89 (Viens, 1995) (table 2).

A 6-km-long glacier, named *Northeastern Glacier* by Post (1980c), is located on the eastern side of the fjord, about 5 km south of Northwestern Glacier. Aðalgeirsdóttir and others (1998) reported on its changes between the 1950s and the middle 1990s (table 5). When the author flew over the terminus on 3 September 2002, it had retreated nearly 2 km from its position in the early 20th century.

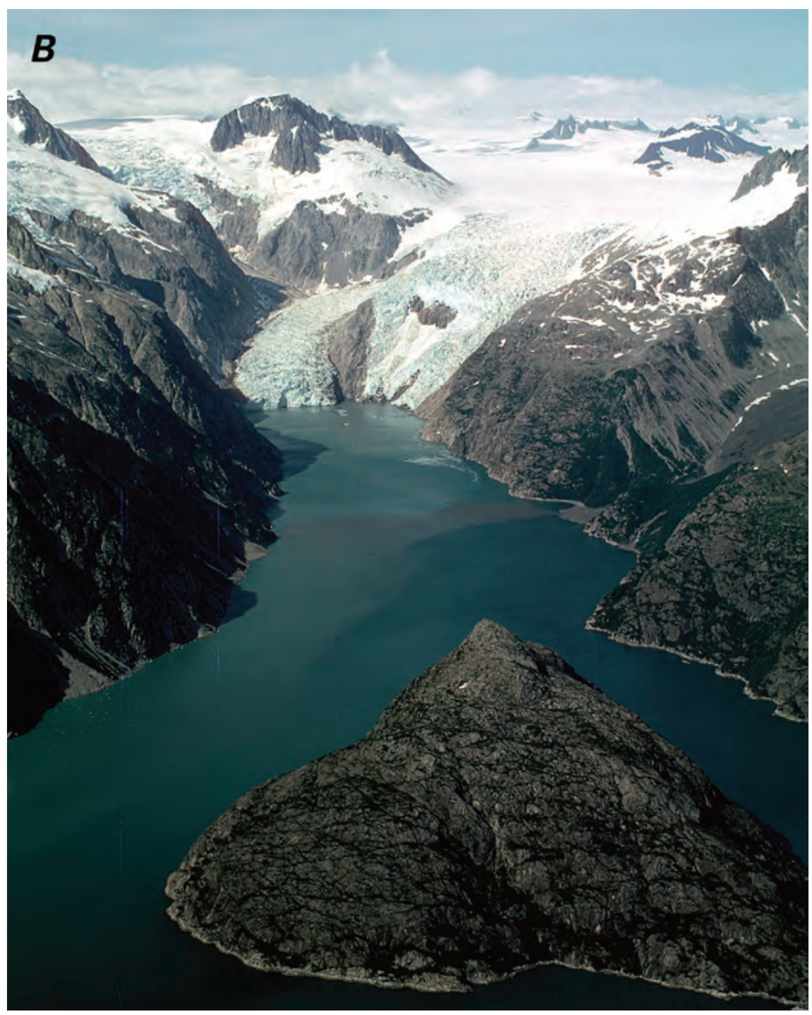


Figure 317.—**A**, *Part of a mosaic of the USGS Seldovia (1963, limited revision 1985) and Blying Sound (1953, limited revision 1982) 1:250,000-scale topographic maps (appendix A) of Northwestern Glacier and environs, showing the position of its terminus at that time.* **B**, *15 July 2000 northwest-looking oblique aerial photograph of the terminus of Northwestern Glacier and the head of Northwestern Fiord. The glacier has retreated more than 25 km since 1909 and substantially since the maps were printed. Continuing retreat has exposed a ridge of bedrock that separates the terminus into two adjacent ice tongues. Much of the margin of the eastern tongue is above tidewater. Exposed bedrock along the margins of both tongues documents recent thinning. Photograph by Bruce F. Molnia, U.S. Geological Survey.*

***Figure 318.**—15 July 2000 northwest-looking oblique aerial photograph showing the terminus of* Ogive Glacier. *Continued retreat and thinning of the glacier has all but separated the terminus from its upper source area. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.*

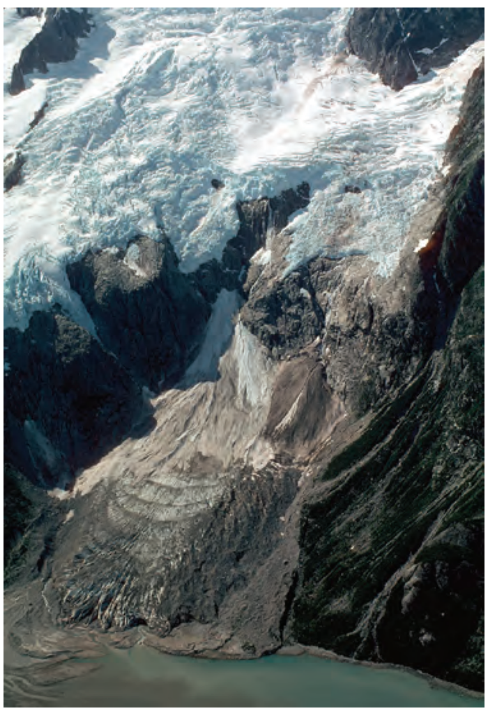


***Figure 319.**—15 July 2000 west-looking oblique aerial photograph showing an unnamed glacier southwest of* Anchor Glacier. *Continued retreat and thinning of the glacier have separated the terminus from its upper source area, producing a relict and reconstituted glacier. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.*

Two previously unnamed glaciers named *Anchor Glacier* and *Ogive Glacier* (fig. 318) by Post (1980c) [see Viens (1995) (table 2)], reach tidewater southwest of Northwestern Glacier. At each glacier, recent retreat has all but separated the terminus from its upper source area. *Anchor Glacier* had a length of 4.8 km, an area of 7 km^2, an accumulation area of 5 km^2, an ablation area of 2 km^2, a width at its terminus of 0.3 km, and an AAR of 0.77 (Viens, 1995) (table 2). *Ogive Glacier* had a length of 6.8 km, an area of 9 km^2, an accumulation area of 6 km^2, an ablation area of 2 km^2, a width at its terminus of 0.4 km, and an AAR of 0.73 (Viens, 1995) (table 2). An unnamed glacier (fig. 319) just southwest of *Anchor Glacier* is located a few meters above tidewater. Its terminus is completely separated from its upper source area. *Southwestern Glacier* (fig. 320) is located south of *Anchor Glacier* at the head of an outwash plain about 1.5 km from the fjord. Elevated trimlines and medial moraines indicate a significant amount of recent thinning and retreat. Many other glaciers that were tributary to the lower part of Northwestern Glacier at the turn of the 20th century are now small relict ice patches stranded high above Harris Bay.

Glaciers of Nuka Bay

McCarty Glacier, a tidewater glacier located at the head of the fjord, and *Little Dinglestadt Glacier* are the dominant glaciers in McCarty Fiord, the eastern Arm of Nuka Bay. McCarty Glacier, which was first studied and mapped on 30 July 1909 by Grant and Higgins (1913, fig. 13), retreated about 3.2 km between 1909 and 1927, another 19 km between 1927 and 1950 (Mercer, 1961b), and another 1.4 km through 1978 (Post, 1980b). Between 1978 and the middle 1990s, the terminus advanced about 700 m. When the author visited McCarty Glacier on 9 August 2004, it had retreated about 400 m from the position of its terminus in the middle 1990s. Aðalgeirsdóttir and others (1998) reported on changes between the 1950s and middle 1990s (fig. 321, table 5). McCarty Glacier has a length of 19.3 km, an area of 111 km^2, an accumulation area of 88 km^2, an ablation area of about 23 km^2, a width at its terminus of 1.3 km, and an AAR of 0.79 (Viens, 1995) (table 2). Aðalgeirsdóttir

***Figure 320.**—View of* Southwestern Glacier, *a former tributary to Northwestern Glacier. 15 July 2000 northwest-looking oblique aerial photograph showing the glacier's terminus with adjacent exposed bedrock, several elevated lateral moraines, and a large abandoned trimline. Parts of the adjacent unnamed glacier and* Ogive Glacier *can be seen on the west wall of the fjord. Photograph by Bruce F. Molnia, U.S. Geological Survey.*

Figure 321.—**A**, *Part of the USGS Seldovia 1:250,000-scale topographic map (1963, limited revision 1985) of McCarty Glacier and environs, showing the position of its terminus at that time.* **B**, *15 July 2000 north-looking oblique aerial photograph of the terminus of McCarty Glacier, located at the head of McCarty Fiord. The glacier retreated, more than 3 km between 1909 and 1928 and 20 km since 1928. An advance in the 1980s and early 1990s was followed by retreat beginning at the end of the 20th century. A fan delta is developing on the east side of the terminus. The central margin has a well-formed calving embayment. Photograph by Bruce F. Molnia, U.S. Geological Survey.*

and others (1998) reported on changes between the 1950s and the middle 1990s of 7-km-long *Little Dinglestadt Glacier* (table 5).

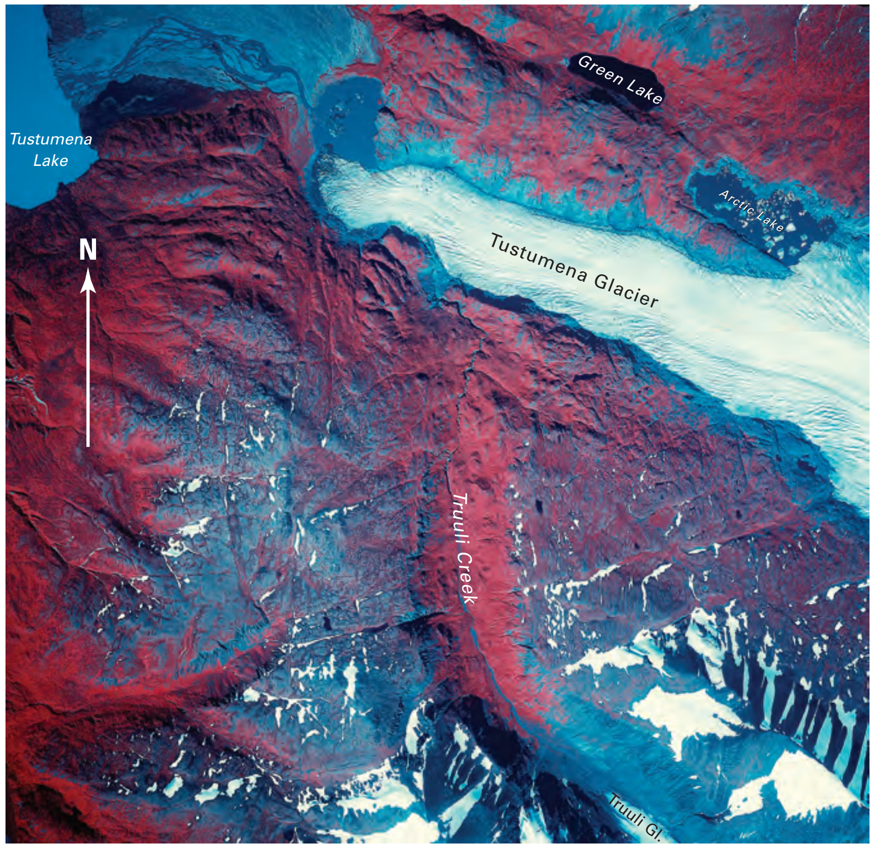
Glaciers of the Western Harding Icefield

According to Field (1975d, p. 531–532), who measured lengths and areas, Kachemak (8 km, 23 km^2), Dinglestadt (19 km, 69 km^2), Chernof (17 km, 61 km^2), Tustumena (32 km, 390 km^2), and Skilak Glaciers (34 km, 160 km^2) are the major named glaciers of the western Harding Icefield. All have terrestrial or lacustrine termini. Aðalgeirsdóttir and others (1998) reported on changes between the 1950s and the middle 1990s of Kachemak Glacier (table 5).

Field (1975d) stated that aerial photographs of Dinglestadt Glacier show evidence of 1.5 km of retreat between 1942 and 1965, including formation and enlargement of the proglacial lake at its terminus. Aðalgeirsdóttir and others (1998) reported on changes between the 1950s and the middle 1990s in 15.5-km-long Dinglestadt Glacier (table 5).

Field (1975d) stated that aerial photographs of Chernof Glacier show evidence of retreat as early as 1942. Aðalgeirsdóttir and others (1998) reported on changes between the 1950s and the middle 1990s in 24-km-long Chernof Glacier (table 5).

Figure 322.—14 August 1984 AHAP false-color vertical photograph (L120F0304) of much of the lower Tustumena Glacier and the retreating terminus of Truuli Glacier. Exposed bedrock around the entire perimeter of the Tustumena Glacier documents recent rapid thinning and retreat. When it was mapped in 1958, the glacier filled the entire basin at its terminus with ice. Since the 1990s, an ice-marginal lake has developed around the terminus. AHAP photograph from the GeoData Center, Geophysical Institute, University of Alaska, Fairbanks, Alaska.



Aðalgeirsdóttir and others (1998) reported on changes between the 1950s and the middle 1990s in 35-km-long Tustumena Glacier (fig. 322, table 5). Aðalgeirsdóttir and others (1998) reported on changes between the 1950s and the middle 1990s in 26-km-long Skilak Glacier (table 5). With the exception of the 1978 to the middle 1990s advance of McCarty Glacier, all Harding Icefield glaciers show evidence of ongoing thinning and retreat.

Unnamed Ice Field Southwest of Harding Icefield

Southwest of Harding Icefield and east of Kachemak Bay is another unnamed ice field (fig. 312). The ice field has a maximum width of about 35 km from east to west and 25 km from north to south. The four largest glaciers have lengths of between 14 and 19 km (Field, 1975d, p. 533). None reach tidewater. According to Field (1975d, p. 533–534) who measured lengths and areas, Yalik (16 km, 151 km^2) and Petrof (14 km, 46 km^2) Glaciers are the major glaciers draining the eastern side of the complex, whereas Doroshin (13 km, 28 km^2), Wosnesenski (11 km, 33 km^2), Grewingk (19 km, 72 km^2), Portlock (14 km, 41, km^2), and Dixon (11 km, 41 km^2) Glaciers are the major outlet glaciers that drain the western side. None reach tidewater, but several terminate at elevations below 100 m. Comparison of recent aerial photography with maps and early observations shows that each of these glaciers substantially retreated during the 20th century.

In 1909, Grant and Higgins (1913) examined Yalik Glacier. At that time, the terminus was separated from the forest by a deglacierized zone of unspecified length. During the next 41 years, part of the glacier‘s terminus retreated as much as 400 m. However, the middle of the terminus showed little change. The author visited Yalik Glacier on 10 August 2004 and observed that about 1.5 km of retreat had occurred since the 1950s.

On 8 August 1909, Grant and Higgins (1913) mapped and examined Petrof Glacier [see 8 August 1909 map (fig. 18) and two 8 August 1909 photographs presented by Grant and Higgins (1913, pls. XLA, XXXIXB)]. At that time, the terminus was separated from the forest by a 300- to 400-m-wide deglacierized zone. During the next 42 years, the glacier's terminus retreated as much as 1.5 km, and an ice-marginal lake developed. When the AHAP program photographed the lake in 1978, it had a length of nearly 3 km.

Dall (1896) visited Grewingk Glacier as early as 1880 and produced its first map. Grove Karl Gilbert, accompanied by Dall and other scientists of the Harriman Expedition, visited the glacier in 1899 (21 July 1899 photograph by G.K. Gilbert, USGS Photo Library photograph Gilbert 456). Gilbert (1904), reported that, between 1880 to 1895, the glacier retreated 75 m; between 1895 and 1899, it retreated another 100 m. During the next half century, no new information was available. By 1951, the date of the USGS Seldovia 1951 1:63,360-scale C-3 topographic map (appendix B), a lake between 1.0 and 1.5 km in width had developed around the northern margin of its terminus. By 1978, the lake surrounded the entire terminus and was as much as 2.5 km wide.

Glaciers of the Islands of Prince William Sound

Of all of the islands of Prince William Sound, Montague Island (fig. 323) is the only one that supports small glaciers. More than 20 are mapped along a 20-km-long part of the crest of the island at elevations of 600 to 800 m. All are confined to relatively small cirques; when the author observed them from the air in July 2000, all showed significant evidence of thinning and retreat.

Figure 323.—*13 August 1982 AHAP false-color vertical photograph of central Montague Island. In the approximately 20 years between the production of the USGS Seward A–1 and A–2 and Blying Sound D–1 and D–2, 1:63,360-scale topographic maps in the 1950s and 1960s and the date of this photograph, many glaciers shown at lower elevations on Montague Island disappeared. A likely explanation is that a cartographer incorrectly mapped the unmelted previous winter snow pack as glacier ice. AHAP photograph no. L118F1591 from the GeoData Center, Geophysical Institute, University of Alaska Fairbanks, Fairbanks, Alaska.*

Summary

During the period of the Landsat baseline (1972–81), with the exception of Aialik and McCarty Glaciers, all of the valley and tidewater glaciers in the Kenai Mountains were stagnant, thinning, and (or) retreating. Into the early 21st century, all of the outlet glaciers in the Kenai Mountains continued to thin, stagnate, and retreat. Aialik and McCarty Glaciers each advanced more than 500 m during the second half of the 20th century but were both retreating by 2004. When Tiger Glacier was observed in 2000, it was at about the same location as it was in 1908. Having retreated during much of the 20th century, Tiger Glacier must have experienced a late 20th century advance to regain its former position.

Kodiak Island

Kodiak Island is located in the western Gulf of Alaska, south of Cook Inlet and east of Shelikof Strait (figs. 1, 324). At a length of about 160 km and a maximum width of nearly 100 km, Kodiak is the largest island in Alaska. Landsat 1–3 MSS images that cover Kodiak Island have the following Path/Row coordinates: 74/19, 75/19, 76/19, 74/20, 75/20, and 76/20 (fig. 3, table 1). Figure 325 is an annotated Landsat MSS false-color composite image mosaic (2908–20125, bands 4, 5, 7; 18 July 1977; Path 74, Row 20; 2909–20183, bands 4, 5, 7; 19 July 1977; Path 75, Row 20) of Kodiak Island showing all of the glacierized mountainous regions. Numerous fjords, several of which

Figure 324.—**A**, *Index map of Kodiak Island showing the glacierized areas on the island.* **B**, *Enlargement of NOAA Advanced Very High Resolution Radiometer (AVHRR) image mosaic of Kodiak Island in summer 1995; National Oceanic and Atmospheric Administration image mosaic from Mike Fleming, EROS Data Center, Alaska Geographic Science Center, U.S. Geological Survey, Anchorage, Alaska.*

nearly bisect the island, are evidence of the extent of Pleistocene glacier erosion on Kodiak Island.

The USGS Kodiak, Alaska (1952), 1:250,000-scale topographic quadrangle map (appendix A) which is based on 1948–52 observations and aerial photography, depicts more than 40 cirque glaciers (Denton, 1975b, p. 630; Wahrhaftig, 1965, p. 40), mostly in a narrow upland region located on the mountainous backbone of the island between Koniag Peak (1,362 m) to the south and Mount Glottof (1,343 m) to the north and in adjacent drainages (fig. 325). Koniag Glacier, the only named glacier on the island, is also the largest; it is about 2.5 km long and descends to elevations below 500 m. One cluster of five glaciers occurs approximately 12 km southwest of Koniag Peak at the head of an unnamed tributary to Uyak Bay. An isolated unnamed 1-km-long-glacier, the southernmost and westernmost glacier on the island, can be seen on the western side of an unnamed 1,040-m-high peak about 32 km southwest of Koniag Peak and 6 km north of Deadman Bay on a 25 July 1979 AHAP false-color infrared vertical aerial photograph (fig. 326). In all, the author estimates that the area of glaciers on Kodiak Island is less than 15 km^2.

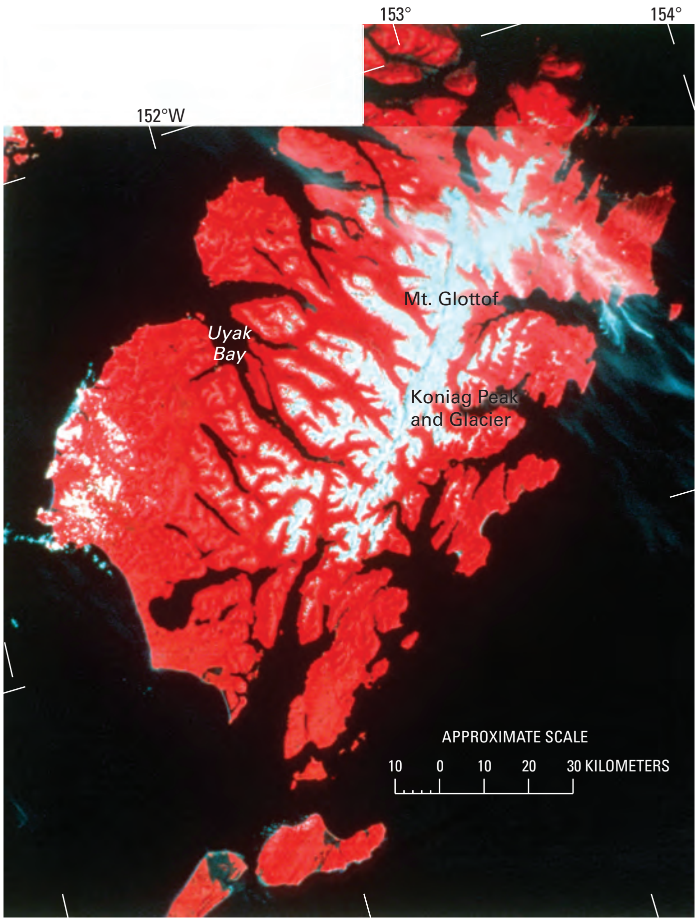


Figure 325.*—Annotated Landsat 2 MSS false-color composite image mosaic of Kodiak Island. The locations of Mount Glottof, Koniag Peak, and Koniag Glacier are indicated. Landsat images (2908–20125, bands 4, 5, 7; 18 July 1977; Path 74, Row 20; and 2909–20183, bands 4, 5, 7; 19 July 1977; Path 75, Row 20) from the U.S. Geological Survey, EROS Data Center, Sioux Falls, S. Dak.*

Figure 326.—*25 July 1979 AHAP false-color infrared, vertical aerial photograph of south-central Kodiak Island showing part of the glacierized mountains that make up the backbone of the island. An unnamed 1.5-km-long snow-covered glacier is located at the head of a valley near the center of the photograph (A). Its valley is fringed by vegetation-free exposed bedrock. Other than the crevasses that can be seen in an unnamed 1.0-km-long glacier (B), all glacier features were snow covered at the time of acquisition of the photograph. AHAP photograph no. L147F61 from the GeoData Center, Geophysical Institute, University of Alaska, Fairbanks, Alaska.*

Summary

During the period of the Landsat baseline (1972–81), all available evidence suggests that the glaciers of Kodiak Island were thinning and retreating. These conclusions are based on a comparison of the size and number of glaciers shown on Kodiak's topographic maps made from 1948–52 data and AHAP photography from the middle of the baseline period (1977–79). No information exists about the status of these glaciers at the end of the 20th century and into the early 21st century. However, given their small size, low elevation, and location on an island experiencing a significant late 20th century temperature increase and surrounded by temperate ocean water, it is likely that they have continued to thin and retreat.

Aleutian Range

Introduction

The Aleutian Range (figs. 1, 327), which extends northeast-southwest along the spine and southeastern side of the Alaska Peninsula for nearly 1,000 km, is bounded on the north by the Neacola River, Chakachamna Lake, and Chakachatna River and on the south by Isanotski Strait and False Pass. The range contains more than 30 glaciers having lengths of 8 km or more; Blockade Glacier is 44 km long (Denton and Field, 1975b, p. 601). Most glaciers, large and small, are unnamed. Seven areas support glaciers, including the Neacola and Chigmit Mountains of the northern Aleutian Range; the Kamishak Bay–Big River area; the Ninagiak River–Puale Bay area; the Mount Kialagvik, Icy Peak, and Mount Chiginagak area southwest of Wide Bay; the Aniakchak Crater area (see Landsat 2, MSS image 2534–20511, 9 July 1976, Path 78, Row 20); the Mount Veniaminof–Stepovak Bay area; and the Pavlof Volcano–Frosty Peak area. The area covered by glaciers in the Aleutian

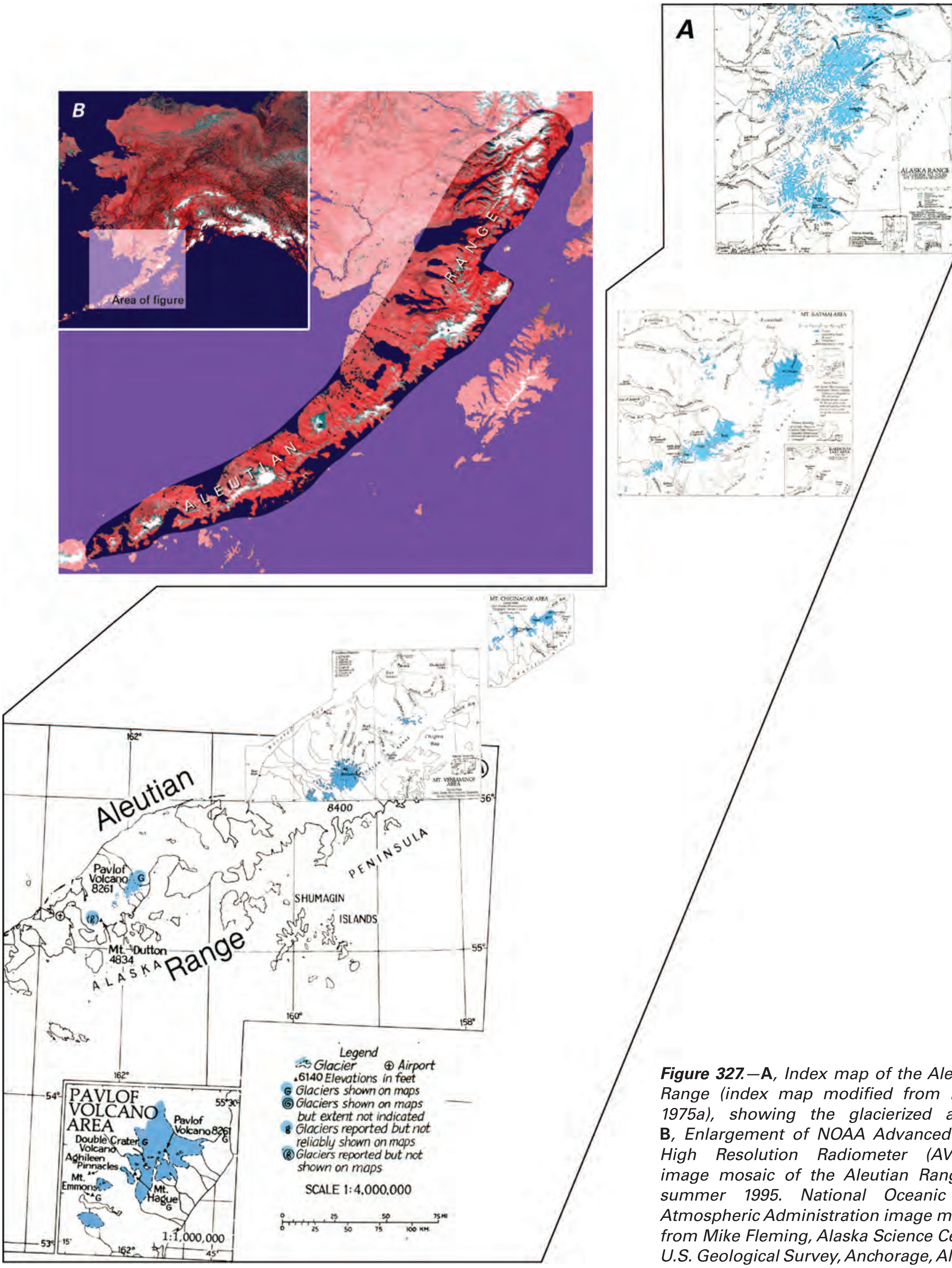


Figure 327.—**A**, *Index map of the Aleutian Range (index map modified from Field, 1975a), showing the glacierized areas.* **B**, *Enlargement of NOAA Advanced Very High Resolution Radiometer (AVHRR) image mosaic of the Aleutian Range in summer 1995. National Oceanic and Atmospheric Administration image mosaic from Mike Fleming, Alaska Science Center, U.S. Geological Survey, Anchorage, Alaska.*

Range is 1,250 km^2 (Post and Meier, 1980, p. 45). Landsat 1–3 MSS images that cover the Aleutian Range have the following Path/Row coordinates: 76/17; 77/17; 76/18; 77/18; 75/19; 76/19; 77/19; 78/19; 76/20; 77/20; 78/20; 79/20; 78/21; 79/21; 80/21; 81/21; and 81/22 (fig. 3, table 1).

Glaciers of the Neacola and Chigmit Mountains

Together, the Neacola and Chigmit Mountains contain more than a thousand glaciers ranging in size from cirque glaciers to some of the largest valley glaciers in the Aleutian Range. Fleming (2000) compiled a 1:250,000-scale Landsat 7 ETM+ satellite image mosaic map of Lake Clark National Park and environs that shows glaciers of the Neacola and Chigmit Mountains and glaciers of the southern Alaska Range. Figure 328 is a modification of part of the Landsat 7 image mosaic. "Little Ice Age" advances of several of the larger valley glaciers resulted in the damming of rivers and the formation of large ice-dammed lakes in both ranges.

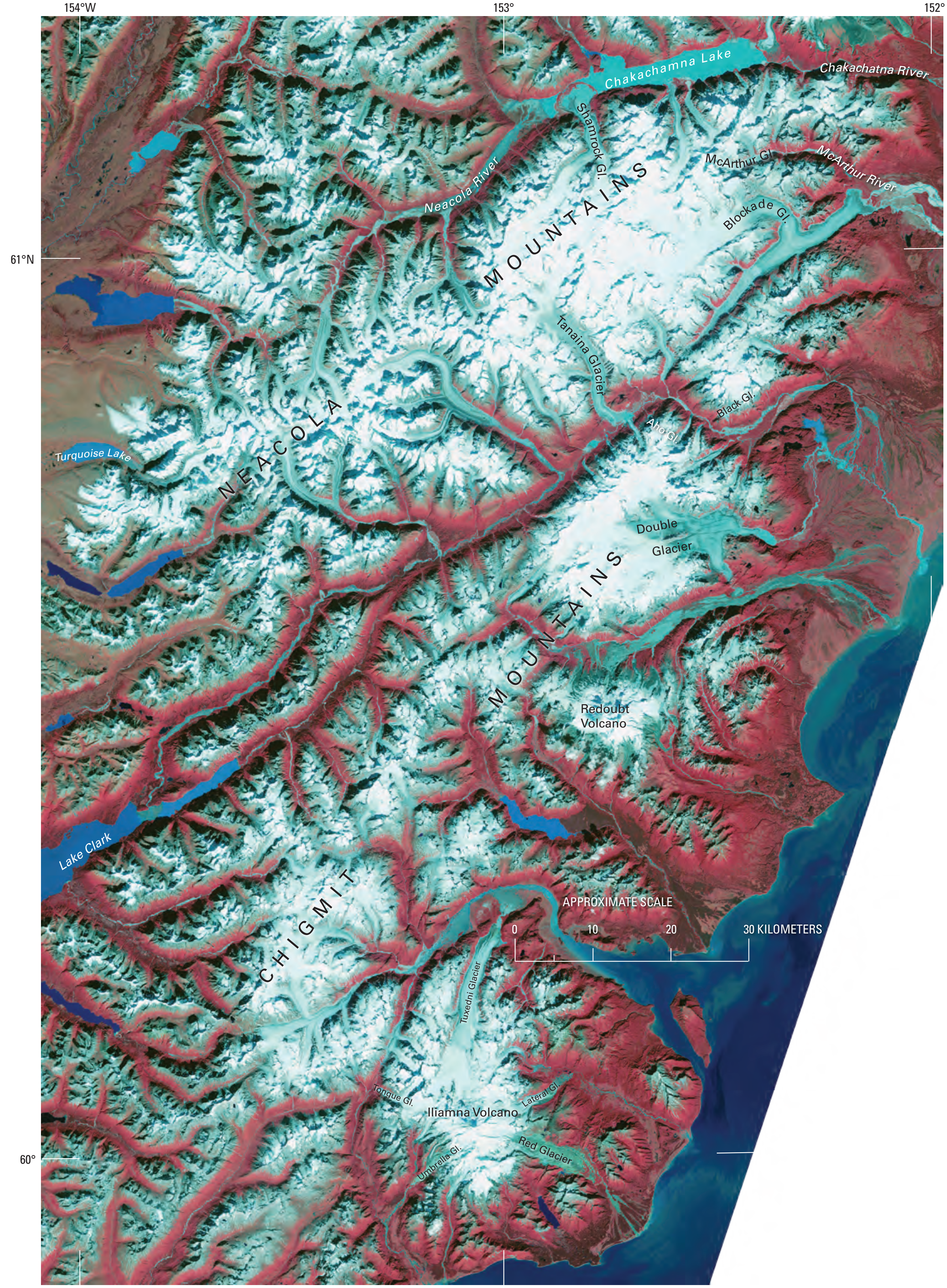
Glaciers of the Neacola Mountains

The 120×30-km Neacola Mountains (fig. 329), the northernmost range in the Aleutian Range, support more than 500 km^2 of glacier ice, including the longest valley glaciers in the Aleutian Range. One, 26-km-long Shamrock Glacier (Denton and Field, 1975b, p. 600) (figs. 59, 330), flows north and reaches into Chakachamna Lake. In the late 19th or early 20th century, its large lobate terminus advanced across the lake and blocked it, forming Kenibuna Lake. In recent years, the glacier has retreated as much as 2.5 km, but the moraine still constrains the width of the lake to just a narrow channel. Between the 1950s and the middle 1990s, on an annual basis, Shamrock Glacier thinned by 0.379 m a^{-1} and had its volume decrease by 0.0503 km^3 (K. A. Echelmeyer, W. D. Harrison, V. B. Valentine, and S. I. Zirnheld, University of Alaska Fairbanks, written commun., March 2001).

About 15 km east of Shamrock Glacier, a pair of unnamed glaciers also extended into Chakachamna Lake (20 July 1980 AHAP false-color infrared vertical aerial photograph no. L108F6636), although only a small distance. They too are actively retreating.

Thirty kilometers to the south, 44-km-long Blockade Glacier (fig. 331), with an area of 254 km^2 (Denton and Field, 1975b, p. 601), bifurcates. The lobe of its eastern terminus flows about 10 km to the northeast, where it drains into the McArthur River, and the lobe of its western terminus flows about 5 km to the southwest, where it dams Blockade Lake. Both termini are actively retreating and thinning. About 25 km to the southwest of the western tongue of Blockade Glacier, Tanaina Glacier (fig. 332), which has a length estimated by the author of approximately 30 km, and an area of approximately 150 km^2, flows into Lake Clark Pass and at times has completely filled its valley with ice, damming Summit Lake. Its retreat during the second half of the 20th century has left the pass ice free and the lake greatly reduced in size. Between the 1950s and the middle 1990s, on an annual basis, Tanaina Glacier thinned by 1.051 m a^{-1} and had its volume decrease by 0.173 km^3 (K. A. Echelmeyer, W. D. Harrison, V. B. Valentine, and S. I. Zirnheld, University of Alaska Fairbanks, written commun., March 2001).

When they were observed on 8 August 2000, a number of unnamed south-flowing southern Neacola Mountains glaciers, located in and adjacent to the through valley southwest of Blockade Glacier, were thinning, retreating, and losing contact with their former tributaries (20 June 1978 AHAP false-color infrared vertical aerial photograph no. L112F4732). Examples are the unnamed glacier at the head of the Glacier Fork of the Tlikakila River, another unnamed glacier located immediately west of Tanaina Glacier, two unnamed glaciers that are the western source of the Telaquana River, and an unnamed glacier that is the southwesternmost valley glacier in the Neacola Mountains. Between the 1950s and the middle 1990s, on an annual basis, this



154°W
153°
152°
61°N
60°
Chakachamna Lake
Chakachatna River
Shamrock Gl.
McArthur Gl.
McArthur River
Neacola River
Blockade Gl.
MOUNTAINS
Tanaina Glacier
Black Gl.
Another Gl.
NEACOLA
Turquoise Lake
Double
Glacier
MOUNTAINS
Redoubt
Volcano
Lake Clark
CHIGMIT
APPROXIMATE SCALE
0
10
20
30 KILOMETERS
Tuxedni Glacier
Tongue Gl.
Lateral Gl.
Iliamna Volcano
Red Glacier
Umbrella Gl.

◄ *Figure 328.—Part of an annotated Landsat 7 ETM+ false-color composite image mosaic of Lake Clark National Park and environs showing the glaciers of the Neacola and Chigmit Mountains. Landsat 7 ETM+ images (7071017009924950 and 707101800924950; bands 2, 3, 4; 6 September 1999; Path 71, Rows 17, 18) courtesy of Mike Fleming, Alaska Science Center, U.S. Geological Survey, Anchorage Alaska.*

glacier thinned by 0.4 m a^{-1} and had its volume decrease by 0.0179 km^3 (K. A. Echelmeyer, W. D. Harrison, V. B. Valentine, and S. I. Zirnheld, University of Alaska Fairbanks, written commun., March 2001).

Figure 329.—*4 September 1966 oblique aerial photograph of the Neacola Mountains showing a number of unnamed cirque glaciers located in the remote central part of the range. Photograph No. 666–26 by Austin Post, U.S. Geological Survey.*

Figure 330.—*8 September 2000 south-looking oblique aerial photograph of the terminus of Shamrock Glacier showing the elevated end and lateral moraine complex, which dates from the first half of the 20th century, the retreating terminus, and the lower one-third of the glacier. Photograph by William R. Reckert, Volunteer for Science, U.S. Geological Survey. This photograph should be compared with figure 59, a 20 July 1980 AHAP false-color infrared vertical aerial photograph (L108F6633) of Shamrock Glacier, Chigmit Mountains, Aleutian Range, to determine changes during the 20 years between the photographs.*

Figure 331.*—Two 8 September 2000 oblique aerial photographs of the two retreating termini of Blockade Glacier.* **A***, West-looking photograph showing the two lobes of the splayed eastern terminus of Blockade Glacier. Both lobes show evidence of recent retreat, especially the northern lobe. An elevated trimline parallels much of the northern margin of the glacier.* **B***, Northeast-looking photograph showing the thinning western terminus of Blockade Glacier at the head of Blockade Lake. Elevated shorelines document the recently much thicker character of the glacier. An elevated trimline parallels much of the northern margin of the glacier. A copious discharge of icebergs documents that calving from the retreating margin is a significant factor in its retreat. On the south side of the valley, a pair of retreating former tributaries to a previously larger West Blockade Glacier can be seen. On the north side, lowering of the lake's surface has exposed the formerly submerged fan-delta top of an unnamed and unseen glacier. Just to its east side, at the top of the valley wall, is the exposed bedrock threshold of an unseen retreating cirque glacier. Photographs by William R. Reckert, Volunteer for Science, U.S. Geological Survey. A larger version of* B *is available online.*

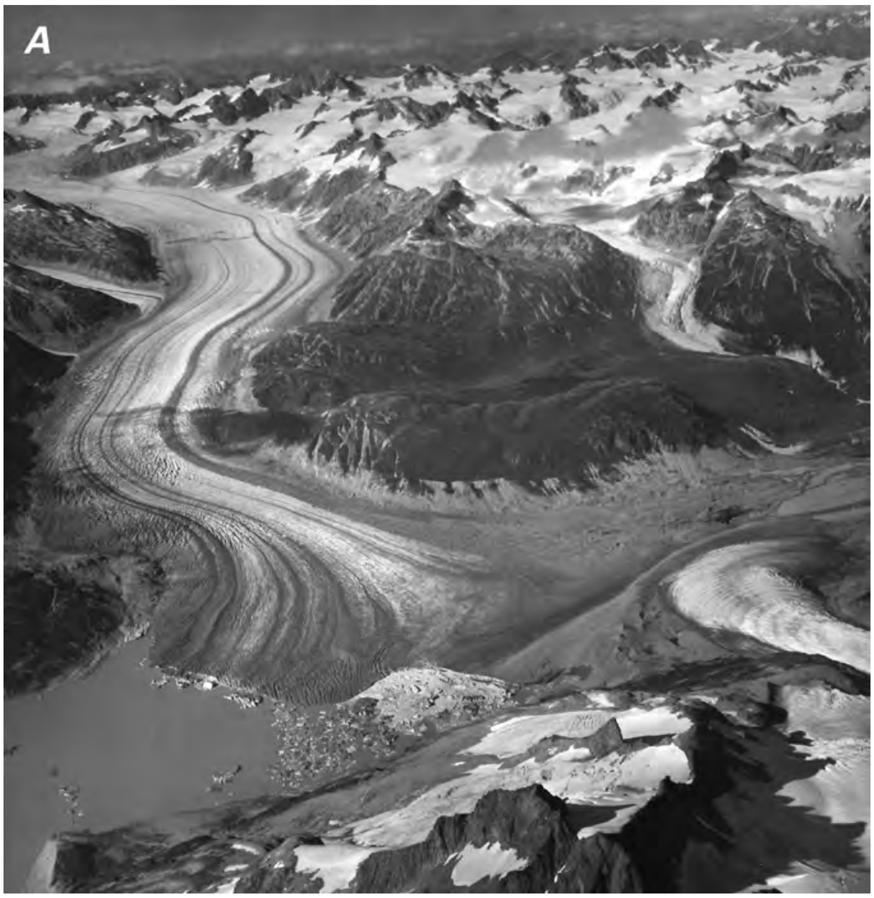
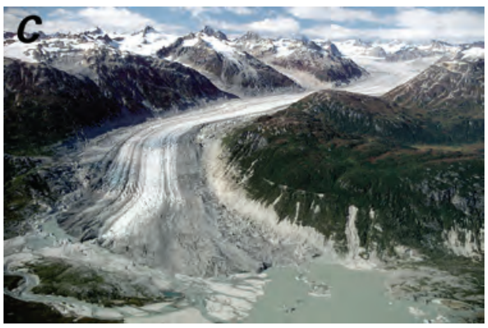


Figure 332.*—Three oblique aerial photographs of Lake Clark Pass showing changes of Tanaina Glacier, an unnamed glacier, and Summit Lake from 1963 to 2000.* **A***, 25 August 1963 north-looking oblique aerial photograph of the terminus of Tanaina Glacier (left) and the terminus of the unnamed glacier (right). The adjacent termini are both in contact with an elevated former terminal moraine ridge of the unnamed glacier and fill the valley floor. Summit Lake is dammed by the iceberg-calving terminus of Tanaina Glacier. The exposed, elevated trimline on the north side of the terminus of Tanaina Glacier documents that the glacier was more than 50 m thicker in the recent past. Photograph no. F632–127 by Austin Post, U.S. Geological Survey.* **B** *and* **C***, see following page.*

Figure 332.—**B**, *August 1970 north-looking oblique aerial photograph of the terminus of Tanaina Glacier (left) and the terminus of the unnamed glacier (right). The termini are no longer in contact, and the draining of Summit Lake has exposed its bed. Both sides of the terminus of Tanaina Glacier have thinned. Retreat along the west side has exposed a significant amount of bedrock and sediment. Little change can be seen at the terminus of the unnamed glacier. Photograph No. 70–N2–55 by Austin Post, U.S. Geological Survey.* **C**, *8 September 2000 north-looking oblique aerial photograph of the retreating terminus of Tanaina Glacier and the recently re-formed Summit Lake. The lake, now at a much lower level, is dammed by sediment and an ice-cored moraine left by the retreat of Tanaina Glacier. A recessional moraine wraps around the west side of the retreating terminus of Tanaina Glacier. Photograph by William R. Reckert, Volunteer for Science, U.S. Geological Survey. A larger version of* C *is available online.*



Glaciers of the Chigmit Mountains

The 195-km-long Chigmit Mountains contain more than 750 km^2 of ice located within a rugged upland area. There are hundreds of cirque glaciers and dozens of outlet valley glaciers, including Double Glacier, the two lobes of which have lengths of 26 and 25 km (Denton and Field, 1975b, p. 602). Additionally, the Chigmit Mountains contain two of the largest glacier-covered volcanoes in the Aleutian Range—Redoubt Volcano (3,099 m) and Iliamna Volcano (3,044 m).

In the northeasternmost Chigmit Mountains, a number of small glaciers drain from an ice-covered upland topped by 1,940-m-high Black Peak. When they were observed on 8 August 2000, the termini of the two largest—8-km-long Black Glacier and a 10-km-long unnamed glacier—showed evidence of recent thinning and retreat. Just to the south, Double Glacier (fig. 333), which has an area of 209 km^2 (Denton and Field, 1975b, p. 602), drains to the east from the largest ice field in the northern Chigmit Mountains. Located between the Tlikakila and Drift Rivers, the unnamed ice field covers an area estimated by the author to be approximately 400 km^2. Topped by 2,072-m-high Double Peak, more than 30 outlet glaciers flow radially from this ice field. Every outlet glacier shows evidence of recent thinning and retreat. Between the 1950s and the middle 1990s, on an annual basis, Double Glacier thinned by 1.067 m a^{-1} and had its volume decrease by 0.243 km^3 (K. A. Echelmeyer, W. D. Harrison, V. B. Valentine, and S. I. Zirnheld, University of Alaska Fairbanks, written commun., March 2001).

Several hundred small unnamed glaciers are located adjacent to the southern side of the eastern end of Lake Clark, Little Lake Clark, and Chokotonk River. When they were observed on 8 August 2000, every one showed evidence of thinning and retreat.

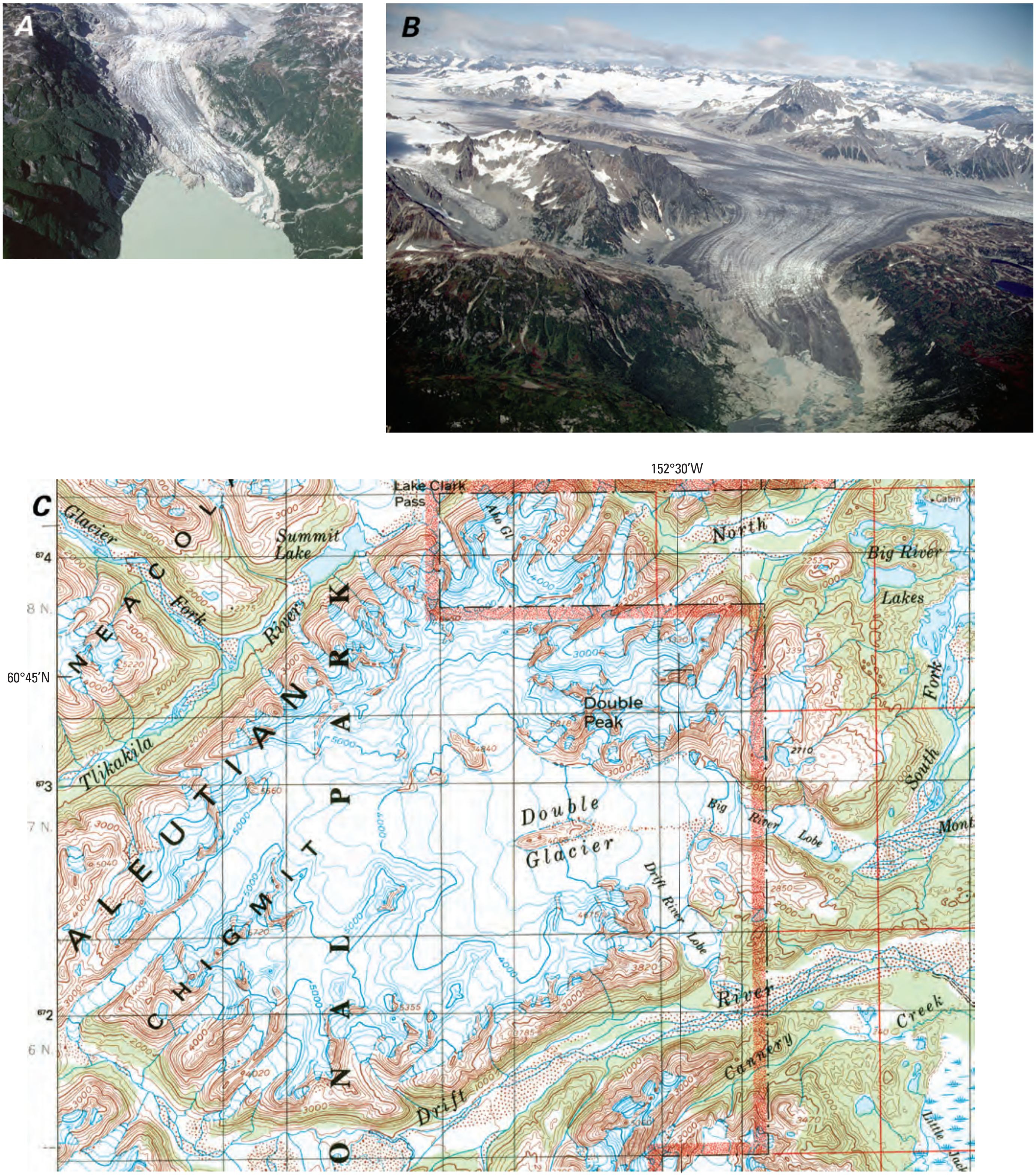


Figure 333.—*Map and two 8 September 2000 west-looking oblique aerial photographs of the northeastern Chigmit Mountains showing Double Glacier.* **A**, *Photograph of the terminus of the retreating Big River Lobe, the northern of Double Glacier's two termini. An elevated lateral moraine on its south side and an elevated trimline on its north side document recent retreat and thinning. During the 20th century, the glacier may have thinned by more than 100 m.* **B**, *Terminus of the retreating Drift River Lobe (right), and an unnamed former tributary (far left). The Drift River Lobe has retreated about 3 km since it was mapped in the mid-1950s, retreating an average of approximately 65 m a^{-1}. The unnamed former tributary has retreated more than 5 km. Photographs by William R. Reckert, Volunteer for Science, U.S. Geological Survey.* **C**, *Part of the USGS Kenai (1958, revised 1986) 1:250,000-scale map showing Double Glacier and other glaciers in the southeastern Chigmit Mountains. A larger version of* A *is available online.*

Glaciers of Redoubt Volcano

Redoubt Volcano, a steep-sided cone about 10 km in diameter at its base and with a volume of 30 to 35 km^3, has been moderately dissected by the action of numerous alpine glaciers. More than a dozen unnamed glaciers descend from Redoubt Volcano's summit. A 1.8-km-wide ice-filled summit crater is breached on the northern side by a northward-flowing glacier, which spreads out and forms a small piedmont lobe in the upper Drift River Valley (fig. 334). When the mountain last erupted in 1989 and 1990, significant melting of the summit glaciers took place, followed by jökulhlaups (glacier-outburst floods) on Drift River. Previously, jökulhlaups in 1966 covered the lower 3 km of Redoubt's northernmost glacier with up to 2 m of volcanic debris. The unnamed glacier's debris-covered terminus is currently about 100 m from Drift River Valley.

Eruptions between 14 December 1989 and 14 March 1990 melted snow and glacier ice and caused winter floods along Drift River that threatened an oil-processing facility at the valley mouth. Trabant and others (1994) reported that pyroclastic flows entrained snow and glacier ice and melted canyons into the unnamed glacier, resulting in the loss of much of the ice in the upper reach of the glacier. The eruption produced an unusual ice diamict consisting of fragments of glacier ice and rock debris in a matrix of snow grains and new volcanic tephra (Waitt and others, 1994). The diamict, which contained rounded fragments of glacier ice as large as 2.5 m, fragments of andesite and other crystalline rocks as large as a meter, and slabs of entrained snow pack as long as 10 m, was deposited on the northern and southern flanks of the mountain. On the northern flank, a northern flow traveled as much as 14 km and covered an area of about 5.7 km^2. On one unnamed glacier located on Redoubt Volcano's southern side, the diamict was as thick as 20 m, even after traveling 4.3 km. Before the end of the eruption, newly erupted lava created flows that entrained additional snow-and-ice blocks from the crevassed glacier and transported them 35 km down valley to Cook Inlet.

When Trabant and Hawkins (1997) investigated Redoubt Volcano, they developed a model for evaluating glacier volumes. Their model determined that the 1989–90 eruptions removed 0.29 km^3 of perennial snow and glacier ice from a 4.5-km segment of the unnamed summit outlet glacier, providing a unique opportunity for verification of their volume model. In a single 2.5-km reach of denuded glacier valley, the volume of ice removed was 9.9×10^7 m^3, about 1 percent less than the model had estimated. The total volume of perennial snow and glacier ice on Redoubt Volcano was estimated to be 4.1 ± 0.8 km^3, about 23 times the volume present on Mount St. Helens, Wash., before its 1980 eruption. Since the 1989–90 eruption, new snow and ice has accumulated in Redoubt's summit crater, replacing much of the snow and ice melted during the volcanic activity (McGimsey, 2001).

Figure 334.*—Oblique aerial photograph of the summit and upper 1,500 m of Redoubt Volcano on 29 July 1978. The valley of the unnamed glacier, which has a conspicuous elevated lateral moraine along its south margin, documents recent thinning of the glacier. Photograph by Bruce F. Molnia, U.S. Geological Survey.*

Glaciers of Iliamna Volcano

Iliamna Volcano is a broad, deeply dissected and highly altered, roughly cone-shaped mountain at the north end of a 5-km-long ridge. Most of the volcano is covered by perennial snow and glacier ice, and more than a dozen large glaciers radiate from the summit area (fig. 335). Large avalanche deposits occur on the flanks of the volcano at several locations.

The northernmost and largest glacier is Tuxedni Glacier, which has a length of 25 km and an area of 106 km^2 (Denton and Field, 1975b, p. 603) (fig. 336) and extends from Iliamna Volcano's summit to nearly sea level. Between the 1950s and the middle 1990s, on an annual basis, Tuxedni Glacier thinned by 0.793 m a^{-1} and had a volume decrease of 0.0693 km^3 (K. A. Echelmeyer, W. D. Harrison, V. B. Valentine, and S. I. Zirnheld, University of Alaska Fairbanks, written commun., March 2001).

Red Glacier (figs. 335, 337), named for the iron-rich red-colored moraines that cover much of the glacier, has a length of 17 km and an area of 51 km^2 (Denton and Field, 1975b, p. 603). It terminates at an elevation estimated by the author at approximately 65 m above mean sea level (amsl). Other named Iliamna glaciers include Umbrella (fig. 338) (26 August 1978 AHAP false-color infrared vertical aerial photograph no. L120F7552), Lateral (fig. 339), and Johnson Glaciers. All of these glaciers and all of Iliamna Volcano's unnamed outlet glaciers show multiple evidence of terminus retreat and thinning in

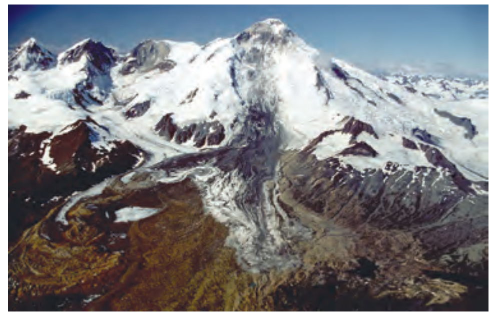


Figure 335.—*Oblique aerial photograph of Iliamna Volcano. 8 August 2000 west-looking view of the summit showing a large volcanic-debris-rich avalanche that descended onto the surface of Red Glacier below. The glacier-dissected topography of the summit ridge can be seen on the south side of the summit. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.*

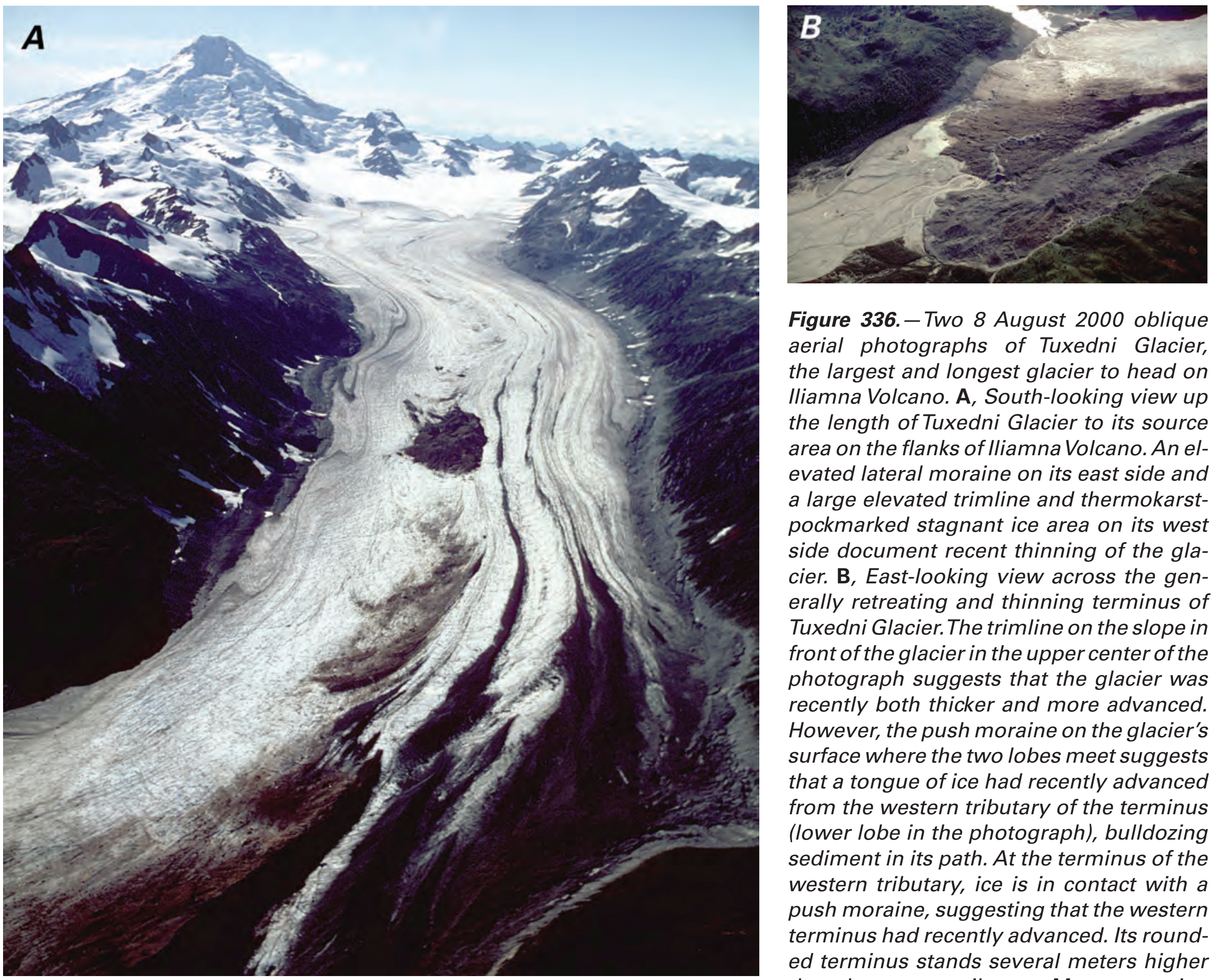
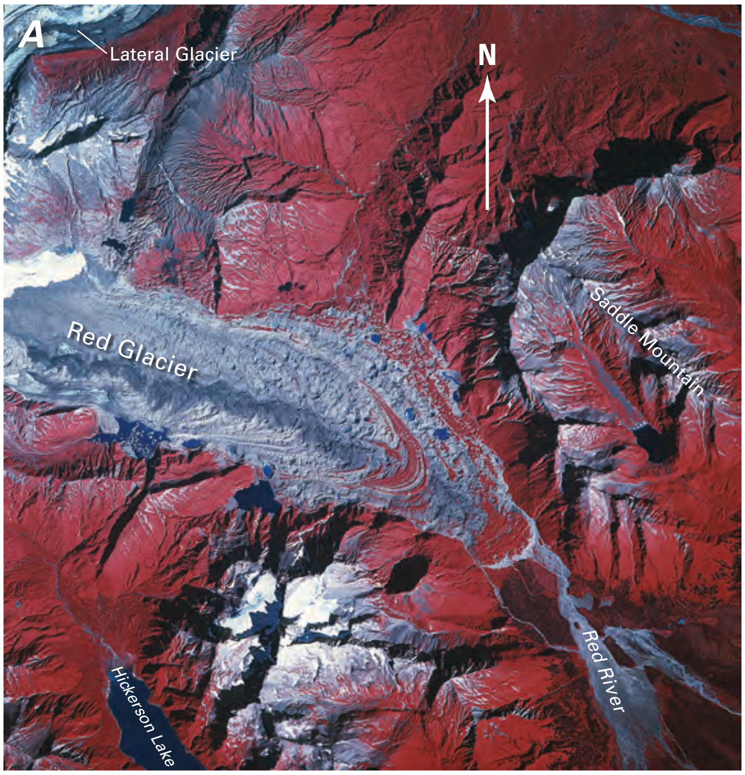


Figure 336.—*Two 8 August 2000 oblique aerial photographs of Tuxedni Glacier, the largest and longest glacier to head on Iliamna Volcano.* **A**, *South-looking view up the length of Tuxedni Glacier to its source area on the flanks of Iliamna Volcano. An elevated lateral moraine on its east side and a large elevated trimline and thermokarst-pockmarked stagnant ice area on its west side document recent thinning of the glacier.* **B**, *East-looking view across the generally retreating and thinning terminus of Tuxedni Glacier. The trimline on the slope in front of the glacier in the upper center of the photograph suggests that the glacier was recently both thicker and more advanced. However, the push moraine on the glacier's surface where the two lobes meet suggests that a tongue of ice had recently advanced from the western tributary of the terminus (lower lobe in the photograph), bulldozing sediment in its path. At the terminus of the western tributary, ice is in contact with a push moraine, suggesting that the western terminus had recently advanced. Its rounded terminus stands several meters higher than the eastern tributary. Many retreating glaciers experience short-lived advances, generally in winter. Photographs by Bruce F. Molnia, U.S. Geological Survey.*



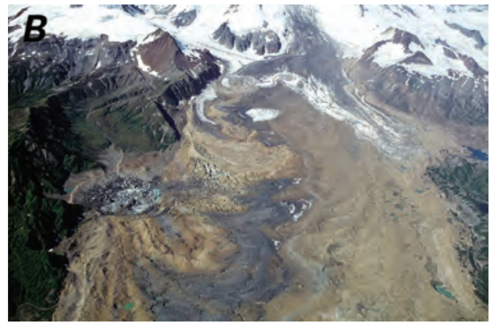


Figure 337.—Two aerial photographs of the terminus and lower reaches of Red Glacier, a large east-flowing glacier covered by iron-rich sediment. **A**, 26 August 1978 AHAP false-color infrared, vertical aerial photograph of the terminus of Red Glacier. Several recessional moraine ridges are covered with vegetation. Circular thermokarst melt pits filled with blue water along much of both margins suggest melting of stagnant ice and ice-cored moraines. AHAP photograph no. L120F7549 from GeoData Center, Geophysical Institute, University of Alaska, Fairbanks, Alaska. **B**, 8 August 2000 west-looking oblique aerial photograph of the upper region of Red Glacier showing a complex surface consisting of multiple-nested moraines, avalanche debris, a recently drained supraglacial lake, stagnant ice, an ice-cored moraine, and an elevated lateral moraine on the glacier's north margin. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of B is available online.

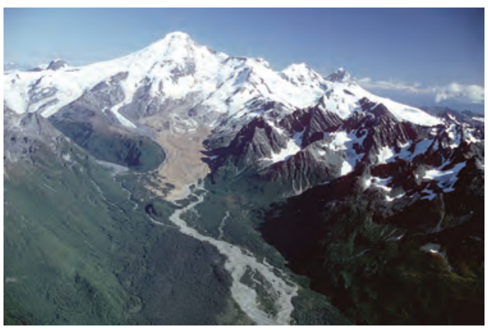


Figure 338.—8 August 2000 northeast-looking oblique aerial photograph of the summit and southwestern quadrant of the Iliamna Volcano showing Umbrella Glacier, the largest glacier on the southwestern flank. Its white-ice northwestern tributary stands more than 20 m above the iron-rich-sediment-covered surface of the main glacier and does not appear to extend beyond its elevated end moraine. Its former eastern tributaries no longer make contact with the glacier. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.

Figure 339.—8 August 2000 southwest-looking oblique aerial photograph of the summit and eastern quadrant of the Iliamna Volcano showing Lateral Glacier (left), Double Glacier (middle), and Johnson Glacier (right). Lateral Glacier's iron-rich-sediment-covered terminus appears to be stagnant. Elevated moraines on the south side and exposed bedrock on the north document thinning of the glacier. Photograph by Bruce F. Molnia, U.S. Geological Survey.

their lower reaches. Iliamna Volcano's glaciers cover about four times the area of Redoubt Volcano's glaciers.

On the basis of radio-echo-sounding measurements made in July 1988 and volume modeling, Trabant (1999) estimated perennial snow and glacier ice volumes on Iliamna Volcano to be 8.6 km^3 for Tuxedni Glacier, 0.85 km^3 for Lateral Glacier, 4.7 km^3 for Red Glacier, and 0.60 km^3 for Umbrella Glacier. The estimated volume of perennial snow and glacier ice on the upper 1,000 m of the volcano is about 1 km^3. Errors are thought to be no more than ±25 percent. The volume estimated for the four largest glaciers is more than three times the total volume of perennial snow and glacier ice on Mount Rainier, Wash., and about 82 times the total volume of perennial snow and glacier ice on Mount St. Helens, Wash., before its 18 May 1980 eruption.

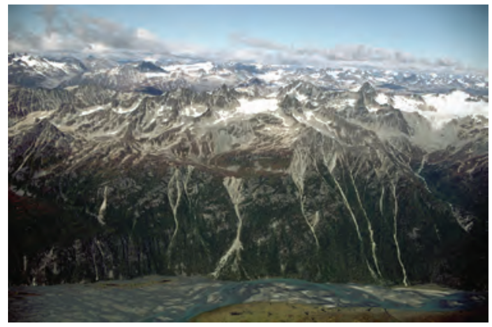


Figure 340.*—8 August 2000 north-looking oblique aerial photograph of the southwestern Chigmit Mountains north of the Tuxedni River showing shrinkage and disappearance of cirque glaciers, including a number of recently ice-free cirques, several with tarn lakes. All of these abandoned cirques are located above an elevation of 1,000 m. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.*

Glaciers West and South of Redoubt and Iliamna Volcanoes

As of an 8 August 2000 observation, all of the outlet glaciers and many of the cirque glaciers located west and south of Redoubt and Iliamna Volcanos were thinning and retreating (fig. 340) (26 August 1978 false-color infrared vertical aerial photograph no. L120F7555). Many of the cirques located on the northern side of the Tuxedni River and in the Pile River and Iliamna River areas in the southernmost Chigmit Mountains appeared to have recently become ice free (26 August 1978 false-color infrared vertical aerial photograph no. L120F7599). In addition to other evidence of glacier thinning and retreat, numerous tarn lakes and ice-free cirques are evidence of recent glacier change and disappearance of some glaciers.

Glaciers of the Kamishak Bay–Big River Area

It is nearly 80 km from the southernmost glacier in the Chigmit Mountains, located just west of Iliamna Bay, to the summit of Mount Douglas (2,153 m), the highest point on an unnamed ice field, that has an area of more than 300 km^2 and supports more than 20 outlet glaciers (fig. 341). Fourpeaked Mountain (2,104 m) is the highest point on the southern part of the ice field. Seven glaciers have lengths of 8 to14 km and termini more than 3 km wide. Two of the largest (and the only named) glaciers—Spotted Glacier (12 August 1982 AHAP false-color infrared vertical aerial photograph no. L131F1827) and Fourpeaked Glacier—have debris-covered termini and show evidence of recent retreat. In 1904, Spotted Glacier's terminus was about 1.5 km from Kamishak Bay, ending at an elevation of about 45 m amsl (Tarr and Martin, 1914). By the time of compilation of the Afognak, Alaska, 1:250,000-scale 1952 USGS topographic map (appendix A), the glacier had retreated several hundred meters and terminated at an elevation closer to 90 m amsl. An unnamed glacier just to the west of Spotted Glacier had a barren zone halo a kilometer wide around its margin in 1982. Since then, its western terminus has separated from the main ice tongue. A number of smaller unnamed glaciers occur on ridges immediately west and southwest of the ice field. The largest is about 4 km long.

Fifty-five kilometers to the west of Mount Douglas is another small concentration of upland glaciers that were last surveyed in 1951. Bounded by Pirate Lake and McNeil River to the north, Strike Creek to the east, and Kilik Lake to the west, about 25 small unnamed glaciers occupy cirques or ridge crests at elevations ranging from about 1,200 to 1,670 m on the USGS 1:250,000-scale Mt. Katmai, Alaska, topographic map (appendix A).

In July 1923, USGS geologist K.F. Mather photographed cliff and cirque glaciers at several locations north of the McNeil River and west of Kamishak Bay. His photographs show small retreating and thinning glaciers at locations that no longer support glacier ice (fig. 342)

► ***Figure 341.****—Annotated Landsat 7 ETM+ false-color composite image of the Kamishak Bay-Big River area showing an unnamed ice field in the Mount Douglas-Fourpeaked Mountain area and numerous unnamed and several named outlet glaciers. Approximate scale 1:175,000. Landsat 7 ETM+ image (7070019000022950, bands 2, 3, 4; 16 August 2000; Path 70, Row 19) from USGS, EROS Data Center, Sioux Falls, S. Dak.*

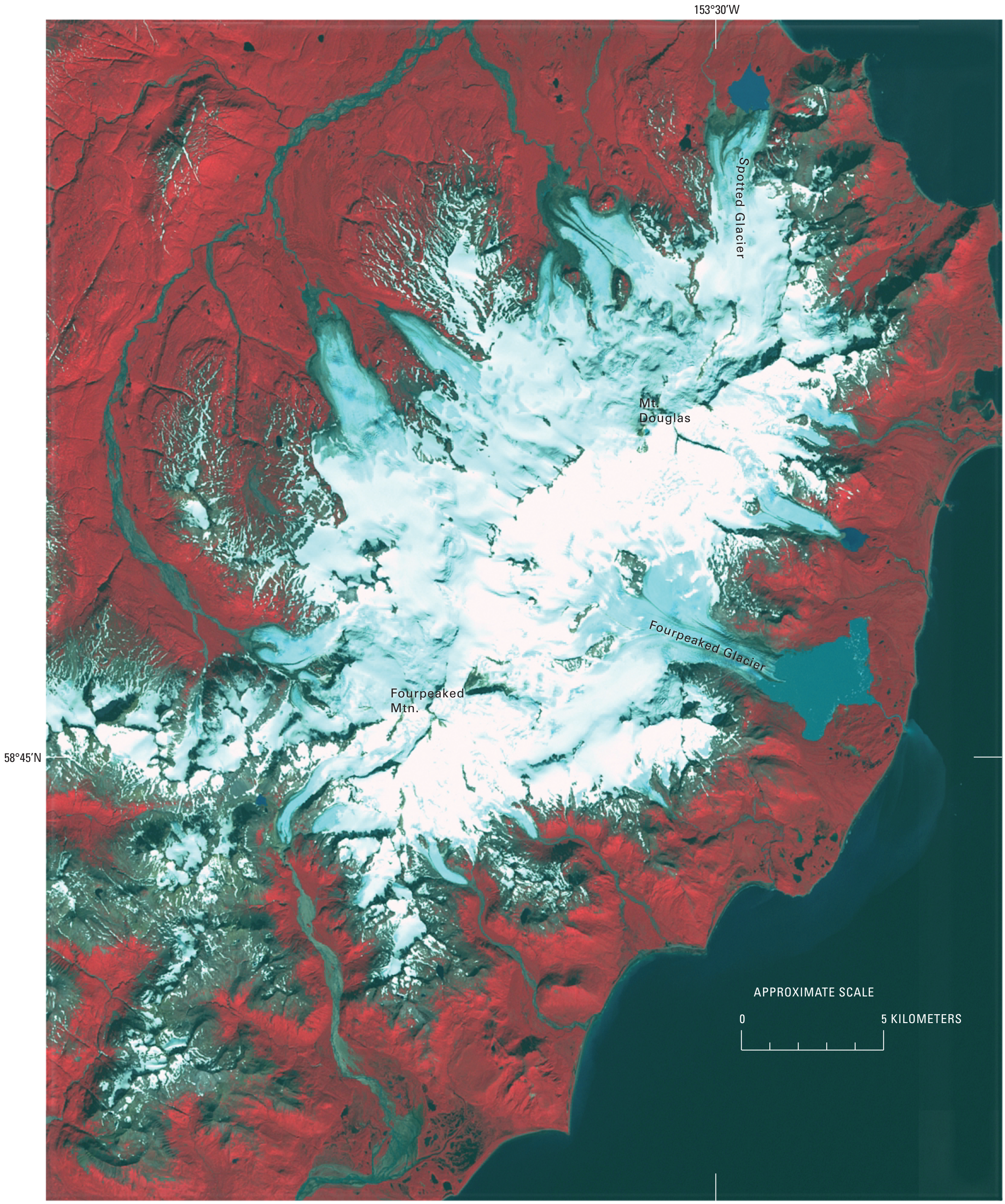

153°30′W
Spotted Glacier
Mt.
Douglas
Fourpeaked Glacier
Fourpeaked
Mtn.
58°45′N
APPROXIMATE SCALE
0
5 KILOMETERS

Figure 342.—*A July 1923 photograph by K.F. Mather of small cirque and cliff glaciers located west of Kamishak Bay showing a complex of retreating unnamed cirque glaciers in a large north-facing basin of a 1,230-m-high mountain, just south of the Paint River. The 1957 USGS topographic map of this area shows no glacier at this location. Photograph Alaska 207 from the USGS Photo Library, Denver, Colo.*

Glaciers of the Ninagiak River–Puale Bay Area

More than a hundred glaciers, at least 20 of which have lengths of 5 km or greater, are located in central and southwestern Katmai National Park and Preserve (fig. 343) and immediately to its southwest. Most descend from a 80-km-long area of ice-covered volcanoes and mountains extending from Devils Desk (1,954 m) on the northeast to Mount Martin (1,844 m) on the southeast. Peaks that support glaciers include Kukak Volcano (2,042 m), Mount Steller (2,225 m), Mount Denison (2,318 m), Snowy Mountain (2,161 m), Mount Katmai (2,047 m), Trident Volcano (1,832 m), Mount Griggs (2,316 m), and Mount Mageik (2,210 m). More than a dozen glaciers are more than 8 km long. The longest is east flowing Hallo Glacier, which is 19 km long and 88 km^2 in area (Denton and Field, 1975b, p. 631) (see Landsat 7 ETM+ browse image 7070019000022950; 16 August 2000, Path 70, Row 19) and originates on the flanks of Kukak Volcano, Mount Steller, and Mount Denison. North-flowing Hook Glacier and a western tributary glacier informally known as *West Hook* also originate on these same peaks. Both are known to surge, the latter as recently as 1984. Other named glaciers include Serpent Tongue Glacier and The Knife Creek Glaciers. There are also many unnamed glaciers in the area, such as the six that descend from the summit of Mount Griggs.

Mount Katmai is a large stratovolcano that is about 10 km in diameter and has a central lake-filled caldera about 4.5×3 km in size. The caldera that contains Crater Lake has a maximum wall elevation of 2,047 m, a floor elevation of about 1,036 m, and relief of more than 1 km. The volcano is one of five explosive eruption vents and calderas that encircle Novarupta Dome. Much of the volcano is mantled by perennial snow and glacier ice, and several valley glaciers radiate down its flanks. Three glaciers also originate from the upper caldera walls and descend into the crater to Crater Lake (Motyka and others, 1977). Before its 1912 eruption, Mount Katmai's summit was similar to the summits of Redoubt and Iliamna Volcanoes, which were completely encircled by active glaciers. As a result of the eruption, about 600 m of the mountain's summit (including snow fields and glaciers) disappeared, leaving many beheaded glaciers. Most lost major parts of their accumulation areas (Muller and Coulter, 1957a). Following the eruption, two small glaciers formed on the talus beneath the crater rim (Muller and Coulter, 1957b).

Because more than 30 km^3 of volcanic material was ejected by the 1912 eruption of Mount Katmai (Denton and Field, 1975b; Griggs, 1922), many glaciers on the mountain and on adjacent peaks are covered by tephra (including light-colored pumice) deposits; in places, the airfall deposits are many meters thick. At Knife Creek on nearby Trident Volcano, Muller and Coulter (1957b) described how one of the five Knife Creek Glaciers (which they referred to as *First Knife Creek Glacier* through *Fifth Knife Creek Glacier*),

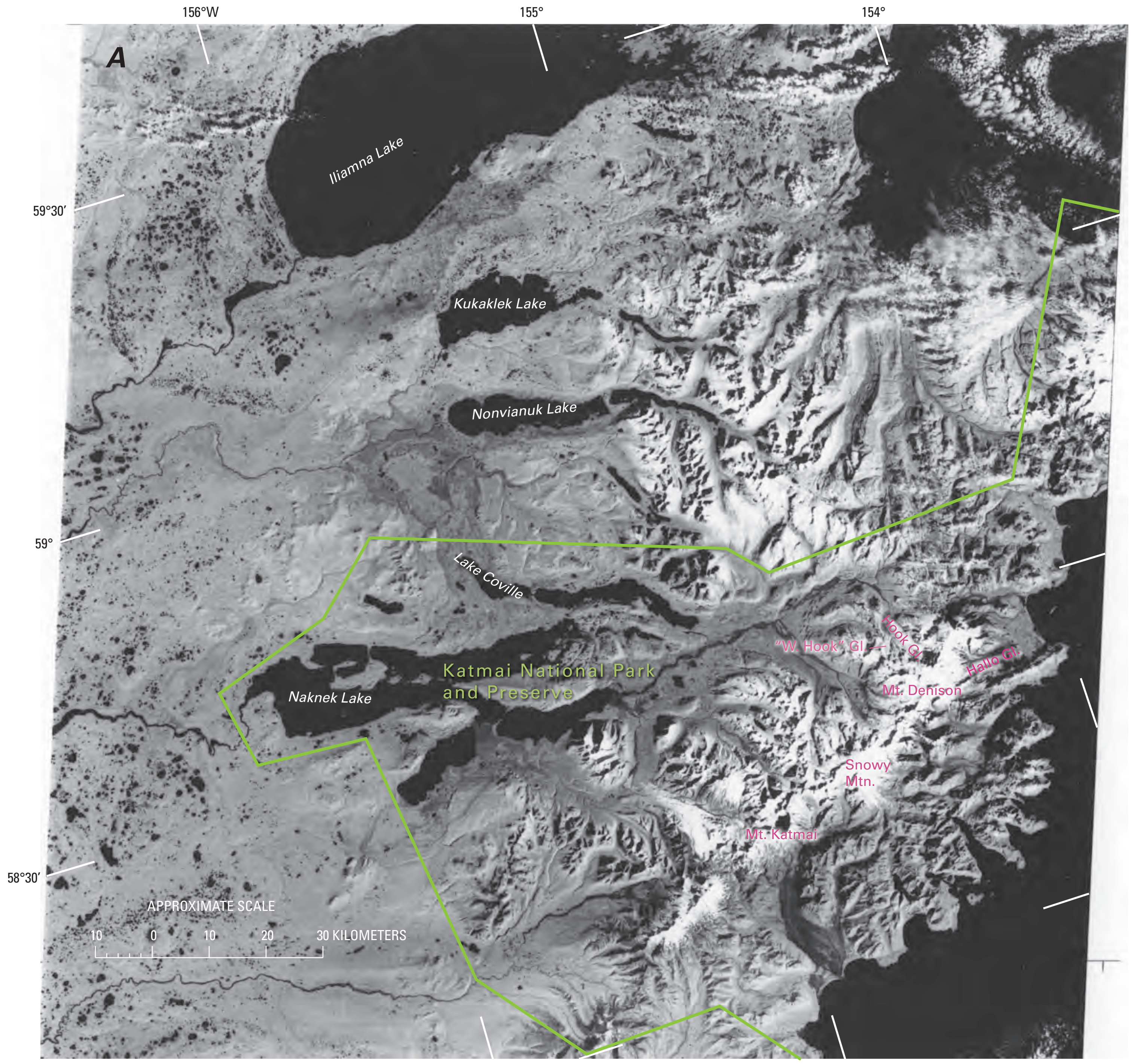


Figure 343.—**A**, *Annotated Landsat 2 MSS image of Katmai National Park and Preserve and environs. Mount Katmai (2,047 m), Snowy Mountain (2,161 m), Mount Denison (2,301 m), and Mount Douglas (2,153 m) (just off the upper right edge of the image) all support large glaciers. The glaciers on Mount Katmai, barely visible on this image, lost major portions of their accumulation areas when Mount Katmai erupted in 1912 (Muller and Coulter, 1957b). The* West Hook Glacier *and Hook Glacier are known to surge; the latter glacier surged in 1984. The glaciers in this area have lengths of up to about 15 km. Evidence of past glaciation is striking. The basin of Iliamna Lake was once glacier filled, and the limit of ice is indicated by an arcuate line of small lakes 35 km west of the present west shore. Other notable moraines occur west of Naknek Lake, Lake Colville, Nonvianuk Lake, and Kukaklek Lake. Landsat image and caption courtesy of Robert M. Krimmel, U.S. Geological Survey. Landsat 2 image (2983–20253, band 7; 10 October 1977; Path 77, Row 19) is from the USGS, EROS Data Center, Sioux Falls, S. Dak.* **B**, *see following page.*

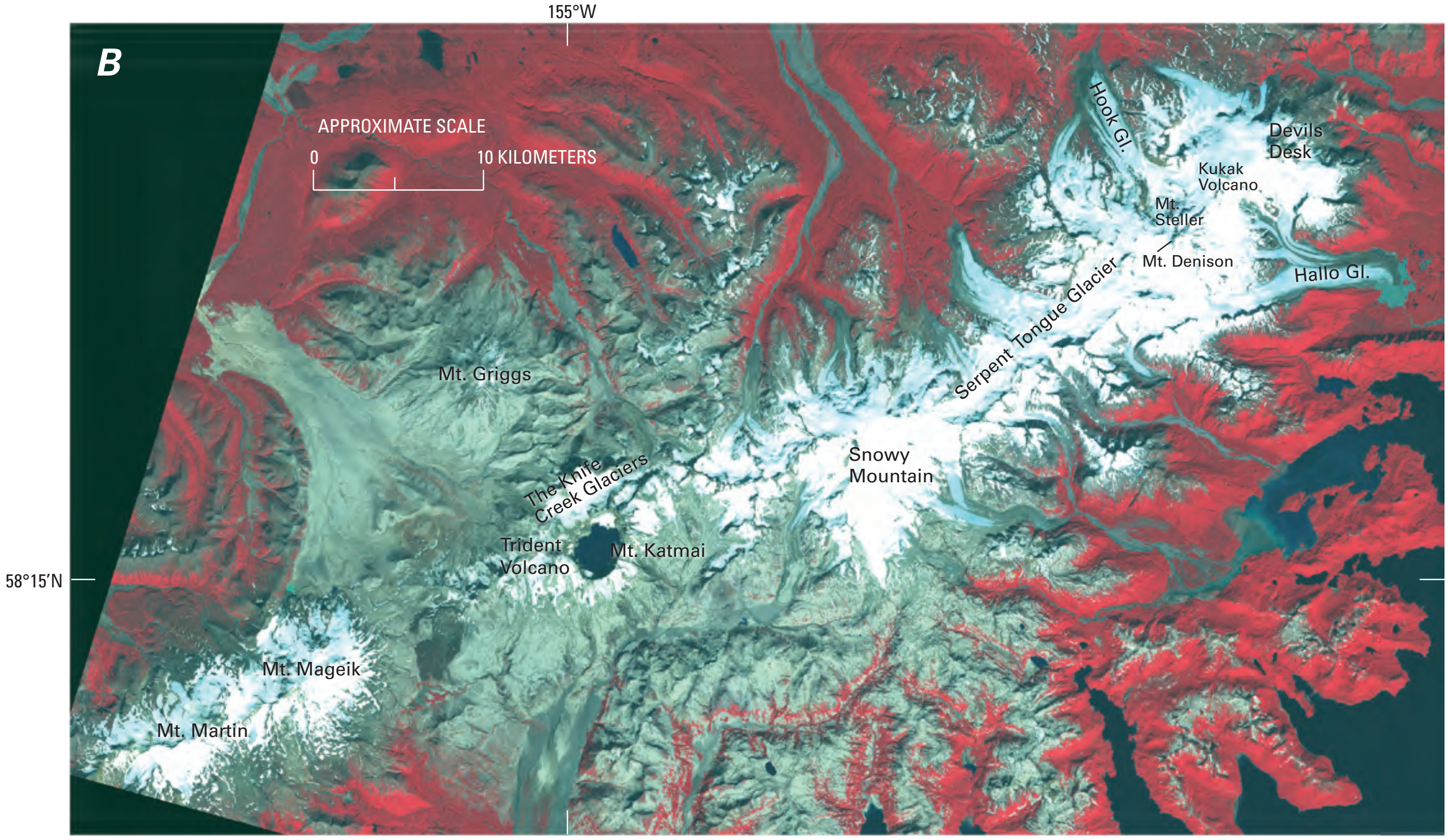


Figure 343.—**B**, *Annotated Landsat 7 ETM+ false-color composite image of the Ninagiak River–Puale Bay area, providing coverage similar to* A *but 23 years later. Approximate scale 1:330,000. Landsat 7 ETM+ image (7070019000022950, bands 2, 3, 4; 16 August 2000; Path 70, Row 19) from USGS, EROS Data Center, Sioux Falls, S. Dak.*

was covered by pyroclastic debris that protected it from subsequent ablation despite the loss of most of its accumulation area during the eruption. The 18 May 1980 eruption of Mount St. Helens, Wash., also beheaded and destroyed glaciers on its northern side.

More than a dozen glaciers descend from the flanks of Mount Mageik and Mount Martin (27 August 1983 AHAP false-color infrared vertical aerial photograph no. L138F6708). Mount Mageik was visited in the early 1920s by Smith (1925) and Hubbard (1935), who described a small crevassed tephra-covered glacier that was located on its northern flank. Mount Martin is a largely ice-covered stratovolcano at the southern end of the Katmai group. Recent volcanic activity has deposited yellow sulfur on its snow- and ice-covered crater walls (6 October 1994 space shuttle photograph no. STS–068–244–010). Several isolated unnamed glaciers located about 25 km southwest of Mount Martin near Kejulik Pass form the headwaters of Takayofo Creek.

The glaciers of the Ninagiak River–Puale Bay area were first described by Spurr (1900), who briefly noted that glaciers were common on mountain axes and also descended down the flanks of the volcanoes into the valleys. Beginning in 1915, Griggs (1922) led five expeditions to the Mount Katmai area to document the impacts of the 1912 eruption. He (Griggs, 1922, p. 171) described the accumulation of volcanic deposits on the surface of glaciers that he traversed in 1916:

> "The appearance of these ice fields was curious in the extreme. Where a glacier was moving rapidly, the variously colored layers of ash were dumped about promiscuously among the glacial seracs, making a bizarre and highly colored picture, the reds, browns, blacks, yellows in vivid contrast to the pure blue ice. Where the glacial motion was slower and steadier the ash deposit still lay as it fell.... Glaciers of this peculiar type extended clear up to the very rim of the crater, above whose depths the loose blocks of ice hung with such a precarious hold that we dared not approach."

Several days later, Griggs (1922, p. 173–4) described the glaciers of the crater rim:

> ...we could see another notch in the rim at about the same altitude as the one where we stood, But this one was occupied by a wall of ice which rose vertically, flush with the crater walls, as though sheared off by the explosion. It was surprising at first sight to find that a glacier could have persisted on the crater rim, unmelted by the heat of

the eruption. ... Ice cliffs, the exposed ends of beheaded glaciers, stretch for several miles along the crater rim. The glaciers bear little if any indication of having dwindled during the eruption. The parts preserved on the outer slope were outside the blast of the explosions, which must have been directed skyward. ... The crater wall has caved in considerably since the eruption and is still slumping away at short intervals. It is such an unstable condition that it is no infrequent experience, while standing on the crater rim, to be startled by a roar as something lets go, and on searching for the cause to find a mass of ice and rock bouncing down the half-mile precipices into the abyss.

Glaciers of the Icy Peak–Mount Kialagvik–Mount Chiginagak Area

Figure 344.*—Summer 1919 southwest-looking panorama of the unnamed cirque and mountain glaciers that descend from the north side of Icy Peak. Kialagvik Creek is in the foreground and the head of Wide Bay is to the east (left). Several cirques show significant evidence of recent glacier thinning and retreat. Photographs Capps 993–995 from the USGS Photo Library, Denver, Colo. A larger version of this figure is available online.*

The distance from Mount Martin to the eastern end of an unnamed ice field that includes as its highest points Mount Kialagvik (~1,596 m) and Icy Peak (1,370 m) is about 100 km. This small ice field, which has an area of about 40 km^2, supports more than a dozen small unnamed glaciers that combine for an area of approximately 15 km^2. They descend from an upland more than 12 km in length to elevations below 300 m. The glacier that forms the headwater of Glacier Creek is more than 8 km long and terminates at an elevation of less than 200 m amsl. A number of unnamed cirque and mountain glaciers are situated on Icy Peak; figure 344 shows some of them on the northern flank of Icy Peak in 1919.

More than a dozen outlet glaciers drain the summit and flanks of Mount Kialagvik. Three unnamed glaciers that form the headwaters of the eastern fork of the Dog Salmon River range in length from about 3 to about 4.5 km. The largest unnamed glacier, which is about 6 km in length, descends from Mount Kialagvik to an elevation of about 300 m and forms the headwaters of the central fork of the Dog Salmon River.

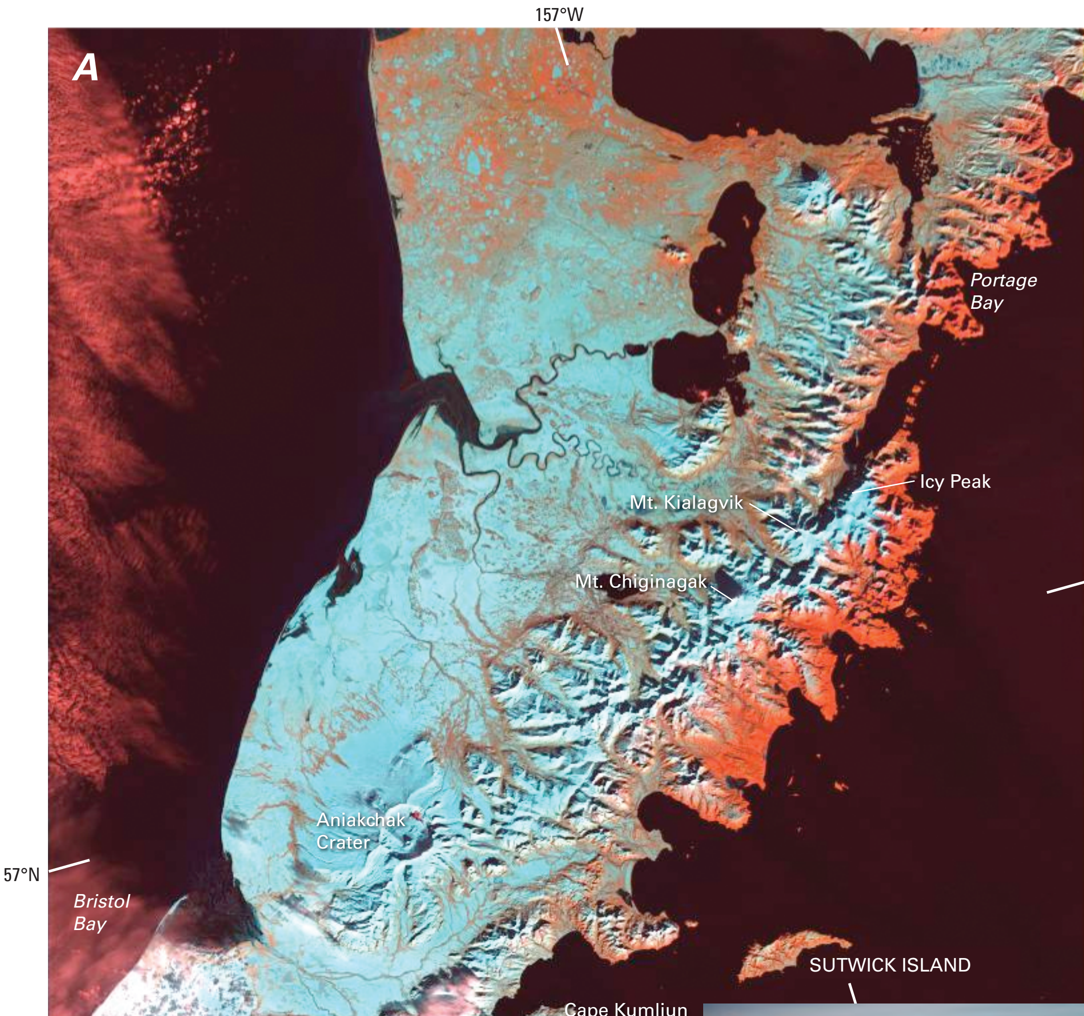
Mount Chiginagak (2,067 m) is a symmetric composite cone about 8 km in diameter. Glaciers cover about 20 to 25 km^2 of its summit and slopes (fig. 345)

Figure 345.*—August 1960 oblique aerial photograph of the glacier-covered summit of Mount Chiginagak. Fresh crevasses are indicative of bergschrund development in individual glacier basins. Photograph No. 12–50 by Austin Post, U.S. Geological Survey.*

at elevations above about 500 m. The earliest description of the glaciers of Mount Chiginagak was provided by Smith and Baker (1924.) From about 10 to 25 km west of the summit of Mount Chiginagak, several ridges are covered by accumulations of ice. The largest, which is nearly 10 km long, forms the headwaters of Painter Creek.

Glaciers of the Aniakchak Crater Area

Denton and Field (1975a) reported that several unnamed glaciers with a combined area of about 0.6 km^2 are located inside the southern wall of 1,340 m-high Aniakchak Crater (fig. 346). Formed during a catastrophic ash-flow eruption about 3,400 years ago, Aniakchak caldera is about 10 km



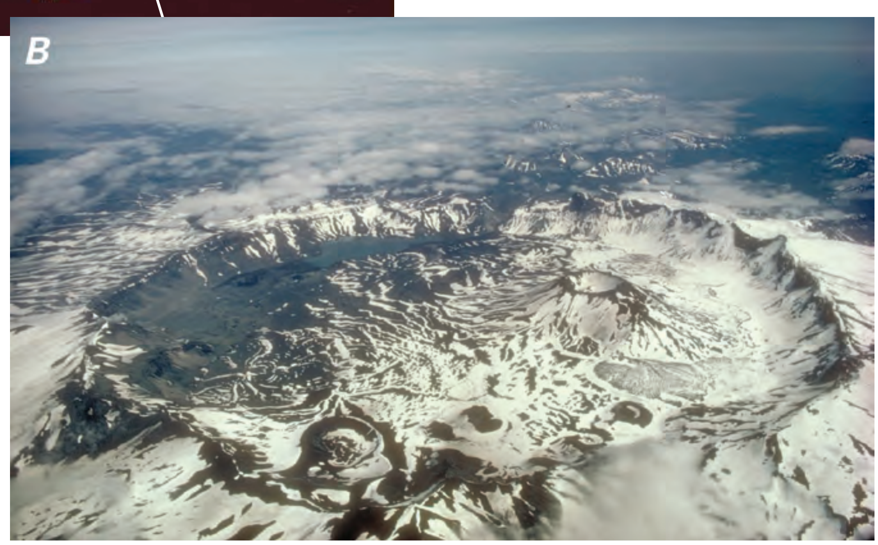


Figure 346.—**A**, *Annotated Landsat 7 ETM+ image of the central Alaska Peninsula from Portage Bay to Cape Kumliun. Visible are Icy Peak, Mount Kialagvik, Mount Chiginagak, Aniakchak Crater, Bristol Bay, and Sutwick Island. Landsat 7 ETM+ image (7072020009930450; 31 October 1999; Path 72, Row 20) is from the USGS, EROS Data Center, Sioux Falls, S. Dak.* **B**, *1977 oblique aerial photograph of the Aniakchak caldera. Photograph by M. Williams, U.S. National Park Service. From Neal and McGimsey (1997b).*

across and averages 500 m in depth (fig. 346). Glacier ice also fills the crater of 1,018-m-high Vent Mountain, a large cinder cone within the crater on the southern side (Knappen, 1929). Glaciers on the crater floor are covered by a thick deposit of pumice.

Glaciers of the Mount Veniaminof–Stepovak Bay Area

Mount Veniaminof (fig. 347) is a broad cone-shaped volcano 2,507 m high and about 35 km across at its base. The size of its steep-walled summit caldera is approximately 8×11 km. The caldera is filled by a large ice accumulation ranging in elevation from about 1,750 to 2,000 m. Ice overflows the southern rim of the caldera and covers more than 200 km^2 of the upper slopes on the southern side of the volcano. Knappen (1929) described the crater's glaciers as follows: "The crater of Mount Veniaminof is filled with a great circular glacier, 8 to 10 km in diameter, which overflows in three directions. To the northeast it flows through small cols, spilling down the mountain and forming Crab Glacier outside the crater; to the south the ice overtops the crater for a length of 3 km or more, but probably this ice stream is relatively shallow; to the west, the ice flows through a canyon estimated as 600 m deep, forming Cone Glacier. The western outlet is fully 300 m lower than either of the others, and a great river of crevassed and shattered ice, perhaps 200 m wide, grinds through the passageway and greatly depresses the level of the ice on that side of the crater."

In the western part of the caldera, a 570-m-high active cone with a small summit crater reaches an elevation of 2,156 m, approximately 330 m above the surrounding glacier ice. In 1983, eruptive activity from this cinder cone melted about 0.15 km^3 of the summit ice cap (fig. 347). The rim of a larger but lower cone protrudes just above the ice surface in the northwestern part of the caldera.

Eight named valley glaciers having a combined area of approximately 15 km^2 descend from the caldera through gaps on the western and northern sides of the rim, and other alpine glaciers occupy valleys on the north-, east-, and west-facing slopes of the mountain. Named glaciers include Cone, Fog, Island, Outlet, Crab, Harpoon, Finger, and Slim Glaciers. An unnamed glacier is located between Fog and Island Glaciers. The terminus of Slim Glacier extends to an elevation 275 m amsl and is 14 km from the summit crater (Denton and Field, 1975b, p. 633). A number of other unnamed glaciers are present to the southwest, east, and northeast. All of Mount Veniaminof's outlet glaciers are tephra covered, so that it is difficult to assess their mass balance. Telltale signs indicate evidence of recent retreat, however.

From about 10 to about 75 km west of the summit of Mount Veniaminof, several ridges are covered by significant accumulations of ice, many with small unnamed outlet glaciers. The largest ridge, which is nearly 20 km long, is located north of Stepovak Bay (26 August 1983 AHAP false-color infrared vertical aerial photograph no. L161F6197) and supports several outlet glaciers up to 4 km long.

Glaciers of Pavlof Volcano–Frosty Peak Area

Located about 120 km southwest of Stepovak Bay, the Pavlof Sister (2,122 m)–Pavlof Volcano (2,507 m)–Little Pavlof (2,038 m)–Mount Hague (~1,450 m) complex hosts an ice accumulation about 20 km long that has more than a dozen outlet glaciers. The glaciers of the Pavlof Volcano area cover an area of more than 130 km^2 (Denton and Field, 1975b, p. 629). Much of the upper slopes of Pavlof Volcano, Little Pavlof Volcano, Double Crater, Pavlof Sister, Mount Hague, and Mount Emmons are also covered by snowfields and glacier ice at elevations above 300 m (fig. 348). Pavlof Volcano is the most active volcano in the Aleutian Range with about 40 documented eruptions since 1790 (McGimsey and Miller, 1995).

The glaciers of this area were mapped by Kennedy and Waldron (1955), who described Mount Hague as having several individual glaciers in its crater

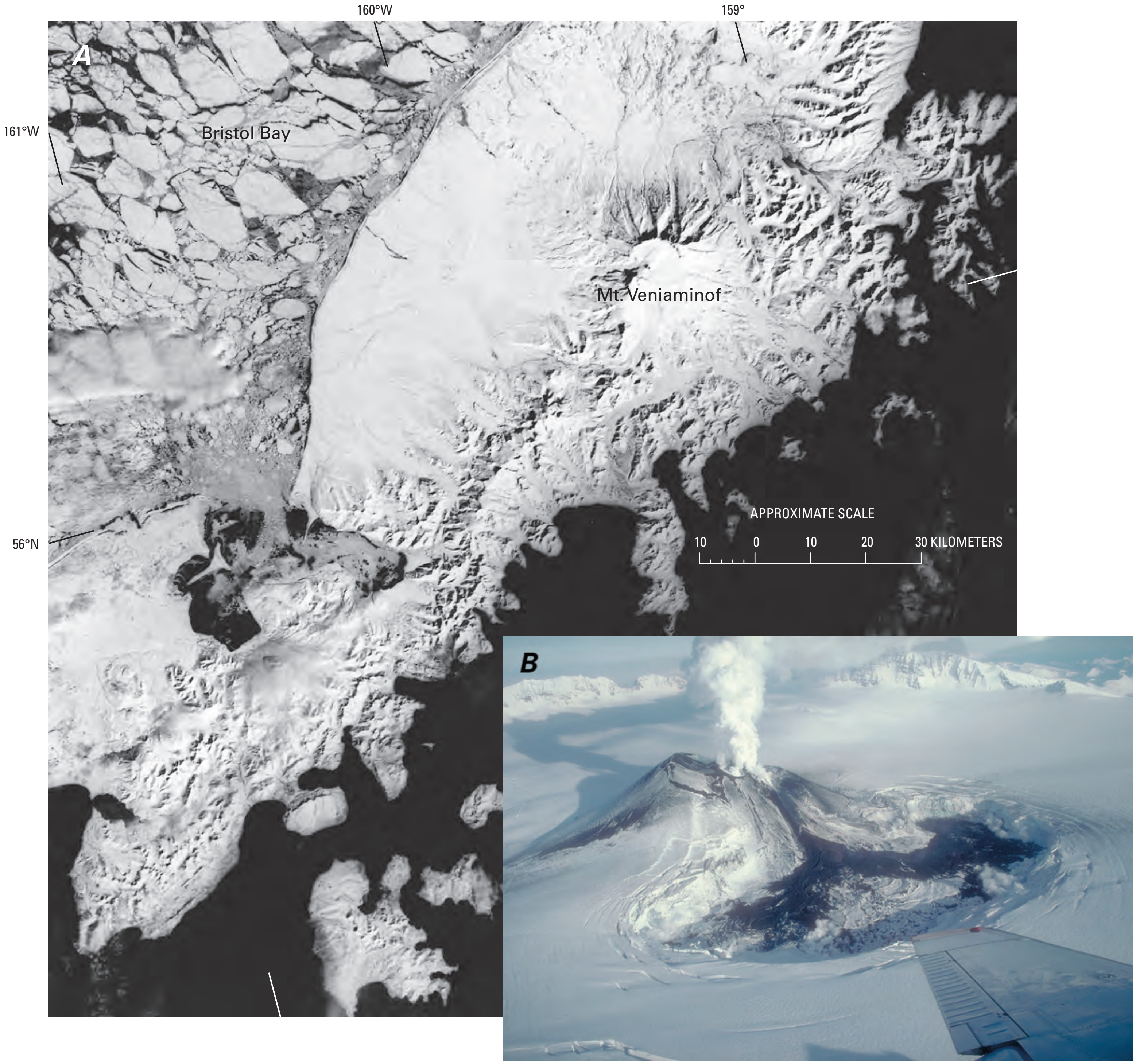


Figure 347.*—The glaciers of the Western Aleutian Range and Aleutian Islands are difficult to observe using Landsat because they are relatively small and because the weather is notoriously poor. Most of these glaciers lie on volcanoes.* **A***, Landsat 2 MSS image of Mount Veniaminof (2,507 m); the volcano was active in 1983 and 1984. Several eruptions have flowed from a cone within the ice-filled caldera, melting a large amount of ice. This March scene is of little value for delineating present-day glaciers because of the snow cover. However, the ice-filled summit caldera and glacier-carved valleys radiating to the north from Mount Veniaminof are visible. Bristol Bay is covered with broken sea ice. Landsat image and caption courtesy of Robert M. Krimmel, U.S. Geological Survey. Landsat 2 image (2427–21001, band 7; 24 March 1976; Path 79, Row 21) is from the USGS, EROS Data Center, Sioux Falls, S. Dak.* **B***, Oblique aerial photograph showing "Steam rising from the intracaldera cinder cone at Mount Veniaminof on 23 January 1984 in the waning stages of the 1983–1984 eruption. Cooling lava flows fill a pit about 2.3×1.0 km that has been melted in the summit ice cap" (Neal and McGimsey, 1997b). Photograph by M.E. Yount, U.S. Geological Survey.*

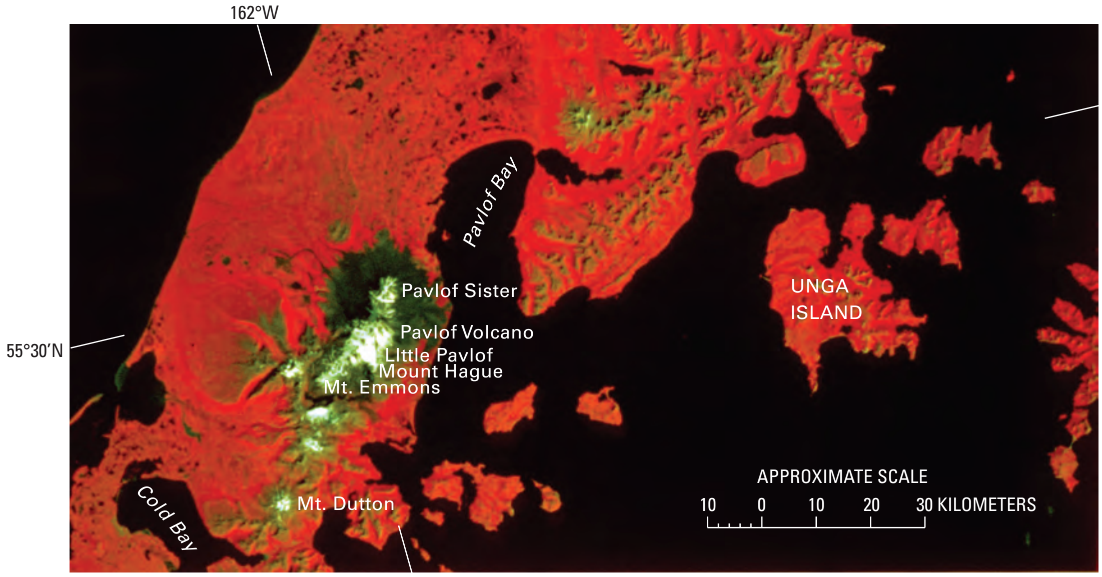


***Figure 348.**—Part of an annotated Landsat 2 MSS false-color composite image of the southern Aleutian Range. The image shows part of the southern Alaska Peninsula from Pavlof Bay to Cold Bay. Visible are Pavlof Volcano, Pavlof Sister, Mount Emmons, Mount Dutton, and Unga Island. Landsat image (2168–821044, bands 4, 5, 7; 6 August 1979; Path 80, Row 21) is from the USGS, EROS Data Center, Sioux Falls, S. Dak.*

and several more on its slopes. Mount Emmons supports a small glacier with an area of a few square kilometers; a glacier with an elliptical shape occurs on the highland immediately adjacent to the southern side of Emmons Lake. The Aghileen Pinnacles also support several small glaciers. Although none of these glaciers have been studied in recent years, Neal and McGimsey (1997a) noted that the most recent eruptive episode at Pavlof Volcano, which began about 11 September 1996 and continued into early 1997, melted a narrow channel through the snow and glacier-ice cover of the volcano.

Frosty Peak (1,746 m) hosts the westernmost and southernmost glaciers in the Aleutian Range. About a dozen descend from its summit ridge and slopes (fig. 349). The largest is an unnamed glacier about 4 km long and as much as 2.4 km wide. The northeastern side of the mountain contains several large Pleistocene and early Holocene cirques that extend as much as 6 km from its summit. Holocene moraines reach as far as 10 km from the peak. The age of the latest advance is unknown but is probably between 3,000 and 10,000 yr B.P. (Funk, 1973; Black, 1976).

Summary

During the period of the Landsat baseline (1972–81), all of the surge-type and non-surge-type valley glaciers in the Aleutian Range were stagnant, thinning, and (or) retreating. Some surge-type glaciers were reported to have surged during the baseline period, but no terminus advances were reported. At the end of the 20th century, all of the observed valley and outlet glaciers in the Aleutian Range continued to thin, stagnate, and retreat. Some glaciers showed evidence of surging near the end of the 20th century, including Capps Glacier, which surged in 2000. However, no reported surge events resulted in terminus advance.

When the terminus of Tuxedni Glacier was observed in 2000, it showed evidence of a recent small advance. However, trimlines and abandoned moraines document a previous long-term history of retreat and thinning. Following the 1989–90 eruptions of Mount Redoubt, new snow and ice has accumulated in its summit crater, essentially replacing all of the glacier ice and snow that was lost during the eruptions. This situation is similar to that of a pair of glaciers that formed in the summit crater of Mount Katmai in the years following its 1912 eruption.

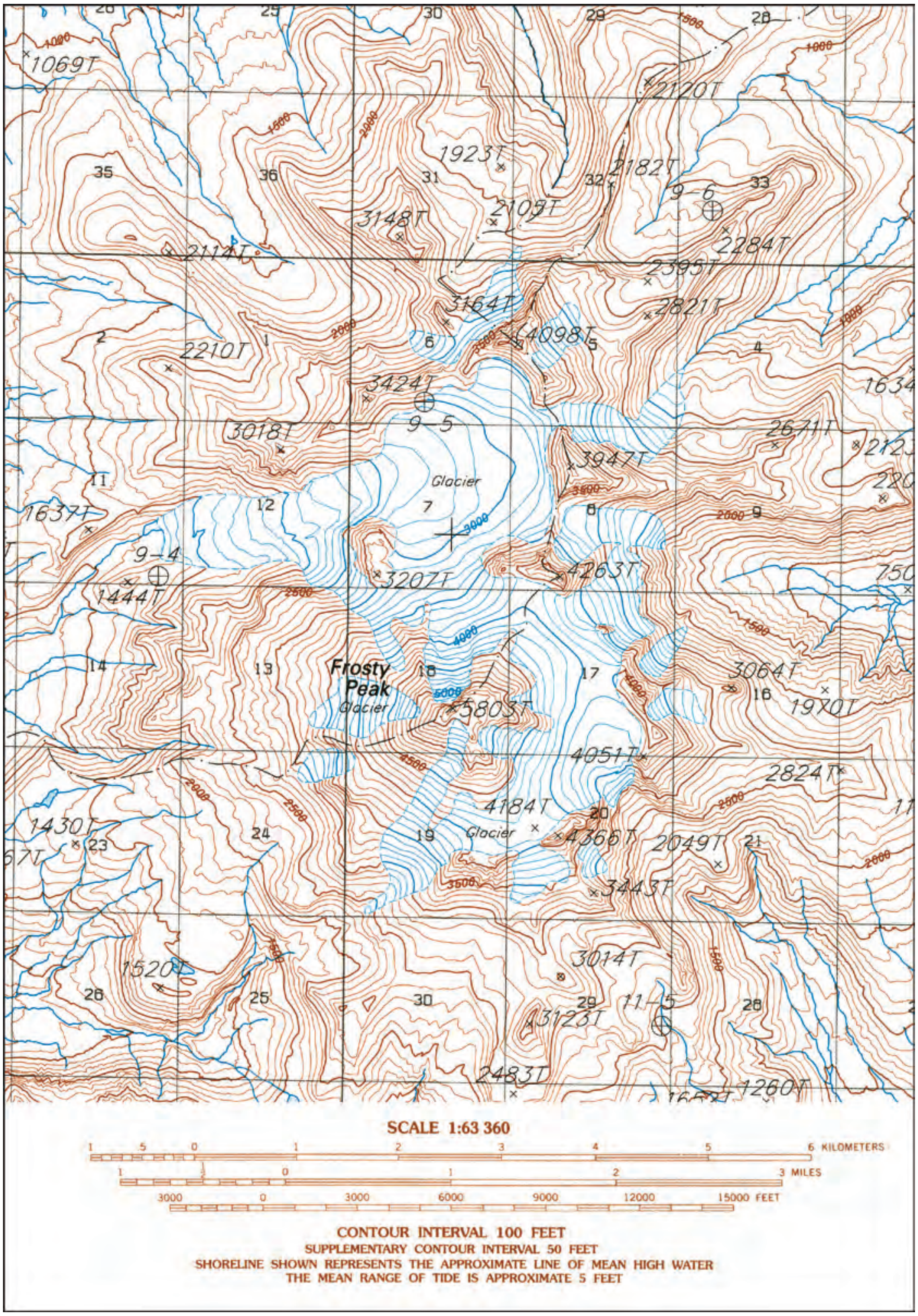


Figure 349.—*Part of the provisional 1:63,360-scale topographic map of the Cold Bay, Alaska A-3 quadrangle. At the end of the 1990s, when the provisional 1:63,360-scale topographic maps of parts of the Cold Bay, Alaska quadrangle based on 1987 aerial photography were released, they showed extensive glacierization of Frosty Peak. No glaciers were shown on the 1943 Cold Bay, Alaska 1:250,000-scale USGS topographic map (appendix A). Because many glaciers are either completely or partially covered by tephra (airborne volcanic ejecta), cartographers, working only with aerial photographs for such areas, where there were no field surveys or very limited data, may have been unable to determine the presence and locations of glaciers. Snow cover would have made this task even more difficult.*

Aleutian Islands

Introduction

The Aleutian Islands volcanic archipelago, the 1,900-km-long island arc that separates the Pacific Ocean from the Bering Sea, extends westward from False Pass at the western end of the Alaska Peninsula to about long 172°E., north of eastern Russia (figs. 1, 350). Wahrhaftig (1965) stated that the islands contain 57 volcanoes, 27 of which are active. “Most high volcanoes bear icecaps or small glaciers and there are a few cirque glaciers on the mountainous islands” (Wahrhaftig, 1965, p. 25). A recent summary of active Alaskan volcanoes by Wallace and others (2000) identified 24 that have been active since the middle 1700s.

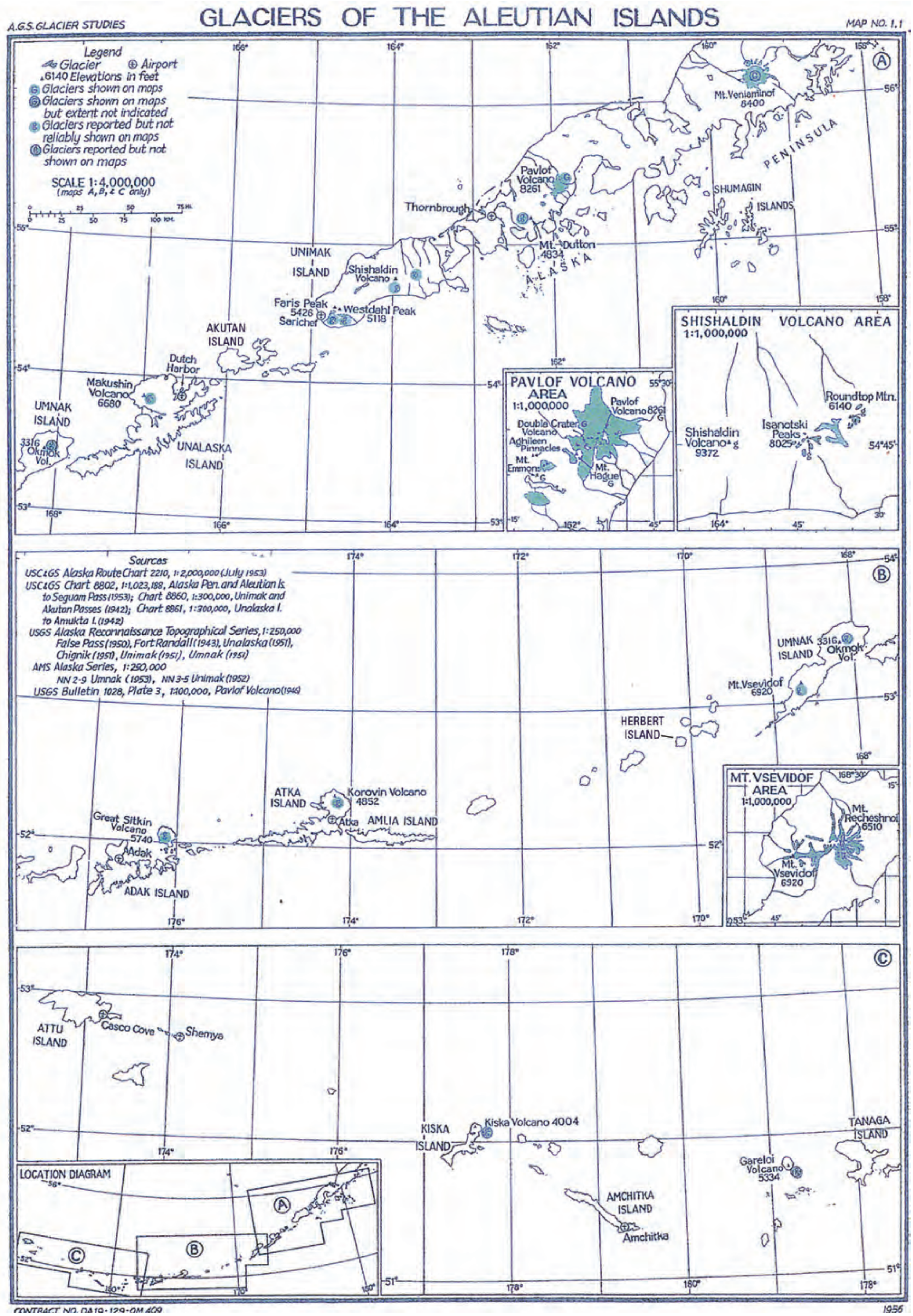
At least 10 islands in the eastern and central part of the arc have been reported to have glaciers. From east to west, islands where glaciers have been reported are Unimak, Akutan, Unalaska, Umnak, Herbert, Atka, Great Sitkin, Tanaga, Gareloi, and Kiska (figs. 1, 350). All of the mapped glaciers of the Aleutian Islands descend from the summits of active or dormant volcanoes, extending either into calderas or down their flanks. All head at elevations greater than 1,200 m. Descriptions of the glaciers of the Aleutian Islands have been presented by Westdahl (1903), Tarr and Martin (1914), Finch (1934), Collins (1945), Sharp (1956), Denton (1975a), Molnia (1982, 1993, 2001), and Field (1990). The total area of glaciers is 960 km^2 (Post and Meier, 1980, p. 45).

It is possible that glaciers may exist on other islands within the Aleutians because there is a lack of basic information on the physical geography of many of them. For instance, Mount Cleveland— a stratovolcano on Chuginadak Island, one of the Islands of the Four Mountains— has a summit elevation of about 1,730 m, higher than many peaks in the Aleutian Islands that support glaciers. Although no information could be found about glaciers on Mount Cleveland, Chuginadak Island shows evidence of recent glacial erosion.

Landsat MSS images that cover the glacierized Aleutian Islands have the following Path/Row coordinates: 81/22, 82/22, 83/22, 83/23, 84/23, 85/23, 86/23, 87/24, 88/24, 89/24, 90/24, 91/24, 93/24, and 94/24 (fig. 3, table 1). These areas are mapped (from east to west) on the False Pass (1949), Unimak (1951), Unalaska (1951), Umnak (1951), Samalga Island (1951), Amukta (1951), Atka (1959), Adak (1957), Gareloi Island (1954), and Kiska (1951) USGS 1:250,000-scale topographic quadrangle maps of Alaska (appendix A). Regardless of the printed publication date for a specific map, the date of the source material used for map compilation is older.

Many of the 10 USGS 1:250,000-scale topographic quadrangle maps (appendix A) are based on old surveys and maps produced by the AMS (later DMA, then NIMA, now the NGA) between 1947 and 1958; on NOAA topographic manuscripts surveyed between 1953 and 1959; and on NOAA nautical charts. Two of the quadrangle maps state that plane-table surveys were the basis for mapping: the first was carried out in 1928 (False Pass map sheet) and the second between 1940 and 1944 (Unalaska map sheet). Only 4 of 10 topographic quadrangle maps state that the topographic contours are based on aerial photography collected between 1934 and 1948: False Pass (1942–43 aerial photography), Unimak (“culture and drainage in part compiled from 1942 trimetrogon aerial photography”), Unalaska (1934, 1943 aerial photography), and Umnak (1942–48 aerial photography). Very few topographic quadrangle maps have been field checked, a process generally restricted to islands where there are military facilities. Some of the maps, especially at higher elevations, are incomplete, showing only form lines for “elevation” and no contour lines. The lack of accurate, modern maps of the Aleutian Islands is the result of the remoteness of the area, nearly perpetual cloud cover on the highest peaks, and the absence of high-resolution, cloud-free photographs and/or images.

A


A.G.S. GLACIER STUDIES
GLACIERS OF THE ALEUTIAN ISLANDS
MAP NO. 1.1
Legend
Glacier
Airport
6140 Elevations in feet
Glaciers shown on maps
Glaciers shown on maps but extent not indicated
Glaciers reported but not reliably shown on maps
Glaciers reported but not shown on maps
SCALE 1:4,000,000
(maps A, B, & C only)
Mt. Veniaminof 8400
PENINSULA
Pavlof Volcano 8261
SHUMAGIN ISLANDS
Thornbrough
Mt. Dutton 4834
ALASKA
UNIMAK ISLAND
Shishaldin Volcano
Faris Peak 5426
Sarichef
Westdahl Peak 5118
AKUTAN ISLAND
Dutch Harbor
Makushin Volcano 6680
UMNAK ISLAND
3316 Okmok Vol.
UNALASKA ISLAND
SHISHALDIN VOLCANO AREA
1:1,000,000
Roundtop Mtn. 6140
Isanotski Peaks 8025
Shishaldin Volcano 9372
PAVLOF VOLCANO AREA
1:1,000,000
Pavlof Volcano 8261
Double Crater Volcano
Aghileen Pinnacles
Mt. Emmons
Mt. Hague
Sources
USC&GS Alaska Route Chart 2210, 1:2,000,000 (July 1953)
USC&GS Chart 8802, 1:1,023,188, Alaska Pen. and Aleutian Is. to Seguam Pass (1953); Chart 8860, 1:300,000, Unimak and Akutan Passes (1942); Chart 8861, 1:300,000, Unalaska I. to Amukta I. (1942)
USGS Alaska Reconnaissance Topographical Series, 1:250,000 False Pass (1950), Fort Randall (1943), Unalaska (1951), Chignik (1951), Unimak (1951), Umnak (1951)
AMS Alaska Series, 1:250,000 NN 2-9 Umnak (1953), NN 3-5 Unimak (1952)
USGS Bulletin 1028, Plate 3, 1:100,000, Pavlof Volcano (1946)
UMNAK ISLAND
3316 Okmok Vol.
Mt. Vsevidof 6920
HERBERT ISLAND
MT. VSEVIDOF AREA
1:1,000,000
Mt. Recheshnoi 6510
Mt. Vsevidof 6920
ATKA ISLAND
Korovin Volcano 4852
Atka
AMLIA ISLAND
Great Sitkin Volcano 5740
Adak
ADAK ISLAND
ATTU ISLAND
Casco Cove
Shemya
KISKA ISLAND
Kiska Volcano 4004
TANAGA ISLAND
Gareloi Volcano 5334
AMCHITKA ISLAND
Amchitka
LOCATION DIAGRAM
CONTRACT NO. DA19-129-QM 409
1956

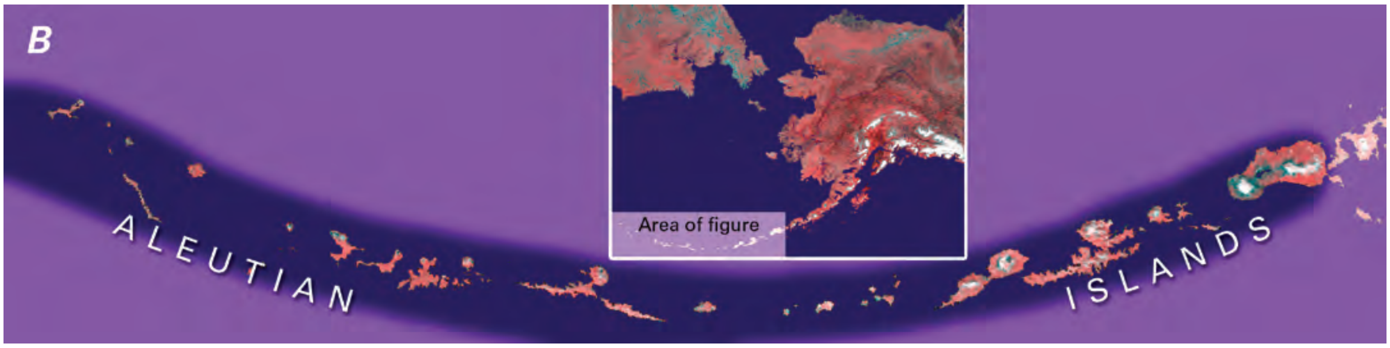


Figure 350.—**A**, *Index map of glacierized Aleutian Islands (modified from Field, 1975a).* **B**, *Enlargement of NOAA Advanced Very High Resolution Radiometer (AVHRR) image mosaic of the glacierized islands of the Aleutian Islands in summer 1995. National Oceanic and Atmospheric Administration image mosaic from Mike Fleming, Alaska Science Center, U.S. Geological Survey, Anchorage, Alaska.*

Consequently, during the last 50+ years, the glaciers of the Aleutian Islands have received minimal scientific attention. As a result, little new information has been produced. Therefore, much of the information in the following descriptions of the individual glacierized islands is significantly outdated, and some of the glaciers described in earlier publications probably no longer exist because of regional climate warming in the 20th and early 21st centuries.

Unimak Island

At a length of about 120 km, Unimak Island is the easternmost and largest of the Aleutian Islands. Glacier ice and snow cover is concentrated on 2,857-m-high Shishaldin Volcano, the Isanotski Peaks (2,446 m) (figs. 351, 352), and Roundtop Mountain (1,872 m) on the eastern part of the island (Denton, 1975a). Field (1975a) stated that these three peaks support a continuous snow and ice cover for nearly 40 km and cover an area greater than 50 km^2. An end-of-summer 1972 Landsat 1 MSS image acquired on 17 September 1972 (see Landsat image 10562–13315; 17 September 1972; Path 82, Row 22), shows a snow-free view of the glacier cover on that date. On the southwestern end of the island, Pogromni Volcano (2,002 m), Faris Peak (1,628 m), and Westdahl Peak (1,560-m-high pyroclastic cone) host an unnamed ice cap, which Field (1990) described as having an area of 26 km^2 from which at least two outlet glaciers flow. As delineated on the Unimak, Alaska, 1:250,000-scale USGS topographic quadrangle map (1951) (appendix A), which is based on 1942 aerial photography, these two outlet glaciers have lengths of about 9 and about 12 km and retreated between 1942 and 1972. An eruption occurred through Westdahl Peak's part of the ice cap in 1992.

Akutan Island

Akutan Volcano, located in the west-central part of Akutan Island and largest of the Krenitzin Island group, is a 1,303-m-high composite stratovolcano having a circular summit caldera about 2 km wide and 60 to 365 m deep and an active intra-caldera cinder cone. A small section of the floor of Akutan's summit caldera is covered with glacier ice. No information could be found about the status of the caldera's glacier.

Unalaska Island

The greatest concentration of glaciers in the Aleutian Islands is on Makushin Volcano (2,004 m) on 107-km-long Unalaska Island. The summit is covered by a small ice cap, which feeds several small unnamed outlet glaciers (fig. 353) descending to elevations below 500 m. A map of the island by Drewes and others (1961) also depicts several small unnamed valley glaciers on the flanks of the Shaler Mountains, which are located in the south-central part of the island. The earliest descriptions of the glaciers on Unalaska Island in the scientific literature date back to the 1880s (Davidson, 1886). Other descriptions are presented by Tarr and Martin (1914), Collins (1945), and Bradley (1948). Sharp (1956) suggested that Unalaska Island has the largest ice cover of any island in the Aleutian chain. Although little new information exists about Unalaska's glaciers, recent observations and maps suggest that all are retreating.

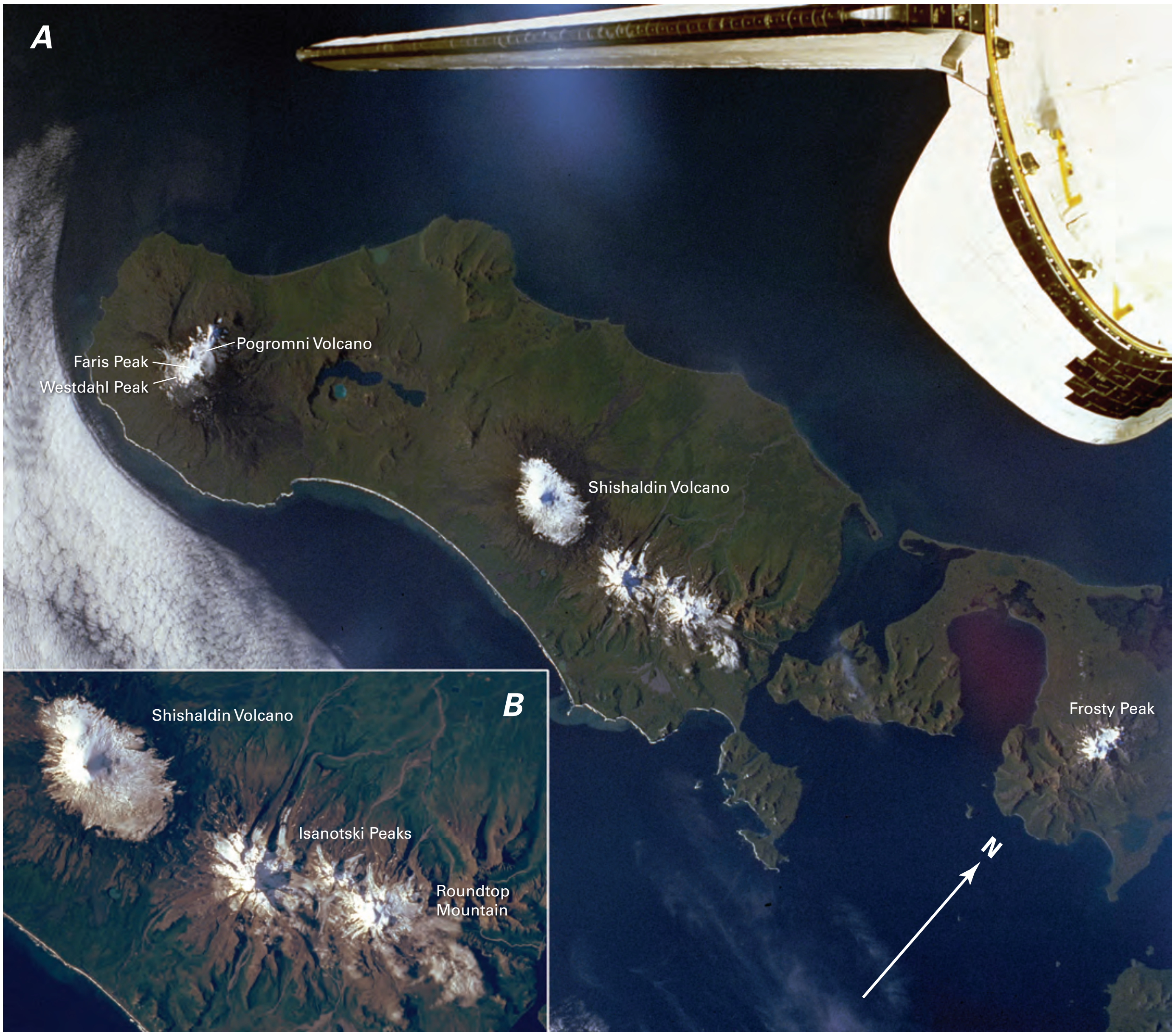


Figure 351.—*Annotated Space Shuttle photographs of the glacierized volcanoes of Unimak Island in September 1992.* **A**, *Space Shuttle photograph of all of Unimak Island and the western end of the Alaska Peninsula. Many glacier-covered stratovolcanoes and pyroclastic cones can be seen. From west to east, these include Pogromni Volcano (2,002 m), Faris Peak (1,628 m), Westdahl Peak (1,560 m), Shishaldin Volcano (2,857 m), the Isanotski Peaks (2,446 m), Roundtop Mountain (1,872 m), and Frosty Peak (1,746 m) at the western end of the Peninsula. National Aeronautics and Space Administration photograph no. STS047–77–034.* **B**, *Enlargement of Space Shuttle photograph of the eastern end of Unimak Island. From west to east, Shishaldin Volcano (2,857 m), the Isanotski Peaks (2,446 m), and Roundtop Mountain (1,872 m), all glacier-covered stratovolcanoes, can be seen. Several large, north-trending valleys, evidence of significant recent glacial erosion can be seen on the north sides of the Isanotski Peaks and Roundtop Mountain. Vegetation-free areas around each peak indicate the recent extent of snow and ice cover. Photograph No. STS047–081–025 from the National Aeronautics and Space Administration .*

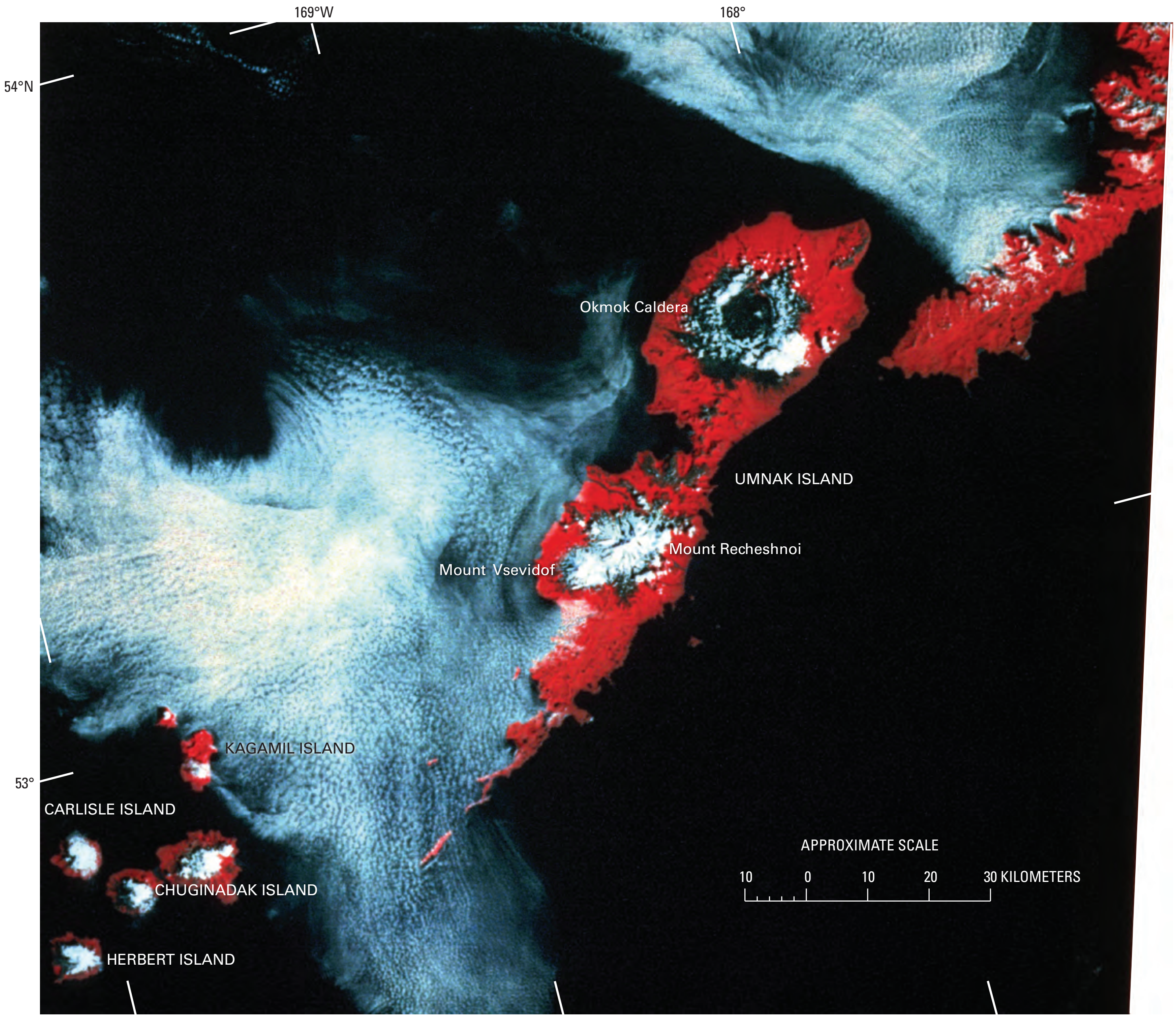
__Figure 352.__—Oblique aerial photographs of Shishaldin Volcano and environs, Unimak Island, Aleutian Islands. **A**, *View from the southeast of retreating, tephra- or debris-covered glaciers on southeast flank of Shishaldin Volcano taken in 1932. Two fingers of ice labeled A and B extend to the north margin of the nearly circular, water-filled depression. The 1-km-diameter depression is mapped as being approximately 3 km from the closest ice margin on the False Pass 1:250,000-scale topographic map of the area, which is based on 1942 and 1943 aerial photography. Photograph Capps 1544a from the USGS Photo Library, Denver, Colo.* **B**, *High-angle oblique, color aerial photograph from east of Isanotski Peaks and Shishaldin Volcano, Unimak Island, Aleutian Islands, taken 21 September 1990. Photograph frame no. CF008 from AeroMap U.S. Used with permission. A larger version of* A *is available online.*

__Figure 353.__—Oblique aerial photograph of the summit region of Makushin Volcano, Unalaska Island, in August 1982. The glacier-capped stratovolcano has several outlet glaciers flowing from its ice cap. A steaming volcanic crater in an ice cauldron can be seen in the middle background. Photograph by C. Nye, Alaska Division of Geological and Geophysical Surveys (Neal and McGimsey, 1997b).

Umnak Island

A late summer Landsat 2 MSS image acquired on 2 September 1977 (fig. 354) shows the glaciers of Umnak Island. Byers (1959) described nine unnamed valley glaciers descending from Mount Vsevidof (2,149 m) and Mount Recheshnoi (1,953 m) (21 August 1983 AHAP false-color infrared vertical aerial photograph no. L155F5808). Mount Vsevidof supports two valley glaciers, whereas Mount Recheshnoi supports at least seven glaciers. At least one small summit glacier and several hanging glaciers, all unnamed, also exist inside the southern rim of 1,073-m-high Okmok Caldera (21 August 1983 AHAP false-color infrared vertical aerial photograph no. L155F5816). A 1945 eruption melted a large area of the caldera's glacier. Okmok Caldera and the eastern part of Mount Recheshnoi are also depicted on a winter Landsat MSS image acquired on 10 March 1976 (Path 83, Row 23). As of 1999, little, if any, glacier ice remained on Umnak's peaks (USGS Alaska Volcano Observatory, oral commun., 2001).

Figure 354.*—Annotated Landsat 2 MSS false-color composite image of glaciers on Umnak Island, Aleutian Islands. Byers (1959) described two valley glaciers on Mount Vsevidof and seven valley glaciers on Mount Recheshnoi. Glaciers have also been described in Okmok Caldera. However, little glacier ice may remain now. Landsat image (29542–10905, bands 4, 5, 7; 2 September 1977; Path 84, Row 23) from the USGS, EROS Data Center, Sioux Falls, S. Dak.*



Herbert Island

On 1 January 2001, NASA's International Space Station acquired a photograph of Chuginadak, Carlise, and Herbert Islands (fig. 355*A*). A 27 September 1996 oblique color aerial photograph of the more than 900-m-high summit caldera of Herbert Island (fig. 355*B*) depicts at least two tongues of ice that descend to the crater floor and at least one hanging glacier. Acquired by AeroMap U.S., this photograph is not only perhaps the first cloud-free photograph of Herbert Island ever obtained, it is also the first documentation

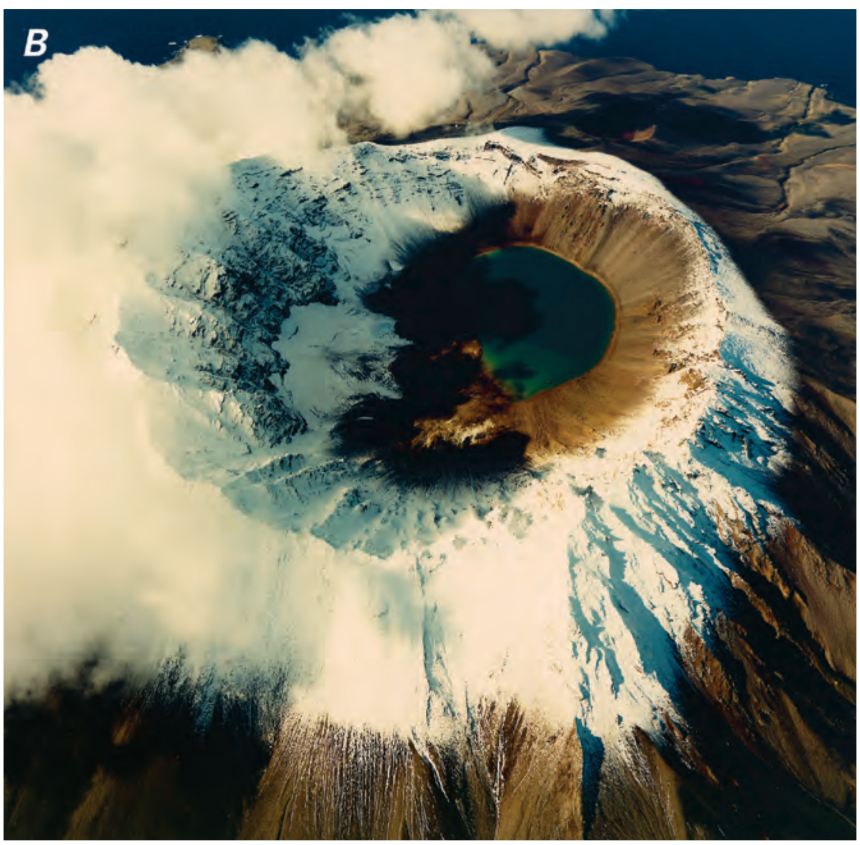


Figure 355.—**A**, *Annotated International Space Station photograph of Chuginadak, Carlisle, and Herbert Islands. NASA photograph No. ISS001–5962 taken on 1 January 2001. Evidence of recent glacial erosion can be seen on the east side of Chuginadak Island. Mount Cleveland, a stratovolcano and the highest point on Chuginadak Island, has a summit elevation of approximately 1,730 m. No information exists about the current status of glaciers on this island. Glaciers were only recently identified as being present on Herbert Island.* **B**, *Oblique color aerial photograph taken 27 September 1996 of the summit crater of Herbert Island, showing at least two tongues of ice that descend to the crater floor and at least one hanging glacier. This is the first documentation of the occurrence of glaciers on Herbert Island. Photograph from AeroMap U.S. Used with permission.*

of any glaciers on the Islands of Four Mountains. No information exists about the past or current status of these glaciers.

Atka Island

The USGS topographic map of Atka (appendix A) shows two volcanoes on Atka Island that support unnamed summit glaciers. Korovin Volcano, a 1,533-m-high stratovolcano that was last active in June 1998, and Mount Kliuchef (1,450 m) have a total glacier-covered area of about 20 km² (fig. 356). Several unnamed ice tongues descend from the summit of Mount Kliuchef; one flowing to the northeast terminates at an elevation of about 525 m. No information exists about the past or current status of these glaciers.

Great Sitkin Island

Great Sitkin Island, located northeast of Adak, was mapped in 1957 on USGS 1:250,000-scale Adak map, which was based on 1954–56 surveys (appendix A). The map shows that Great Sitkin Volcano, a 1,740-m-high stratovolcano with caldera and dome that was last active in September 1974, has an unnamed ring glacier on the eastern side of its crater and nine small unnamed glaciers of varying length descending from its summit. The largest of these glaciers was about 3 km in length. No information exists about the past or current status of these glaciers.

Tanaga Island

Tanaga Island is a semi-circular island with a length of about 40 km and a maximum width of about 15 km. The AMS (1957) 1:25,000-scale map of Tanaga Island shows a few unnamed glaciers about 1.6 km in length on 1,806-m-high Tanaga Volcano, a stratovolcano flanked by two stratocones that were last active in 1914. Several unnamed smaller glaciers are also shown on an unnamed 1,449-m-high stratovolcano to the east. The largest glacier shown on this volcano headed at about 1,295 m and descended to about 875 m. No glaciers are shown on the most recent USGS 1:250,000-scale topographic quadrangle maps of the island (Adak, 1957; Gareloi Island, 1954) (appendix A). No information exists about the past or current status of these glaciers.

Gareloi Island

The Gareloi Island 1954 USGS 1:250,000-scale topographic map (appendix A) shows a small glacier-covered area on Mount Gareloi, a 1,573-m-high stratovolcano last active in August 1989. At least two small glaciers were situated on the northern side of its cone (Coats, 1956). A single, very small glacier (<0.04 km²) is also shown on the southeastern side of the summit of Mount Gareloi, according to the USGS 1:250,000-scale topographic quadrangle map (appendix A). No information exists about the past or current status of these glaciers.

Kiska Island

In 1943, Kiska Island possessed a small glacier on Kiska Volcano, a 1,220-m-high stratovolcano last active in June 1990. Henderson and Putnam (1947) visited the glacier at least once in 1943 and described it (p. 32) as being a "small, decadent, dirty piece of ice, but it still merited the name glacier." However, no evidence of this or any glacier is shown on Kiska Volcano on the most recent 1951 USGS 1:250,000-scale topographic quadrangle map of the area (appendix A). No additional information exists about this glacier.

Summary

Less information exists about the glaciers of the Aleutian Islands than for any other area in Alaska. The extremely limited information that is available is generally four to six decades old. Glaciers for which information exists are retreating and (or) thinning.

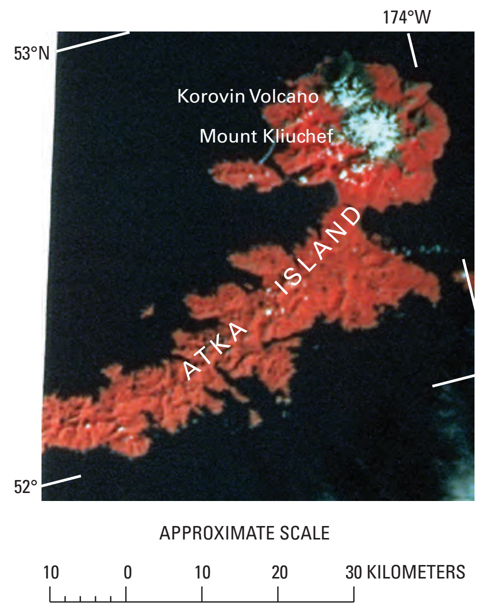


Figure 356.*—Part of an annotated Landsat 2 MSS false-color composite image of Korovin Volcano and Mount Kliuchef, Atka Island, Aleutian Islands. Both volcanoes have summit glaciers totaling about 20 km² in area. Landsat image (2975–21252, bands 4, 5, 7; 23 September 1977; Path 87, Row 24) is from the USGS, EROS Data Center, Sioux Falls, S. Dak.*