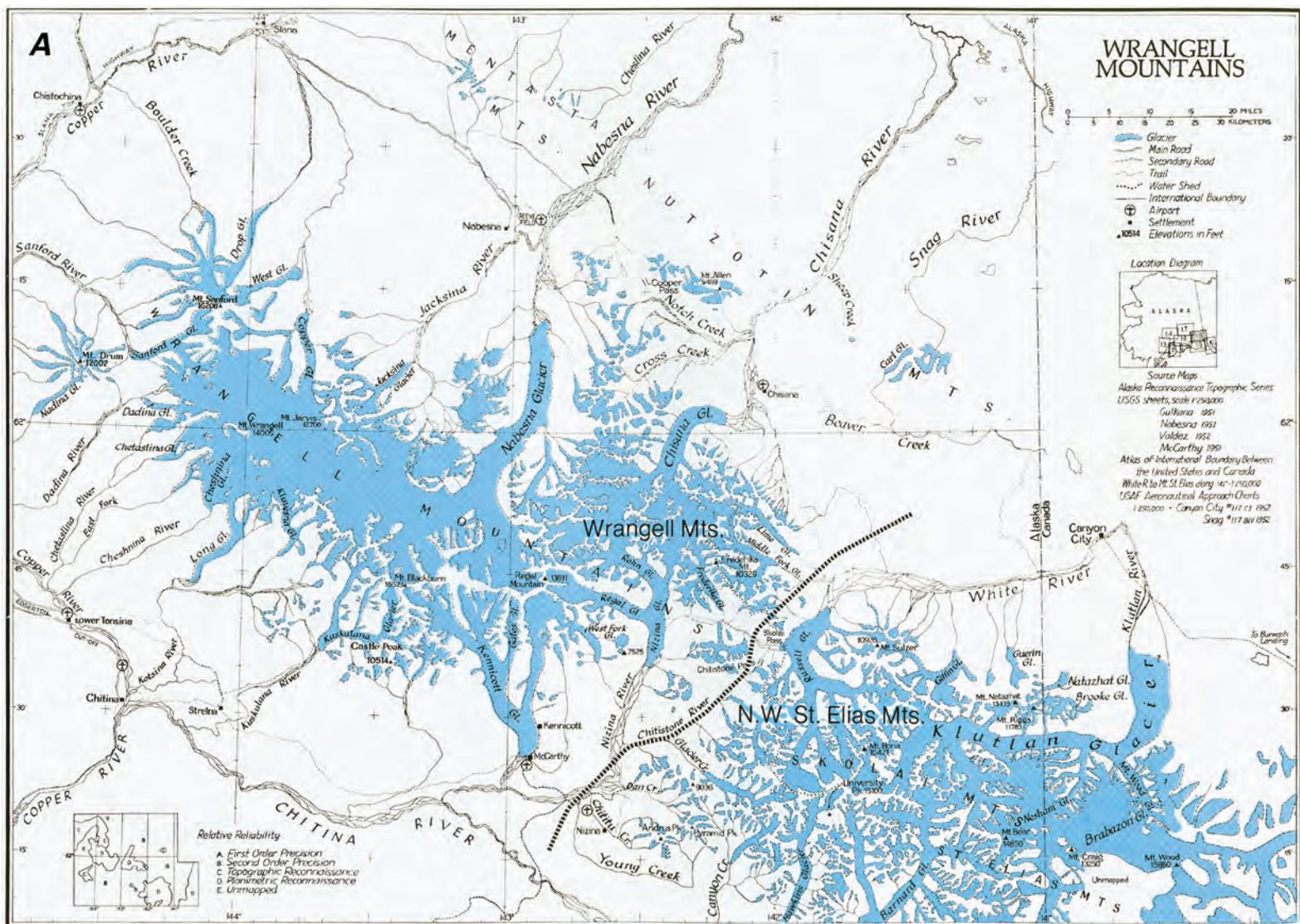


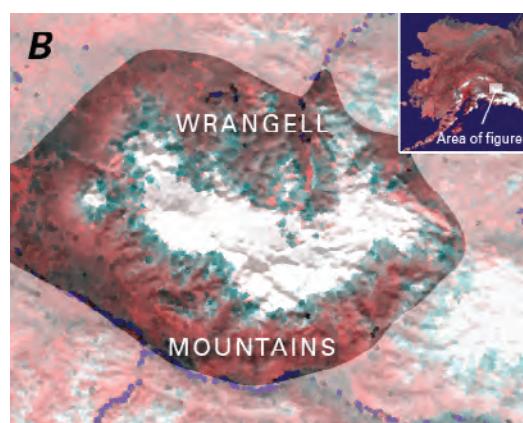
# Wrangell Mountains

## Introduction

The Wrangell Mountains (figs. 1, 357), a large young volcanic massif having a maximum length of about 155 km and width of 85 km, are located between Nabesna (to the north), Skolai Pass and the Chitistone River (to the east), the Chitina River (to the south), and the Copper River (to the west). They are included in the Wrangell-St. Elias National Park and Preserve, Alaska,



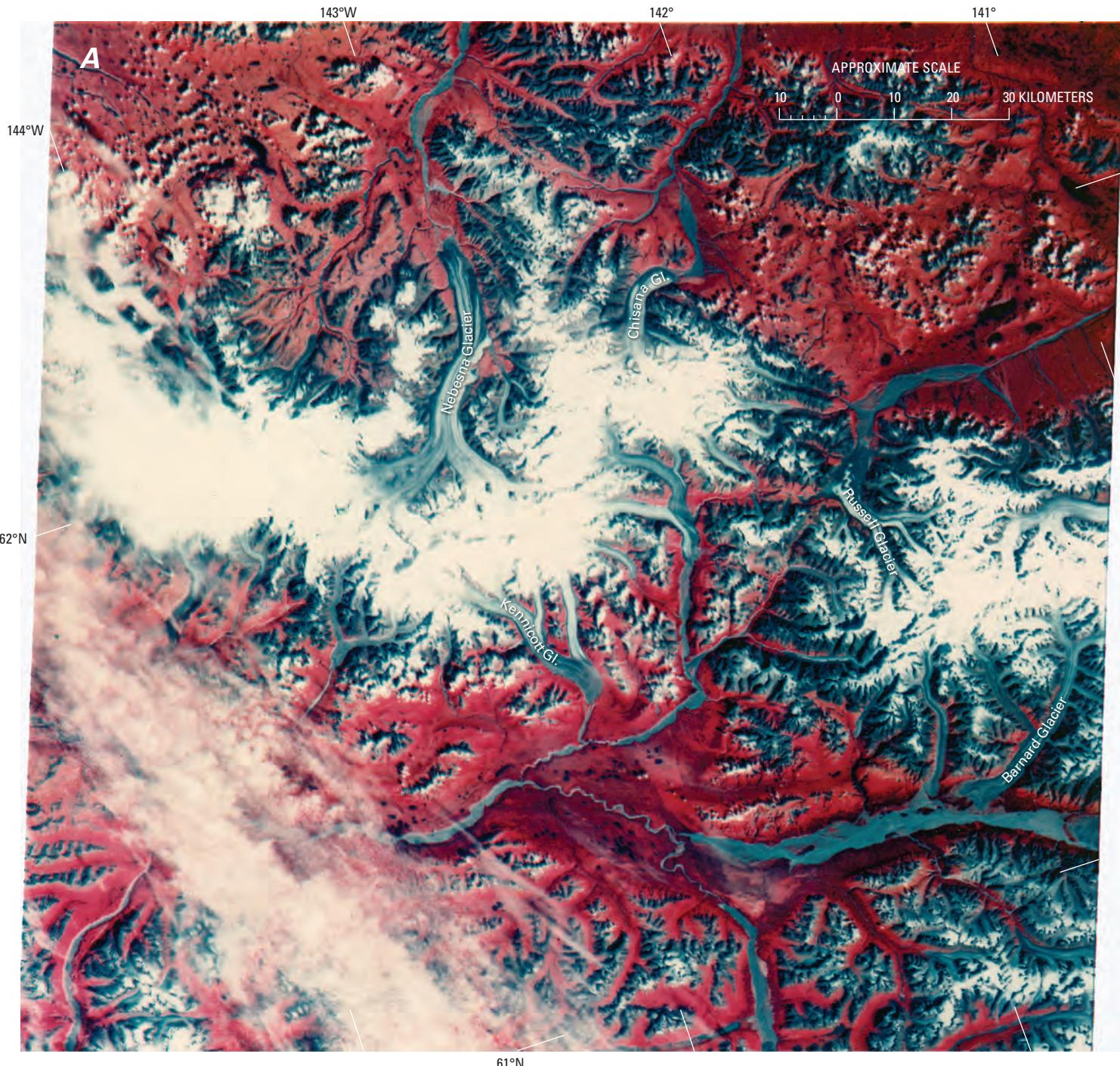
**Figure 357.**—**A**, Index map of the glacierized Wrangell Mountains (modified from Field, 1975a). **B**, Enlargement of NOAA Advanced Very High Resolution Radiometer (AVHRR) image mosaic of the glacierized Wrangell Mountains in summer 1995. National Oceanic and Atmospheric Administration image mosaic from Mike Fleming, Alaska Science Center, U.S. Geological Survey, Anchorage, Alaska.



which is contiguous with Kluane National Park, Yukon Territory, Canada, on the east. The highest peaks are Mount Blackburn (4,996 m), Mount Sanford (4,949 m), Mount Wrangell (4,317 m—an active volcano with a summit caldera), Regal Mountain (4,220 m), Mount Jarvis (4,091 m), Mount Zanetti (3,965 m), Rime Peak (3,883 m), and Mount Drum (3,661 m). The peaks are either Quaternary volcanoes or are composed of layered volcanic material. Mount Drum and Mount Sanford are free-standing mountains that support a number of glaciers radiating from their summits.

In total, the Wrangell Mountains support about 50 outlet glaciers that have lengths of 8 km or more and have a glacier-covered area of 8,300 km<sup>2</sup> (Post and Meier, 1980, p. 45) (fig. 358). Table 6, which is based on Krimmel's analysis of an 18 August 1972 Landsat 1 MSS image (1026–20220) of the area, provides data on the AARs of 14 glaciers in the Wrangell Mountains. Many are surge-type glaciers. At the center of the west-central Wrangell Mountains

**Figure 358.**—A, Annotated Landsat 1 MSS false-color composite image of the Wrangell Mountains and northwestern part of the St. Elias Mountains. An enlargement of this image, combined with topographic maps, was used to determine the accumulation area ratios (AARs) (see table 6) and snowline altitudes on 14 glaciers in this area. ► B, Contour map of equal snowline altitude (in meters) showing that snowline altitudes are higher to the northeast of the mountains and thus indicating less snow accumulation there. Landsat image and caption courtesy of Robert M. Krimmel, U.S. Geological Survey. Landsat image (1026–20220; bands 4, 5, 7; 18 August 1972; Path 70, Row 17) is from the USGS, EROS Data Center, Sioux Falls, S. Dak.



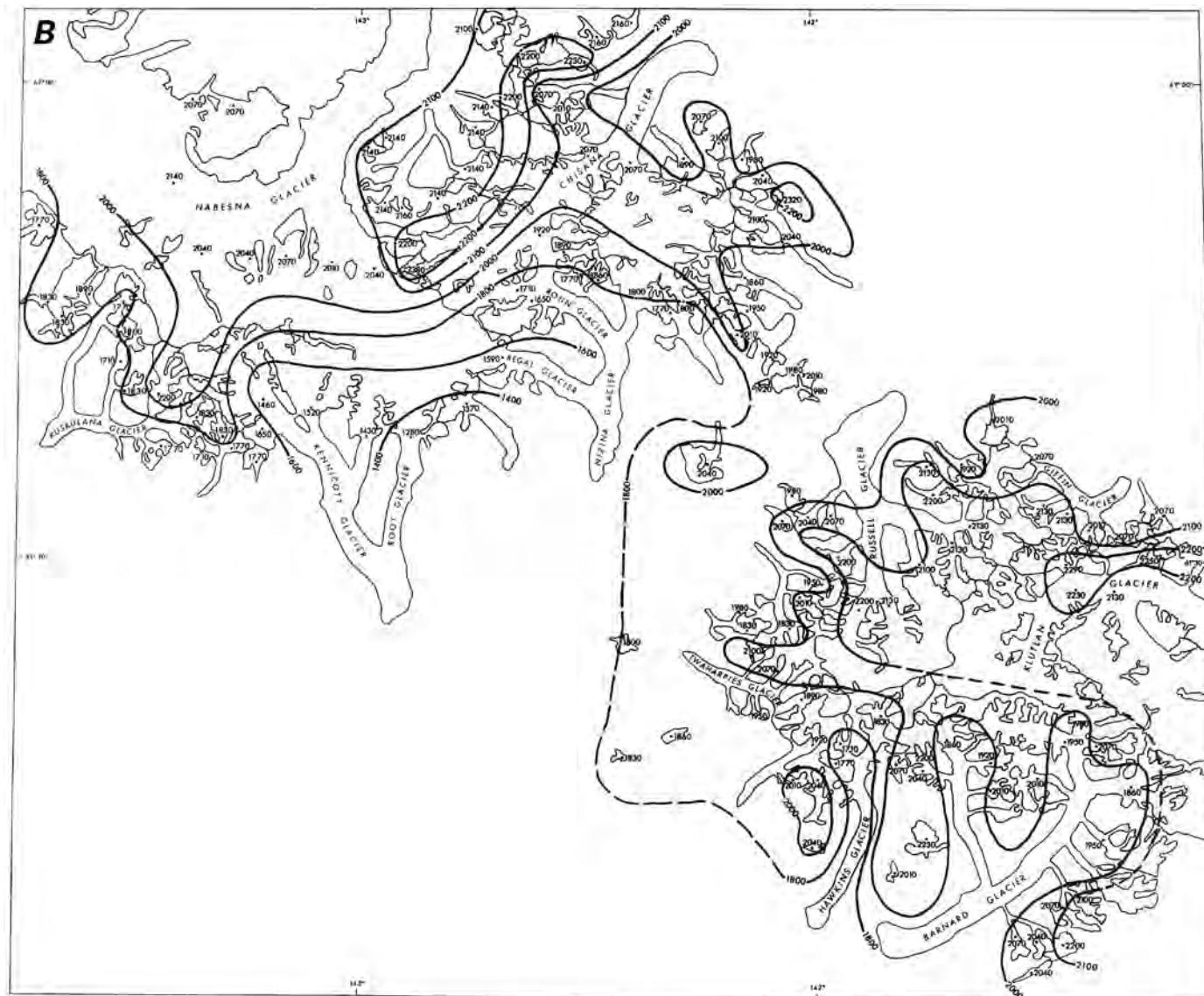


TABLE 6.—*Wrangell Mountains accumulation area ratios (AAR)*

[Data courtesy of Robert M. Krimmel, USGS, derived from Landsat 1 MSS image 1026–20220, 18 August 1972]

Glacier name	AAR
Hawkins	0.39
Barnard	0.67
Russell	0.64
Chisana	0.73
Nabesna	0.64
Kuskulana	0.55
Kennicott	0.60
Nizina	0.67
Lakina	0.65
Kluvesna	0.64
Giffin	0.56
Twaharpies	0.55
Chitistone	0.63
Lime	0.62

is a broad upland ice field covering an area of about 750 km<sup>2</sup> and extending eastward from the crater of Mount Wrangell to the head of Nabesna Glacier, a distance of about 35 km. It is bounded on the north by Mount Sanford and Mount Jarvis. Nabesna Glacier, which is 87 km long, and has an area of 819 km<sup>2</sup> (Denton and Field, 1975c, p. 566), is the largest of the outlet glaciers in the Wrangell Mountains as well as the largest inland glacier in North America. In the eastern part of the mountains, a series of interconnected unnamed ice fields are drained by Chisana, Lime, Middle Fork, and Frederika Glaciers, and Nizina Glacier and its tributaries.

Landsat 1–3 MSS images that cover the Wrangell Mountains have the following Path/Row coordinates: 69/17, 70/16, 70/17, 71/16, 71/17, and 72/16 (fig. 3, table 1). These areas are mapped on the USGS Gulkana, Alaska (1959), McCarthy, Alaska (1960), Nabesna, Alaska (1960), and Valdez, Alaska (1960) 1:250,000-scale topographic maps (appendix A). Landsat 7 ETM+ images of the Wrangell Mountains also have been acquired, and several are included in this section.

Topographic information, including information about glaciers of this area, was collected as early as 1885 (Allen, 1887); the first sketch maps appeared as early as 1892 (Rohn, 1900). A 1:750,000-scale map (fig. 359) depicting the location of many of the glaciers of the Wrangell Mountains and 1:250,000-scale topographic maps showing details of individual glacier

termini appeared in 1902 and were printed in USGS Professional Paper 41 (Mendenhall, 1905). Much of these early topographic data were collected by T.G. Gerdine, W.J. Peters, and D.C. Witherspoon, all of the USGS. Gerdine was often assisted by W.C. Mendenhall, who was mapping the geology of the region (Mendenhall, 1905). Remarkably, the map, made in a remote, unknown region and using late 19th century planetable and telescopic-alidade methods, remains accurate. A 1908 topographic survey by Witherspoon and H.M. Lafollette produced a 1:62,250-scale topographic map that included the eastern margin of Kennicott Glacier and was published in USGS Bulletin 448 (Moffit and Capps, 1911).

Rock glaciers are abundant throughout the Wrangell Mountains (fig. 360), as 1905 photographs by Moffit (USGS Photo Library photographs Moffit 384 and 390) and 1908 photographs by Capps (USGS Photo Library photographs Capps 141 and 142) show. Capps (1910b) mapped more than 30 rock glaciers in the area to the south and east of Kennicott Glacier, describing features common to rock glaciers in the Wrangell Mountains as follows: "They vary greatly in size, but are usually many times longer than wide, occupying, as they do, the bottoms of cirque-like valleys. Some have wide, fan-shaped heads and narrow down to a tongue below. Others are narrow above, and deploy into spatulate lobes below.....but the greater number are narrow bodies of nearly uniform width, from one-tenth to one-fourth of a mile wide and from one-half to 2½ miles long. The surface slopes vary in different cases from 9° to 18° for the whole course of the rock glacier." (Capps. 1910b, p. 360). Capps thought there was a resemblance to true glaciers. In many of the rock glaciers, fragmental rocks extend all the way to the head of the cirque; no ice



**Figure 359.**—Part of a map of the Mount Wrangell District, Alaska, a 1:750,000-scale map based on data collected between 1885 and 1902, depicting the location of many of the glaciers of the Wrangell Mountains. From Mendenhall (1905, plate number XI). A larger version of this figure is available online.



**Figure 360.**—1961 northeast-looking oblique aerial photograph of a rock glacier on the west side of Bonanza Peak, east of Kennicott Glacier. A road is shown on this rock glacier on the 1911 topographic map. The buildings constructed on the northwest side of the rock glacier, below the snowline, and the roads on its surface suggest that the surface of this rock glacier is stationary and stable and has been for many years. University of Washington photograph No. F7-61 by Austin Post, U.S. Geological Survey.

is visible, and there is little or no snow on the surface. In several cases, however, the rock glaciers grade into true glaciers at their upper ends, without any sharp line of demarcation, so that gradation between the two is complete (fig. 360).

### Glaciers of the Regal Mountain – Frederika Mountain Area and the Eastern Wrangell Mountains

Outlet glaciers of the eastern Wrangell Mountains (Chisana, Lime, Middle Fork, Frederika, Shelter Valley, and Whiskey Hill Glaciers) originate from a 20×10-km unnamed upland ice field surrounded by several isolated peaks with elevations higher than 2,500 m. The highest of these is 3,150-m-high Mount Frederika. Glaciers of the southeastern Wrangell Mountains (Rohn, Regal, West Fork, Root, and Gates Glaciers) originate mainly on the southern flanks of Regal Mountain. Rohn and Regal Glaciers descend from the eastern flank of Regal Mountain as well, and Rohn Glacier is also fed from the northern flank of Regal Mountain and the unnamed upland ice field. Other, generally smaller glaciers, flow from isolated accumulation areas located on upland ridges and isolated peaks.

Chisana Glacier (fig. 361), which is 39 km long and 440 km<sup>2</sup> in area (Denton and Field, 1975c, p. 567), is the northeasternmost and third largest glacier in the Wrangell Mountains. It drains several large interconnected accumulation areas north of Regal Mountain and Frederika Mountain. Chisana Glacier has been also named *Tanana Glacier* (Rohn, 1900) and was locally called *Shushana Glacier* (Orth, 1967).

The terminus of Chisana Glacier was visited independently in 1899 by Brooks and then by Rohn and again in 1908 by Capps, who stated that “a comparison of the photographs taken by Rohn in 1899 with those taken by the writer nine years later show surprisingly little change in the aspect of the glacier....” (Capps, 1910a, p. 45). At one place, a slight recession had occurred in the edge of the glacier. Although there was little change, Capps’ 1908 photograph (USGS Photo Library photograph S.R.15) clearly shows an arcuate ridge located more than 500 m downvalley of the terminus that was deposited by the glacier some time in the recent past.

Denton and Field (1975c) reported that little change can be seen when the 1908 terminus position is compared with the one shown in Washburn’s 1938 photograph. Denton and Field (1975c) stated that the glacier had retreated about 600 m and showed a pronounced lateral recession and a shrinkage of its first tributary by 1957, the date of the photography used to produce the first



**Figure 361.**—30 August 2000 northwest-looking oblique aerial photograph of the retreating terminus of Chisana Glacier. The exposed bedrock along its margin appeared after 1957. Its appearance suggests thinning of as much as 50 m during the second half of the 20th century. Photograph by Bruce F. Molnia, U.S. Geological Survey.

1:63,360-scale topographic map of the glacier (USGS, Nabesna A-3, Alaska, 1960) (appendix B). After 1957, the terminus of Chisana Glacier fluctuated; even though the glacier experienced a number of small surges, it continued to thin and retreat. In August 1978, Austin Post (written commun., 1978) reported that three or four recent moraines were located adjacent to the active ice margin. When the author observed it from the air on 30 August 2000, the terminus of Chisana Glacier showed much evidence of active thinning and retreat (fig. 361).

To the southeast of Chisana Glacier, in the area west of Bow Pass, a number of small glaciers originate from isolated accumulation areas that are independent of the larger interconnected accumulation area. Several drain into Boomerang Creek. All show evidence of thinning and retreat. The only Wrangell Mountains' glacier observed surging on 30 August 2000 is also located near Bow Pass (fig. 362).

Middle Fork Glacier, a surge-type glacier that is 13 km long and 38 km<sup>2</sup> in area (Denton and Field, 1975c, p. 567), is located to the northeast of Frederika Peak. It was last reported surging between 1964 and 1966 (Post, 1967a). When the author observed it from the air on 30 August 2000 (fig. 363), its upper part showed evidence of thinning.

Frederika Glacier, another surge-type glacier, is 19 km long and 58 km<sup>2</sup> in area (Denton and Field, 1975c, p. 562) (1905 Moffit photograph, USGS Photo Library photograph Moffit 338); 1908 Capps photograph, USGS Photo Library Capps 104). The earliest description of the glacier was made by Hayes (1892, p. 133) in 1891 during a surge: "The glacier terminates in a nearly vertical ice cliff stretching across the lateral valley a mile in length and about 250 feet high. Its surface is free from moraine, but is extremely rough and broken, wholly unlike the surface of stagnant ice at the end of a retreating glacier. At the foot of the cliff is a small accumulation of gravel and ice fragments being pushed along by the advancing mass."

When Capps (1910a) visited in 1908, melting and erosion had removed all signs of the former surge. He described the glacier's surface as being remarkably smooth and sloping evenly to a thin edge, stating that "It was easier to take a pack train across this low ice-tongue than to ford the torrential



**Figure 362.**—30 August 2000 northwest-looking oblique aerial photograph of an unnamed surging glacier in the Bow Pass area, northeastern Wrangell Mountains. This glacier was the only one in the Wrangell Mountains observed to be surging in 2000. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.



**Figure 363.**—Two 30 August 2000 northwest-looking oblique aerial photographs of parts of Middle Fork Glacier showing much evidence of thinning and retreat of upper reach tributaries. **A**, View of the junction area of the two primary tributaries of Middle Fork Glacier. The northern tributary has an elevated trimline on its north margin, at the right edge of the photograph. The glacier, which enters the northern tributary from the cirque to the left of center, has retreated into the cirque, leaving an elevated loop moraine that extends several kilometers downglacier. The southern tributary also has an elevated trimline on its north margin, and its height suggests more than 50 m of recent thinning. **B**, Slightly overlapping view of the width of Middle Fork Glacier just downglacier from A, showing an elevated trimline on its north margin, the elevated loop moraine, and many other elevated moraines. Although the terminus of the glacier was not observed, upglacier evidence suggests significant thinning. Photographs by Bruce F. Molnia, U.S. Geological Survey. Larger versions of these figures are available online.

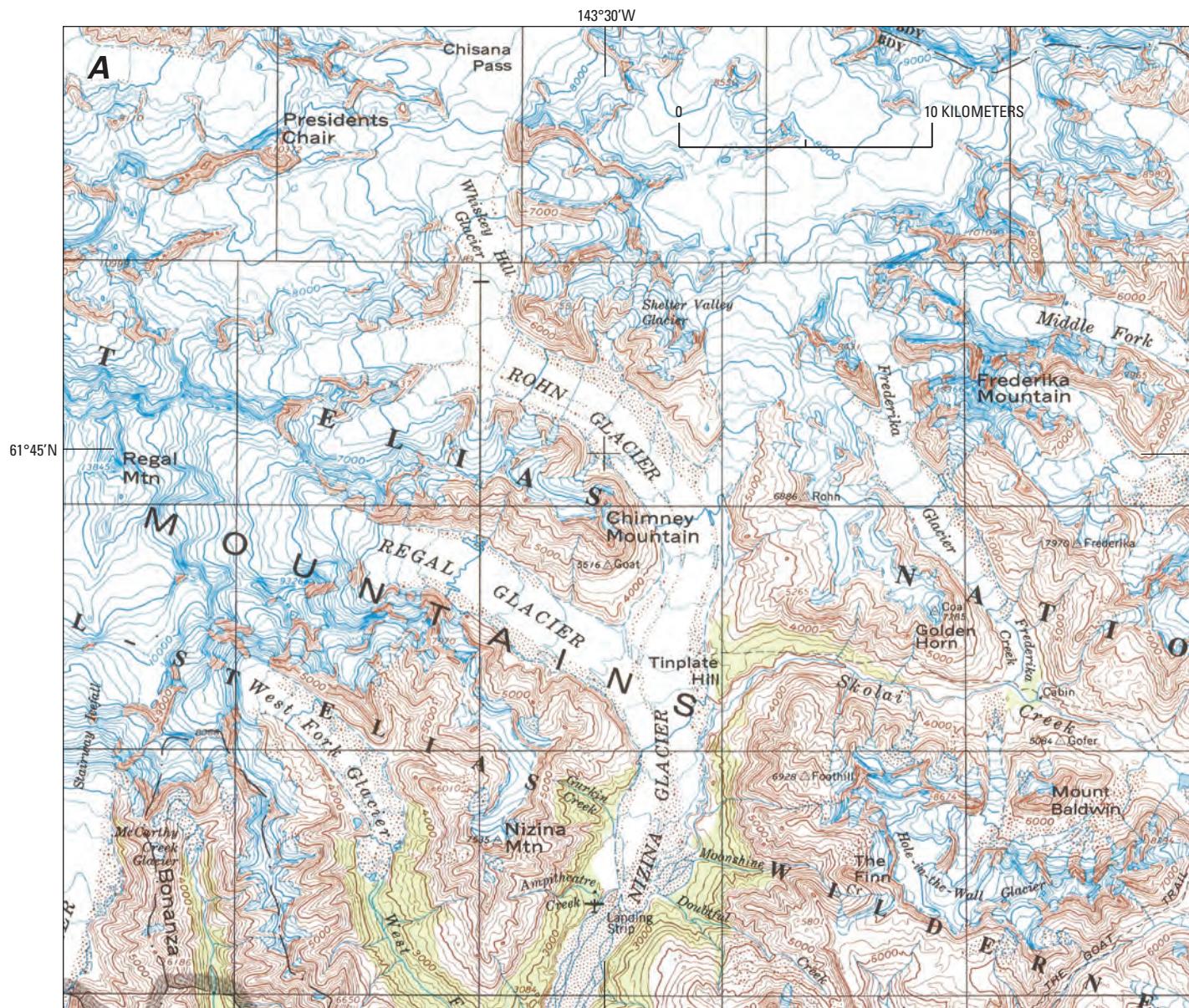


**Figure 364.**—Two 20th century views of the Hole-in-the-Wall Glacier. **A**, 1905 view from the north, looking south at the edge of the then-surging margin of Hole-in-the-Wall Glacier. The duration and displacement of the surge are unknown. Photograph Moffit 339 from the USGS Photo Library, Denver, Colo. **B**, A 1966 photograph showing that Hole-in-the-Wall Glacier has retreated and thinned since the 1905 surge. Elevated lateral moraines are present along both margins of the glacier. Shortly after this photograph was taken the glacier surged again. U.S. Geological Survey photograph by E.M. MacKevett, Jr. From Winkler (2000, fig 39). A larger version of A is available online.

stream below.” (Capps, 1910a, p. 56). This gently sloping terminus was photographed by Moffit in 1905.

North-flowing Hole-in-the-Wall Glacier, which is 9 km long and 19 km<sup>2</sup> in area (Denton and Field, 1975c, p. 562), is a surge-type glacier that originates from an isolated accumulation area west of Chitistone Pass. Its terminus is within a few kilometers of the terminus of Frederika Glacier. Capps (1910a) saw its terminus in 1908 when it was surging (1908 Capps photograph, USGS Photo Library photograph Capps 105) and described it (p. 56) as “a beautiful cascade glacier [that] tumbles out from between castellated peaks and pushes northward to Skolai Creek.” Hole-in-the-Wall was the only advancing glacier that Capps observed during the field season, and he concluded that he was “...unable to account for the singular change in conditions which has caused Frederika Glacier, which 17 years ago was advancing, to retreat, and at the same time has brought about the advance of a glacier just to the south, which in 1891 was retreating.” (Capps, 1910a, p. 56). The dates of the onset and completion of the surge are unknown, but a 1905 photograph by Moffit (fig. 364A) shows that the glacier was surging at that time. Several years of retreat followed (fig. 364B). Hole-in-the-Wall Glacier surged again late in 1966 (Meier and Post, 1967). Winkler (2000) stated that the glacier has recently retreated 0.7 to 1.4 km and thinned by as much as 80 m.

Nizina Glacier (fig. 365A–C) is the name given to the ice tongue formed by the joining of Rohn and Regal Glaciers. Both its principal tributaries descend from the eastern slopes of Regal Mountain, although Rohn Glacier also receives ice from the northern flank of Regal Mountain and the unnamed upland ice field to the north. Nizina Glacier, which is 51 km long and 429 km<sup>2</sup> in area (Denton and Field, 1975c, p. 562), is the southeasternmost large valley glacier in the Wrangell Mountains. When a gold rush began at Chisana in 1913, the shortest route from the Chitina Valley was a 60-km-trek over the Nizina, Rohn, and Chisana Glaciers. The surface of the Nizina Glacier became a popular highway. When it was photographed in 1905 by Moffit and again in 1913 by Capps (1905 Moffit photograph, USGS Photo Library photograph Moffit 341; 1913 Capps photographs, USGS Photo Library photographs Capps 519, 520, and 521), its eastern margin blocked the valley of Skolai Creek and formed a lake at least 3 km long. By 1937, when Bradford Washburn photographed it, the glacier thinned enough to permit the lake to drain and a stream channel to develop along the eastern margin of Nizina Glacier (Denton and Field, 1975c). Little net change had occurred when it was next photographed in 1964 by Post (Denton and Field, 1975c). When the author

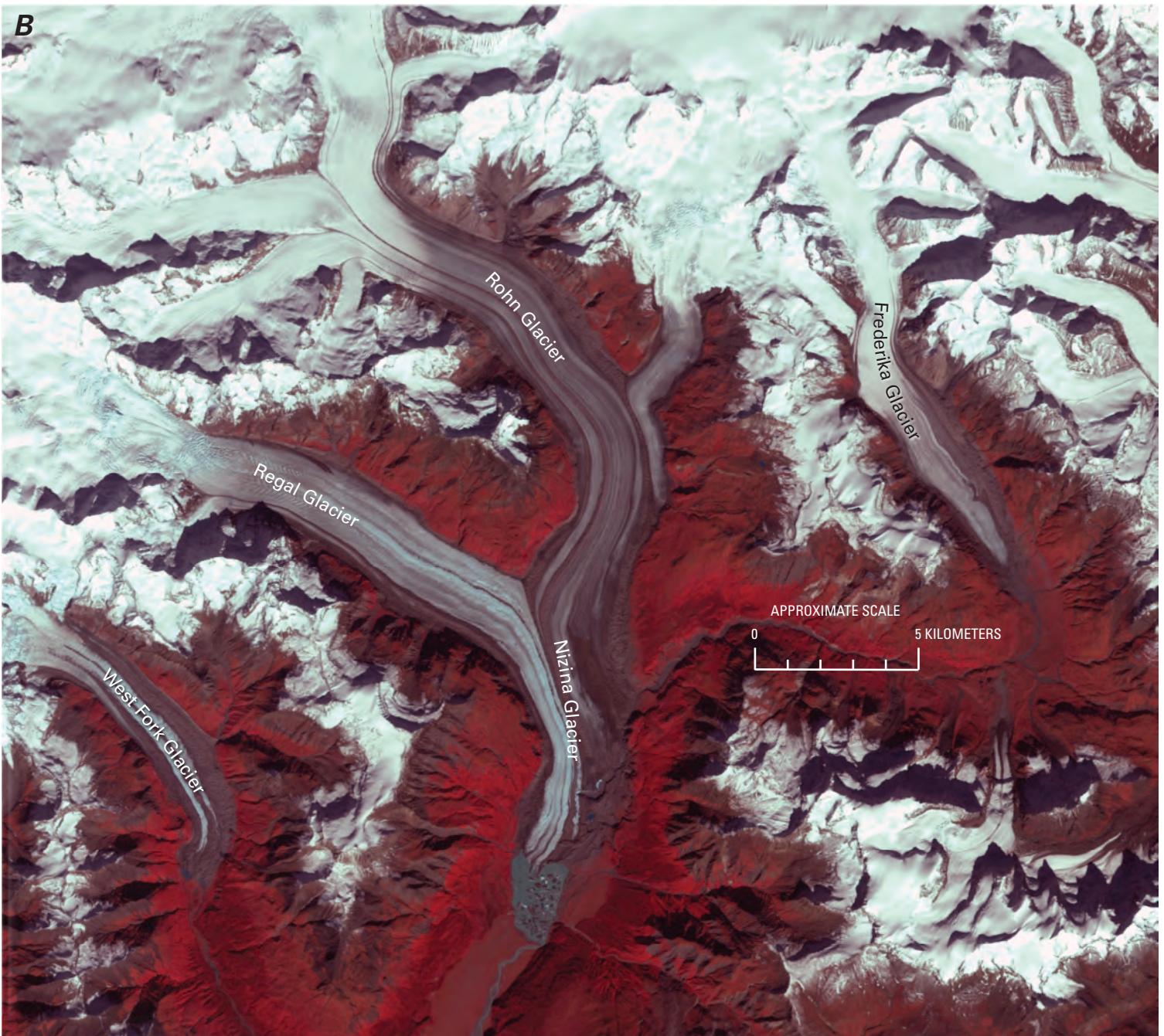


observed it from the air on 30 August 2000 (fig. 365C), a 3-km-long ice marginal lake had developed at its terminus, and large tabular icebergs were calving into the lake. Compared to 1957 aerial photographs, the terminus has retreated at a rate of approximately  $90 \text{ m a}^{-1}$ . The author also observed the upper regions of both Rohn and Regal Glaciers from the air on 30 August 2000 (fig. 366) and noted that both showed much evidence of thinning.

West Fork Glacier, which is 18 km long and about  $49 \text{ km}^2$  in area, (Denton and Field, 1975c, p. 562), originates from several small interconnected accumulation areas on the southern side of Mount Regal. When the author observed it from the air on 30 August 2000, its upper part showed evidence of thinning.

Between West Fork and Root Glaciers, several small glaciers flow from isolated accumulation areas located on upland ridges at the head of McCarthy Creek. Moffit photographed two of these glaciers—McCarthy Creek Glacier and an unnamed glacier—in 1919 and 1922 (1919 Moffit photographs, USGS Photo Library photographs Moffit 849 and 850; 1922 Moffit photograph, USGS Photo Library photograph Moffit 844), and the author photographed them from the air on 30 August 2000. In 1919, little could be said about the status of McCarthy Creek Glacier, but the unnamed glacier was thinning and retreating. Eighty-one years later, both showed evidence of thinning, and the unnamed glacier was retreating.

**Figure 365.**—Map, Landsat image, and photograph of the Nizina Glacier. **A**, Section of USGS McCarthy, Alaska (1960, revised 1981) 1:250,000-scale map showing the Nizina Glacier and its tributaries. **B**, Enlarged section of annotated Landsat 7 ETM+ false-color composite image of Nizina Glacier. Landsat 7 image (LE7064017000125350; 10 September 2001; Path 64, Row 17) from the USGS, EROS Data Center, Sioux Falls, S. Dak. **C**, 30 August 2000 south-looking oblique aerial photograph of the terminus of Nizina Glacier. Since 1957, a 3-km long ice-marginal lake has developed due to the retreat of the glacier. Photograph by Bruce F. Molnia, U.S. Geological Survey.



Root and Gates Glaciers are the principal eastern tributaries of Kennicott Glacier (1919 Moffit photograph, USGS Photo Library photograph Moffit 832). Both descend from the southern flank of Regal Mountain. The western side of Kennicott Glacier dams the mouth of Hidden Creek Valley, located approximately 16 km north of Kennicott Glacier's stagnant terminus. Annually, 3-km-long Hidden Creek Lake forms, dammed by the margin of Kennicott Glacier. Between July and September, the lake drains subglacially, releasing as much as 4 to  $5 \times 10^7$  m<sup>3</sup> of water (Cunico and others, 2001), causing a jökulhlaup on the Kennicott River. In 2000, a year in which the lake drained completely in approximately 75 hours, Cunico and others (2001) studied the mechanics of the glacier to understand the evolution of the flood. They placed 22 survey targets on the glacier's surface over an area about equal in width to the lake, from near the glacier/lake margin to a distance of about 1 km from the margin. They surveyed the targets over a 24-day period as the lake filled and then drained. Independent monitoring of changes in the lake's level revealed that, as the lake filled, targets 300 to 400 m away from the lake rose at nearly the same rate as the lake, typically about 0.5 m d<sup>-1</sup>. Several rose faster than the lake. The rate of vertical movement fell off rapidly with distance from the lake. At a distance of about 1 km, vertical movement of the targets seemed to be uncorrelated with lake stage. Cunico and others (2001) concluded that the general pattern of observed displacement is consistent with a wedge of water extending beneath the glacier to a distance of perhaps 300 to 400 m from the visible margin of the lake and exerting buoyant stresses on the ice that were then transmitted into the main body of the glacier and caused flexure. For a given value of lake stage, target elevations were invariably higher as the lake drained than they were as the lake filled. Moreover, survey targets at a distance of about 400 m or more from the lake continued to rise for some time even after the lake began to drain. The lag time between the beginning of lake drainage and the beginning of target dropping increased with distance from the lake, the lag being about 14 hours 400 m from the lake. They concluded that movement of water from the lake into temporary storage—a sort of hydraulic jacking—was responsible for the observed ice displacements. Using the vertical downdrop of the ice as a guide, they calculated that the volume of the subglacial water "wedge" plus the water released from distributed storage is about  $7.0 \times 10^6$  to  $1.1 \times 10^7$  m<sup>3</sup> (Cunico and others, 2001).

The surfaces of both Root and Gates Glaciers possess multiple ogive-like undulations; a USGS photograph from the early 1980s shows that the surface of Root Glacier features many pits (Winkler, 2000, fig. 71). When the author observed them from the air on 30 August 2000, the upper regions of both glaciers showed much evidence of thinning, and the terminus of Kennicott Glacier was stagnant.

With only a few exceptions, almost every glacier in the Wrangell Mountains that descends below 2,000 m shows evidence of thinning, retreat, or stagnation. However, at higher elevations such as the Frederika Peak area, temperatures remain cold enough and precipitation is sufficient to nourish existing ice accumulations in spite of changing climate. Hence, in the eastern Wrangell Mountain, glaciers at elevations above 2,500–3,000 m show no evidence of ice loss.

## Glaciers of Mount Blackburn and the Southeastern Wrangell Mountains

Mount Blackburn, the highest peak in the Wrangell Mountains, is an erosional remnant of a large shield volcano. The mountain is covered with ice and gives rise to several large glaciers: Kennicott Glacier (fig. 367) which flows to the southeast; part of Nabesna Glacier which flows to the northeast; and Kuskulana Glacier, which flows to the south and west. Other, generally



**Figure 366.**—30 August 2000 oblique aerial photograph of the central Rohn Glacier adjacent to Chimney Mountain, looking to the northwest. In the 88 years since Rohn Glacier was photographed by S.R. Capps, the glacier has thinned as much as 30 m. The trimlines and the barren zone adjacent to the eastern tributary are evidence of this change. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.

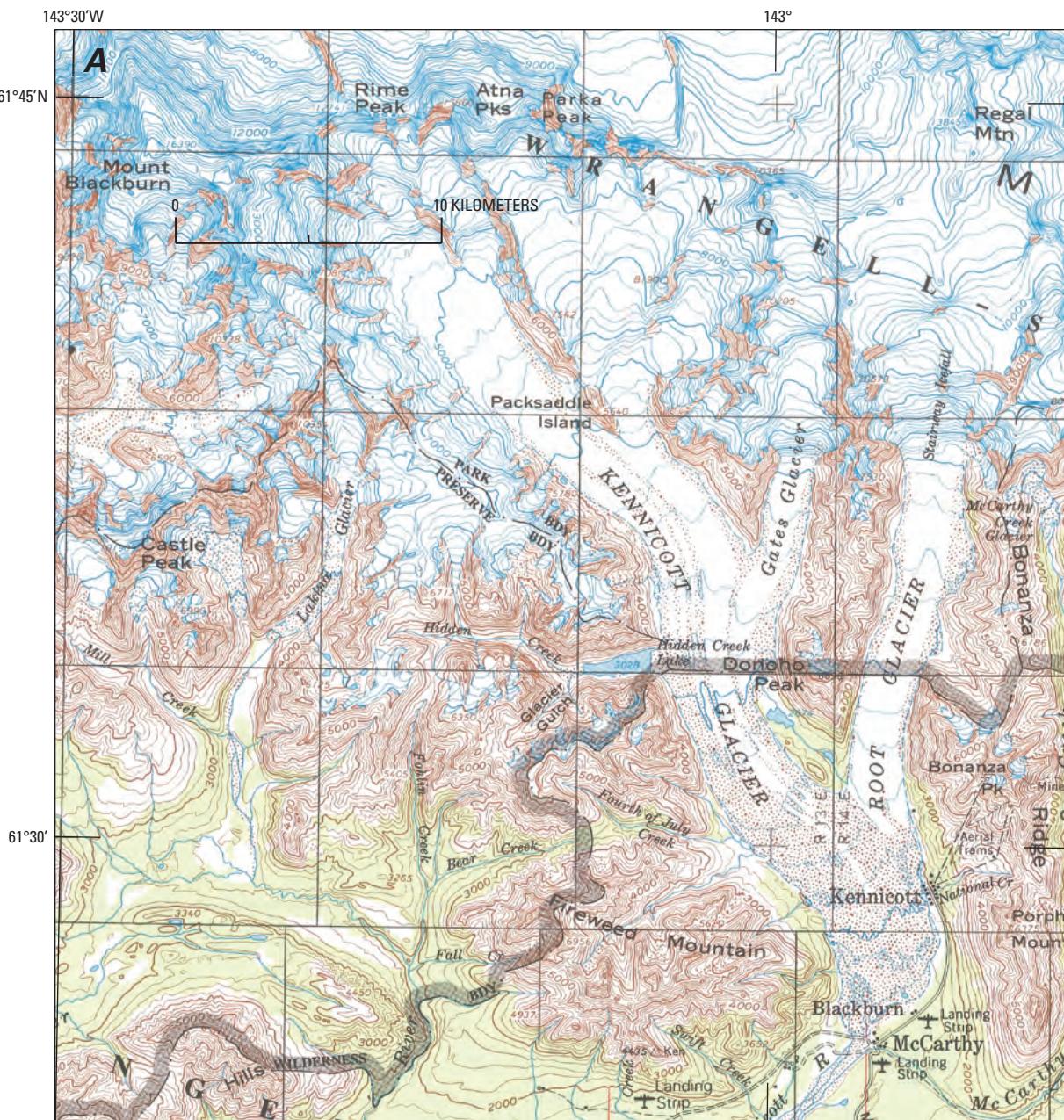
smaller glaciers, flow from isolated accumulation areas located on upland ridges and isolated peaks (fig. 368).

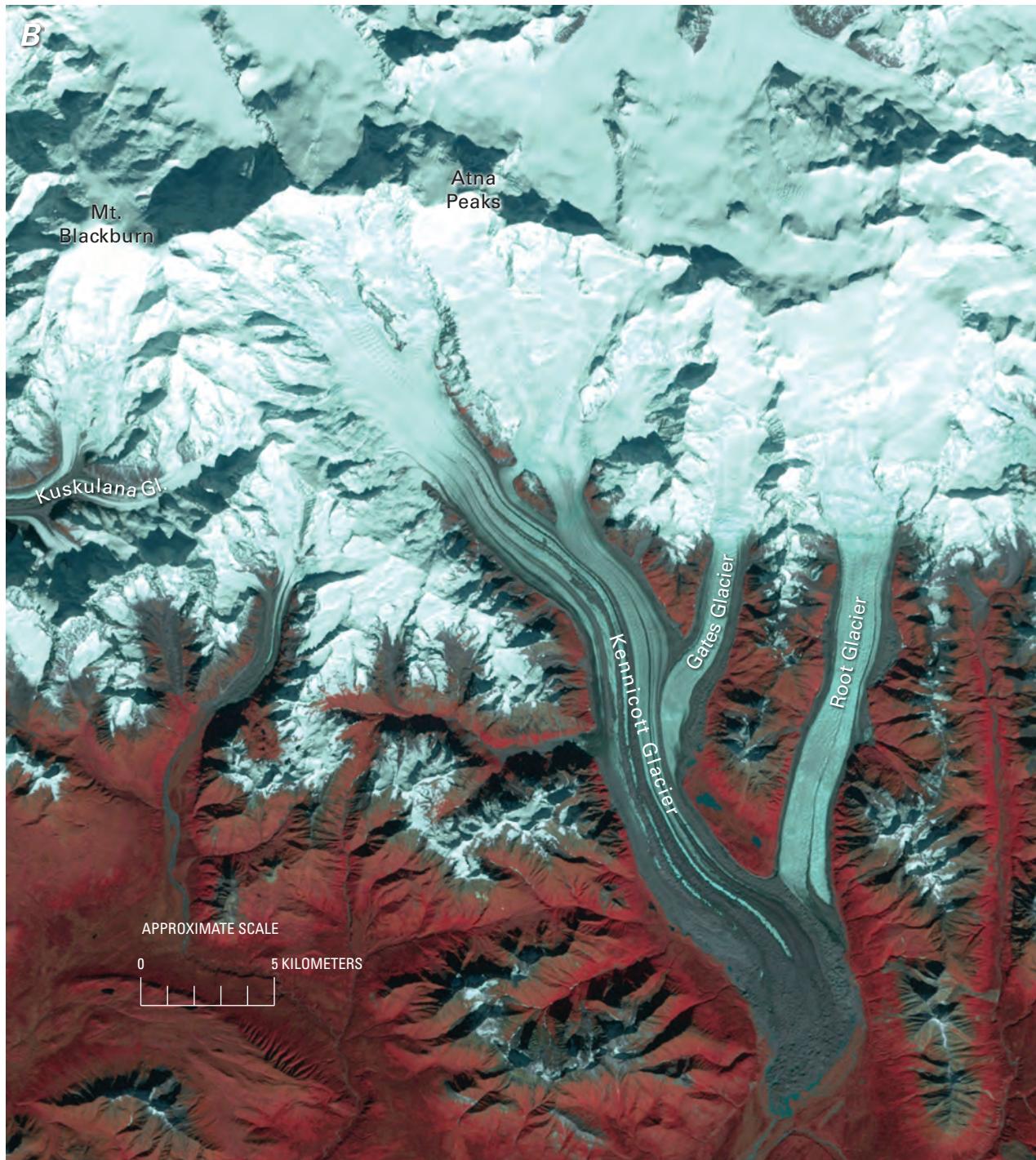
### Kennicott Glacier

Kennicott Glacier (figs. 367A–D), which is 44 km long and 551 km<sup>2</sup> in area (Denton and Field, 1975c, p. 562), is the second largest in the Wrangell Mountains. It heads on the eastern side of Mount Blackburn but also receives ice from a 10-km-long ridge capped with Rime Peak, the Atna Peaks, and Parka Peak. Its primary eastern tributaries, Root Glacier and Gates Glacier, descend from the southern flanks of Regal Mountain. Much of the glacier's surface is debris-covered and has been since at least 1900 (1905 Capps photographs, USGS Photo Library photograph Capps 123, 124, and 125; 1919 Moffit photograph, USGS Photo Library photograph Moffit 826).

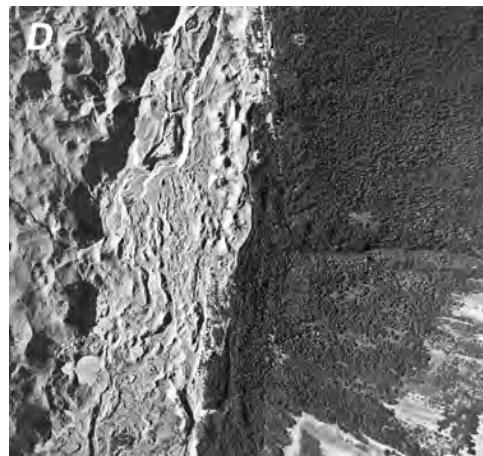
As early as the end of the first decade of the 20th century, questions were being asked about whether the glacier was stagnant. After visiting the glacier in 1910, Reid (1913a) wrote that the glacier was stagnant and inactive, as it had been since before 1899. Two years later, he repeated his assertion, stating

**Figure 367.**—Map, Landsat image, and aerial photographs of the Kennicott Glacier.  
A, Section of the USGS McCarthy, Alaska (1960, revised 1981) 1:250,000-scale map showing the Kennicott Glacier and its tributaries. B–D, see following page.





**Figure 367-B.** Enlarged section of annotated Landsat 7 ETM+ false-color composite image of the Kennicott Glacier area. Landsat 7 image (LE7064017000125350; 10 September 2001; Path 64, Row 17) from the USGS, EROS Data Center, Sioux Falls, S. Dak. **C** and **D**, see opposite page.



**▲ Figure 367.—C,** 30 August 2000 north-looking oblique aerial photograph of the head of Kennicott Glacier with Rime Peak, the Atna Peaks, and Parka Peak. Elevated lateral moraines and vegetation growing on the eastern margin document continued thinning of the glacier. Photograph by Bruce F. Molnia, U.S. Geological Survey. **D,** 30 August 1999 black-and-white vertical aerial photograph of part of the eastern margin of Kennicott Glacier showing a marginal sediment zone, possibly with some ice-core remaining and a pitted, hummocky ice-cored moraine zone with several water-filled thermokarst pits. Photograph from U.S. Bureau of Land Management, roll 3, frame 14. A larger version of D is available online.



**Figure 368.—**A 1919 photograph by F.H. Moffit of a small unnamed glacier located at the head of Rock Creek, a tributary to the Kotsina River. Located on the flanks of an unnamed 2,332-m peak, this glacier, the southwesternmost glacier in the Wrangell Mountains, shows several signs of thinning and retreat. The glacier is typical of small cirque and mountain glaciers that originate from isolated accumulation areas southwest of Mount Blackburn. Photograph Moffit 644 from the USGS Photo Library, Denver, Colo.

that Kennicott Glacier was unchanged from 1911 to 1912 (Reid, 1913b). In September 1918, Bateman (1922) placed a line of stakes on the surface of the glacier at a location about 6.5 km above the terminus. Upon returning the following year, he determined that the stakes had moved as much as 25 m in the ensuing 374 days, a confirmation that very slow motion was taking place.

When Bradford Washburn photographed Kennicott Glacier in 1937 and 1938, the terminus had retreated several hundred meters (Denton and Field, 1975c). Little net change had occurred when it was next photographed by Post in 1964 (Denton and Field, 1975c). When the author observed it from the air on 30 August 2000 (fig. 367C), its upper region showed evidence of thinning.

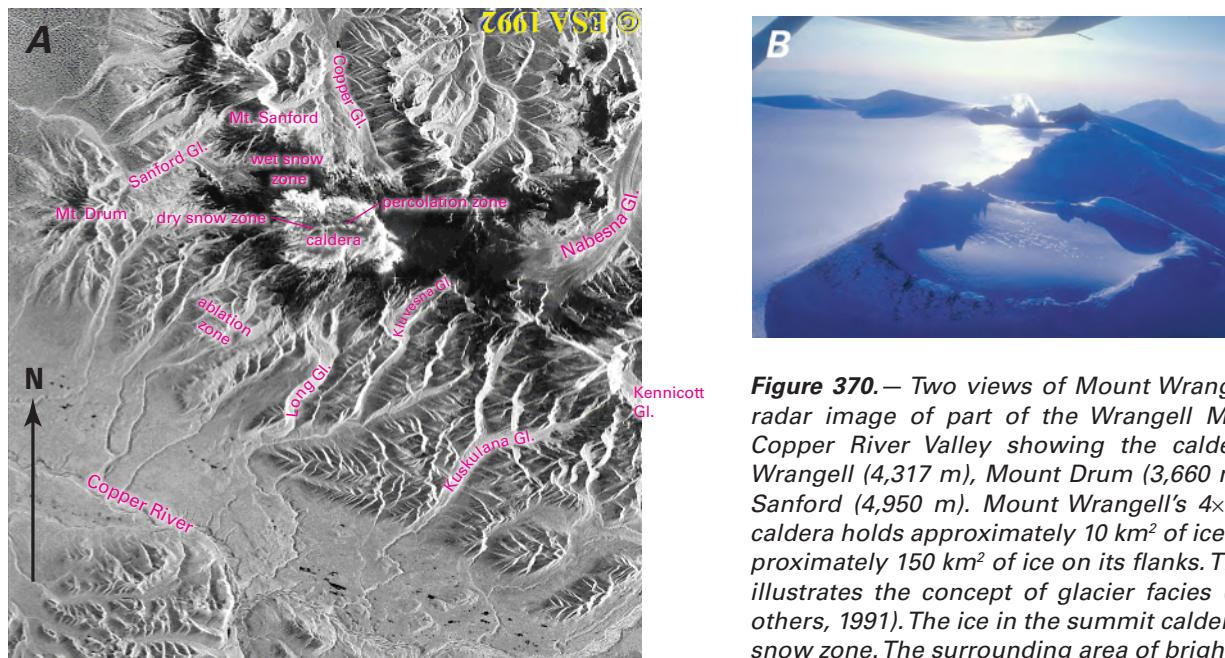


The apparently stagnant Kuskulana Glacier, its southern half covered by moraine, is 25 km long and has an area of 156 km<sup>2</sup> (Denton and Field, 1975c, p. 563) (fig. 369). Little information could be found about changes in Kuskulana Glacier. Denton and Field (1975c) stated that the glacier changed little from the late 1930s to the late 1950s. They attributed a lateral barren zone, seen in photographs made by Bradford Washburn in 1937 and 1938, to recent surface lowering. It is very apparent in several early 1980s photographs of the junction of the eastern and northeastern tributaries of the glacier that the surface lowering of the stagnant terminus continued during the Landsat baseline period. When the author observed it from the air on 30 August 2000, no evidence of terminus advance or glacier thickening could be seen. Kuskulana Glacier is difficult to discern in its entirety on Landsat 7 ETM+ false-color composite images because supraglacier morainic debris masks the underlying ice.

**Figure 369.**—31 August 1984 oblique aerial photograph of the junction of the northeast tributary of the Kuskulana Glacier and the main trunk of the glacier. Elevated lateral moraines and thinning tributaries document recent thinning of the glacier. Photograph 84-R3-032 by Robert M. Krimmel, U.S. Geological Survey.

## Glaciers of Mount Wrangell

Mount Wrangell, the youngest and only currently active volcano in the Wrangell Mountains, is a large andesitic shield volcano with a volume of about  $900 \text{ km}^3$  (Nye, 1983) (fig. 370A) (1902 Brooks photograph, USGS Photo Library photograph Brooks 1111). Nearly all of the mountain is covered by glacier ice and perennial snow. Its glaciers drain into both the Copper River and Yukon River drainages. Its top is capped by a  $4 \times 6 \text{ km}$  ice-filled summit caldera (fig. 370B), the depth of which approaches 1 km (Benson and Motyka, 1978; Clarke and others, 1989). Three craters are located along its northern rim, (from west to east): Mount Wrangell Crater, North Crater, and East Crater. Studies by Benson and others (1975), Benson and Motyka (1975, 1978), Benson and others (1985), and Benson and Follett (1986) showed that the volume of ice in the North Crater has decreased significantly since studies began during the IGY. Between 1957 and 1984, the crater's ice thinned significantly, and its surface elevation decreased by nearly 200 m. Between 1965 and 1976, about  $3.2 \times 10^7 \text{ m}^3$  of ice was lost to melting and evaporation. In the 20 years between 1965 and 1984, about 85 percent of the crater's ice disappeared. An increase in heat flux, a result of the 27 March 1964 Alaskan earthquake, is thought to be responsible for the crater's ice loss. To account for the ice lost between 1965 and 1976, an average volcanic heat flux of  $62 \text{ W m}^{-2}$ —approximately 1,400 times Earth's average heat flux—is required. Elsewhere in the summit caldera, little change has been noted in the surface elevation of the caldera's ice cover.



**Figure 370.**—Two views of Mount Wrangell. **A**, Digital radar image of part of the Wrangell Mountains and Copper River Valley showing the caldera of Mount Wrangell (4,317 m), Mount Drum (3,660 m) and Mount Sanford (4,950 m). Mount Wrangell's  $4 \times 6 \text{ km}$  summit caldera holds approximately  $10 \text{ km}^2$  of ice. There are approximately  $150 \text{ km}^2$  of ice on its flanks. This scene also illustrates the concept of glacier facies (Williams and others, 1991). The ice in the summit caldera is in the dry snow zone. The surrounding area of bright tone is probably the percolation zone, where melt features such as ice lenses, layers, and pipes contribute to the stronger backscatter. Beyond the percolation zone is the wet snow zone with a dark tone caused by low backscatter from the wet surface. Below the wet snow zone is the ablation zone, illustrated by the many glaciers flowing away from Mount Wrangell, particularly Nubesna Glacier at the upper right of the scene. Copyright for this image rests with the European Space Agency (ESA). Printed with permission. Caption modified from the Alaska Science Facility (ASF). **B**, 1981 oblique aerial photograph of a part of Mount Wrangell's ice-filled caldera. Photograph by Roman Motyka, Alaska Division of Geological and Geophysical Surveys. From Neal and McGimsey (1996). A larger version of B is available online.

## Glaciers Descending from Mount Wrangell's Summit Caldera

More than a dozen glaciers radiate from Mount Wrangell's summit. Starting from the southeasternmost and moving in a clockwise direction, Denton and Field (1975c, p. 563–564, 566) determined the following lengths and areas: Kluvesina Glacier (22 km, 71 km<sup>2</sup>); Long Glacier, which originates within the caldera of Mount Wrangell (fig. 371) (39 km, 121 km<sup>2</sup>); Cheshnina Glacier (14 km, 28 km<sup>2</sup>); *East Chetaslina Glacier*; Chetaslina Glacier (17 km, 60 km<sup>2</sup>); *East Fork Glacier* (16 km, 43 km<sup>2</sup>); Chichokna Glacier; Dadina Glacier (18 km, 32 km<sup>2</sup>); *Betseli Glacier*; *North Mackeith Glacier*; *Center Mackeith Glacier*; *South Mackeith Glacier*; *Athna Glacier* (26 August 1981 AHAP false-color infrared vertical aerial photograph no. L99F4733); and Copper Glacier (29 km, 172 km<sup>2</sup>).

Seasonal studies (Sturm, 1995) and photogrammetric investigations (Sturm and others, 1991) show that the 30-km-long *Athna Glacier* and the smaller *South* and *Center Mackeith Glaciers* have been advancing from 5 to 18 m a<sup>-1</sup> since the onset of increased heat flux following the 1964 earthquake. All of Mount Wrangell's other outlet glaciers have remained stationary or retreated. Sturm stated that the advancing glaciers display little seasonal variation in surface velocity, whereas other glaciers, such as *East Chetaslina Glacier* and *West Chetaslina Glacier*, experience a 50-percent increase in surface velocity in spring and summer. These glaciers have a common accumulation zone located around North Crater.

Analysis of 1957 photography of Copper Glacier (Denton and Field, 1975c) show that it is fronted by two sets of moraines that are located about 5 and 7 km in front of the terminus. Identified as not more than a few hundred years old, the more distant of the two moraines may represent Copper Glacier's "Little Ice Age" maximum position.

Northward-flowing Nabesna Glacier (fig. 372A–E) (1916 Capps photograph, USGS Photo Library photograph Capps 5) originates high on the southeastern slopes of the ice field that covers the summit area of Mount Wrangell and also receives ice from the northwestern slopes of Mount Regal. Nabesna is the largest of Mount Wrangell's outlet glaciers and the largest in the Wrangell Mountains. It is about 87 km long and 819 km<sup>2</sup> in area (Denton and Field, 1975c, p. 566) and has as many as 40 tributaries. Capps first visited Nabesna's terminus in 1908, at which time the first 3 km of the glacier were covered by thick debris. Capps (1910a, p. 40) stated that "The extent of the terminal moraine shows that the glacier is at present retreating. It has been deposited so recently that over most of it no vegetation has as yet obtained a foothold....."

Denton and Field (1975c) analyzed available photography to determine the mass balance of Nabesna Glacier. They stated that a 1938 photograph by Bradford Washburn indicated slow shrinkage of the lower part of the glacier and some withdrawal from the terminal moraine. They also indicated that other photographs obtained in 1957 and 1964 showed a continuation of this trend. An early 1980s photograph by D.H. Richter (Winkler, 2000, fig. 4) showed that thinning of the glacier at elevations above 2,250 m had exposed several nunataks. When the author observed the terminus from the air on 30 August 2000 (fig. 372E), he noted a number of characteristics suggesting that it is actively retreating and thinning.

East of Nabesna Glacier and northwest of the terminus of Chisana Glacier in the drainage of Cross Creek is an area of small named and unnamed retreating glaciers (26 August 1981 AHAP false-color infrared vertical aerial photograph no. L99F4720). One unnamed glacier located at the head of Ramshole Creek has retreated more than 3 km from its "Little Ice Age" maximum position. The next glacier to the west, another unnamed glacier, has retreated approximately 1.7 km from its "Little Ice Age" maximum position. Many smaller glaciers in the vicinity have completely disappeared.



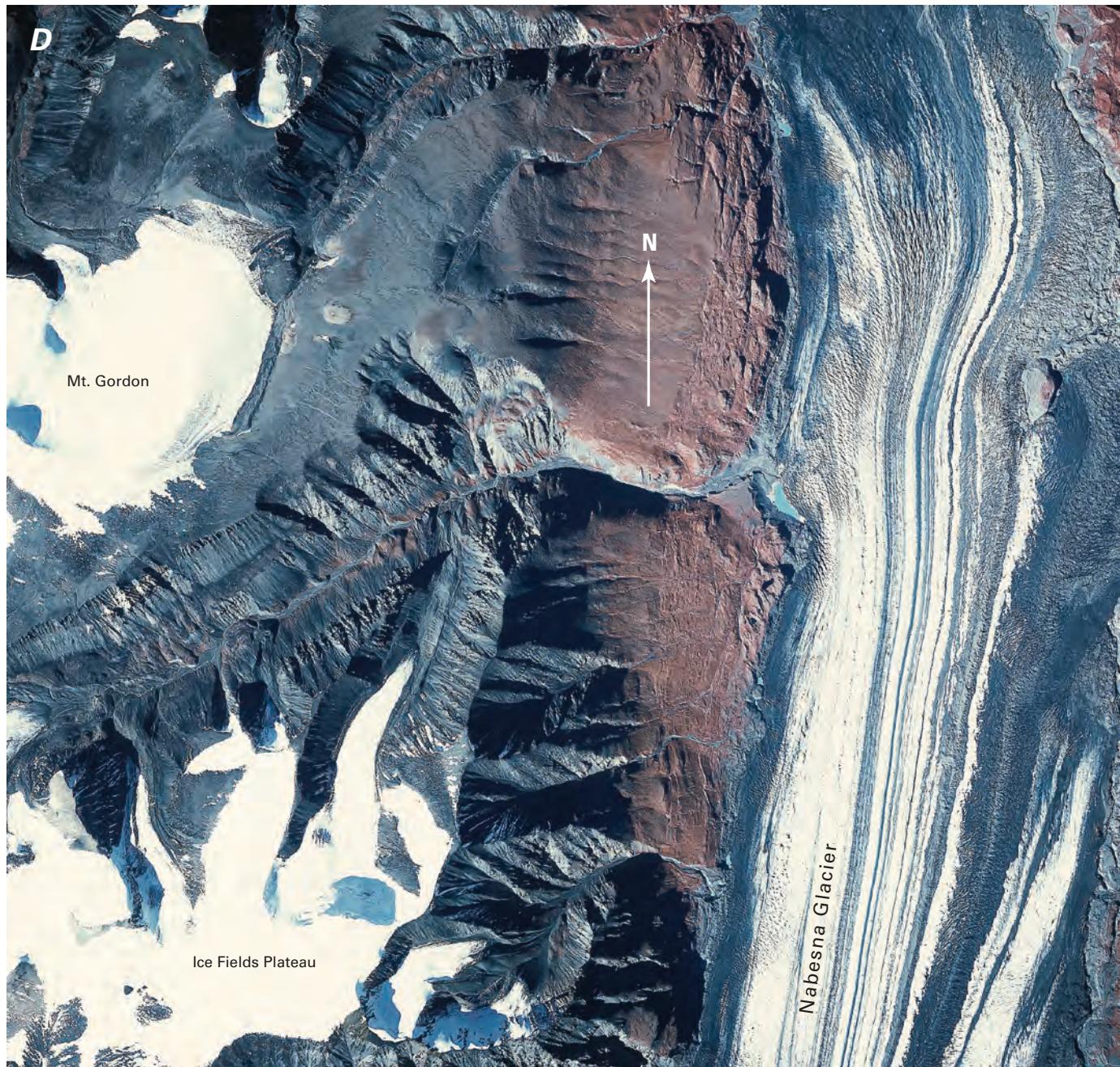
**Figure 371.**—30 August 2000 oblique aerial photograph of the pitted, partially vegetation-covered, hummocky terminus of Long Glacier. The terminus has retreated several kilometers during the second half of the 20th century. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.

**Figure 372.**—Views of Nabesna Glacier. A, Sections of USGS 1:250,000-scale maps of Nabesna, Alaska (1960, revised 1982) and McCarthy, Alaska (1960, revised 1981) mosaicked to show Nabesna Glacier, the Icefields Plateau, and Mount Gordon. B–E, see following pages.



**Figure 372.**—B, Part of the topographic reconnaissance map of the central Copper River region, Alaska, a 1:250,000-scale map based on field topographic surveys conducted prior to 1902 showing the larger outlet glaciers of the eastern Wrangell Mountains. Published as Plate Number XX in USGS Professional Paper 41 (Mendenhall, 1905). C, Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) false-color composite image showing the same general area. It is remarkable that the 1902 map of such a remote area, using ground-based surveying techniques compares favorably to the depiction of the glaciers on the Landsat 7 ETM+ image. Landsat image (7064017000125350; 10 September 2001; Path 64, Row 17) from the USGS, EROS Data Center, Sioux Falls, S. Dak. A larger version of B is available online.





**Figure 372.**—D, 26 August 1981 AHAP vertical, false-color aerial photograph of part of the northern Nabesna Glacier, just south of its terminus. Evidence of thinning exists along both margins. Also visible are the Icefields Plateau and Mount Gordon; both show evidence of recent retreat. AHAP photograph no. L99F4725 from the GeoData Center, Geophysical Institute, University of Alaska, Fairbanks, Alaska. E, 30 August 2000 southeast-looking oblique aerial photograph showing the retreating and thinning terminus of Nabesna Glacier. An ice-marginal lake has developed on the eastern side of the margin through the retreat of the terminus. Photograph by Bruce F. Molnia, U.S. Geological Survey.



## Mount Drum

Mount Drum (fig. 373A, B) (26 August 1981 AHAP false-color infrared vertical aerial photograph no. L99F4740), a glacier-capped stratovolcano, is the westernmost volcano in the Wrangell Mountains. Its last eruption was between 125,000 and 150,000 years ago (Richter and others, 1995). Eleven outlet glaciers with lengths of 3 to 16 km descend from the perennial ice field that covers the mountain at elevations above 2,400 m. Nadina Glacier, the only named glacier, is the largest, having a length of 16 km and an area of 25 km<sup>2</sup> (Denton and Field, 1975c, p. 564). At elevations below about 1,000 m, its stagnant terminus is covered by vegetation, including mature spruce trees. When observed from the air by the author on 9 July 1999 and 31 August 2000 (fig. 373B), all of the outlet glaciers showed signs of stagnation, thinning, or retreat.

## Mount Sanford

A complex shield volcano, Mount Sanford is the second highest peak in the Wrangell Mountains and is covered by a perennial ice and snow cover at elevations above 2,400 m. Last active at least 100,000 years ago, it possesses some of the steepest topography in North America. The upper reaches of Sanford Glacier descend about 2.5 km in a distance of only about 1.5 km. On its southern side, ice flowing from Mount Sanford merges with ice descending from the northern side of Mount Wrangell.

Ten glaciers (4 formally named) having lengths of 8 to 27 km descend from the summit of Mount Sanford. The largest, Sanford Glacier, is debris-covered and has a length of 27 km and an area of 199 km<sup>2</sup> (Denton and Field, 1975c, p. 564) (fig. 374) (26 August 1981 AHAP false-color infrared vertical aerial photograph no. L99F4737). A comparison of the position of the glacier as mapped in 1902 by Mendenhall and Gerdine (Mendenhall, 1905) and the position seen on Bradford Washburn's 1938 photograph, shows Sanford Glacier extending about 3 km further to the north on the earlier map and connected to two tributaries originating on Mount Drum. Denton and Field (1975b) questioned the reliability of the earlier map.

The three other named glaciers include Sheep Glacier (1908 Capps photograph, USGS Photo Library photograph Capps 544), with a length of 9 km and an area of 9 km<sup>2</sup> (Denton and Field, 1975c, p. 565); Drop Glacier, with a length of 24 km and an area of 55 km<sup>2</sup> (Denton and Field, 1975c, p. 565); and West Glacier with a length of 18 km and an area of 39 km<sup>2</sup> (Denton and Field, 1975c, p. 565). These glaciers and all of the other unnamed glaciers that descend from Mount Sanford showed signs of stagnation, thinning, or retreat when the author observed them from the air on 31 August 2000.

## Glaciers of Mount Jarvis and Mount Gordon and the Ice Fields Plateau

Mount Jarvis, a shield volcano, is the 2,852-m-high summit of an 8-km-long ice-covered ridge located east of Copper Glacier. Three large glaciers and several smaller ones flow eastward from the ridge. The largest, Jacksina Glacier, has a length of 19 km and an area of 72 km<sup>2</sup> (Denton and Field, 1975c, p. 566). When the author observed them from the air on 31 August 2000, all of the Jarvis ridge glaciers showed signs of stagnation, thinning, or retreat.

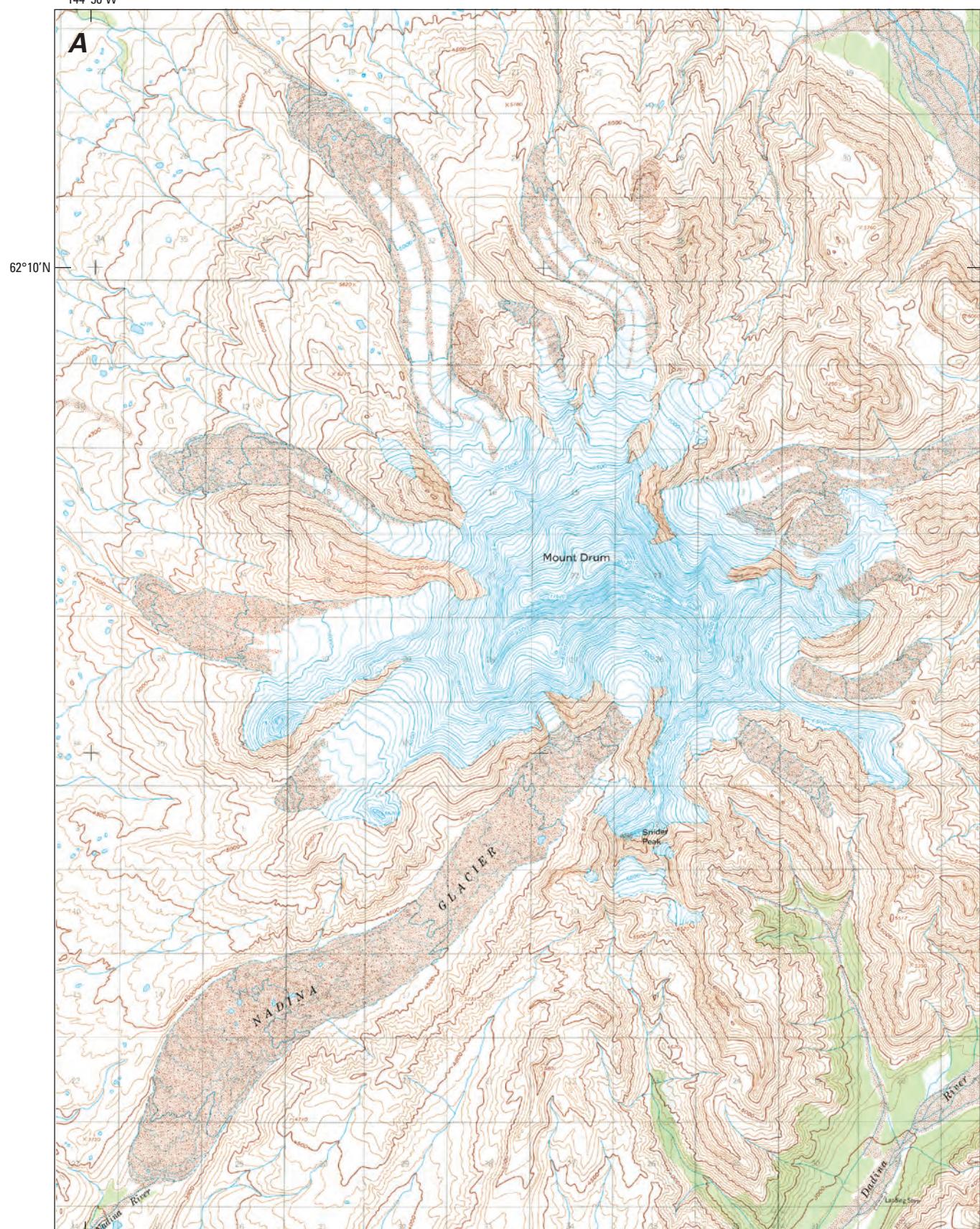
Less than a million years old, Mount Gordon is a 2,755-m-high cinder cone with its summit almost completely covered by ice. When it was photographed by the AHAP Program on 26 August 1981, a few very small outlet glaciers descended from the crater. An ice-free cirque on its northern flank suggests that there has been a recent loss of glacier ice from the mountain's flanks.

The Icefields Plateau is a 13.5×7.5-km ice-covered upland located south of Mount Gordon, between Jacksina Glacier and Nabesna Glacier. With a surface elevation of about 2,500 m, it supports about 10 small outlet glaciers. When they were photographed by the AHAP Program on 26 August 1981, all of the glaciers showed signs of stagnation, thinning, or retreat.

► **Figure 373.**—Map and aerial photograph of the glaciers of Mount Drum. A, Section of the USGS Gulkana, Alaska A-2, 1:63,360 topographic map (1959), based on 1955 and 1957 photography, showing all of the glaciers that descend from Mount Drum. B, see following page.

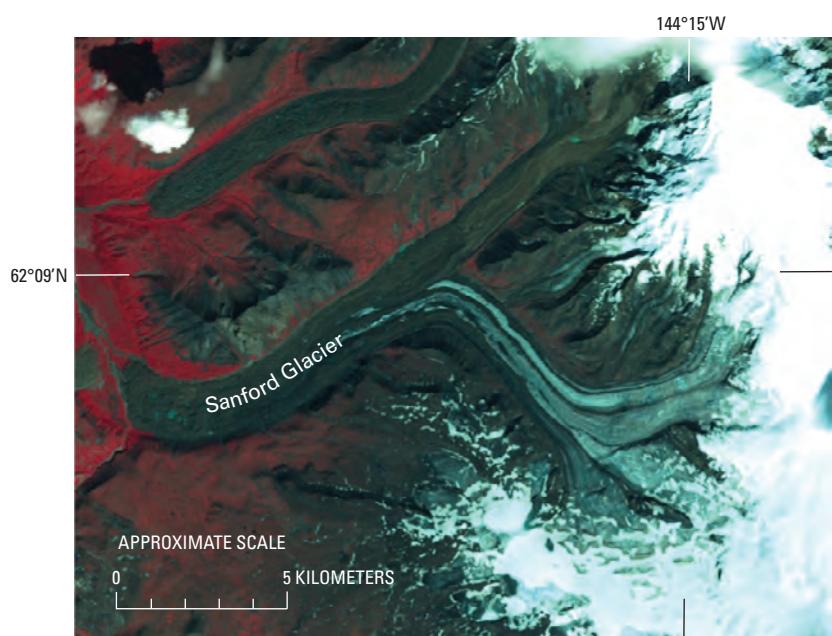
144°50'W

A



1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 11000 12000 13000 14000 15000 16000 17000 18000 19000 20000 FEET  
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 KILOMETERS

CONTOUR INTERVAL 100 FEET  
DOTTED LINES REPRESENT 50 FOOT CONTOURS  
DATUM IS MEAN SEA LEVEL



**Figure 374.**—Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) false-color composite image of Sanford Glacier. The glacier descends from Mount Sanford on the northeast and Mount Wrangell on the southeast. Landsat image (7064017000125350; 10 September 2001; Path 64, Row 17) from the USGS, EROS Data Center, Sioux Falls, S. Dak.

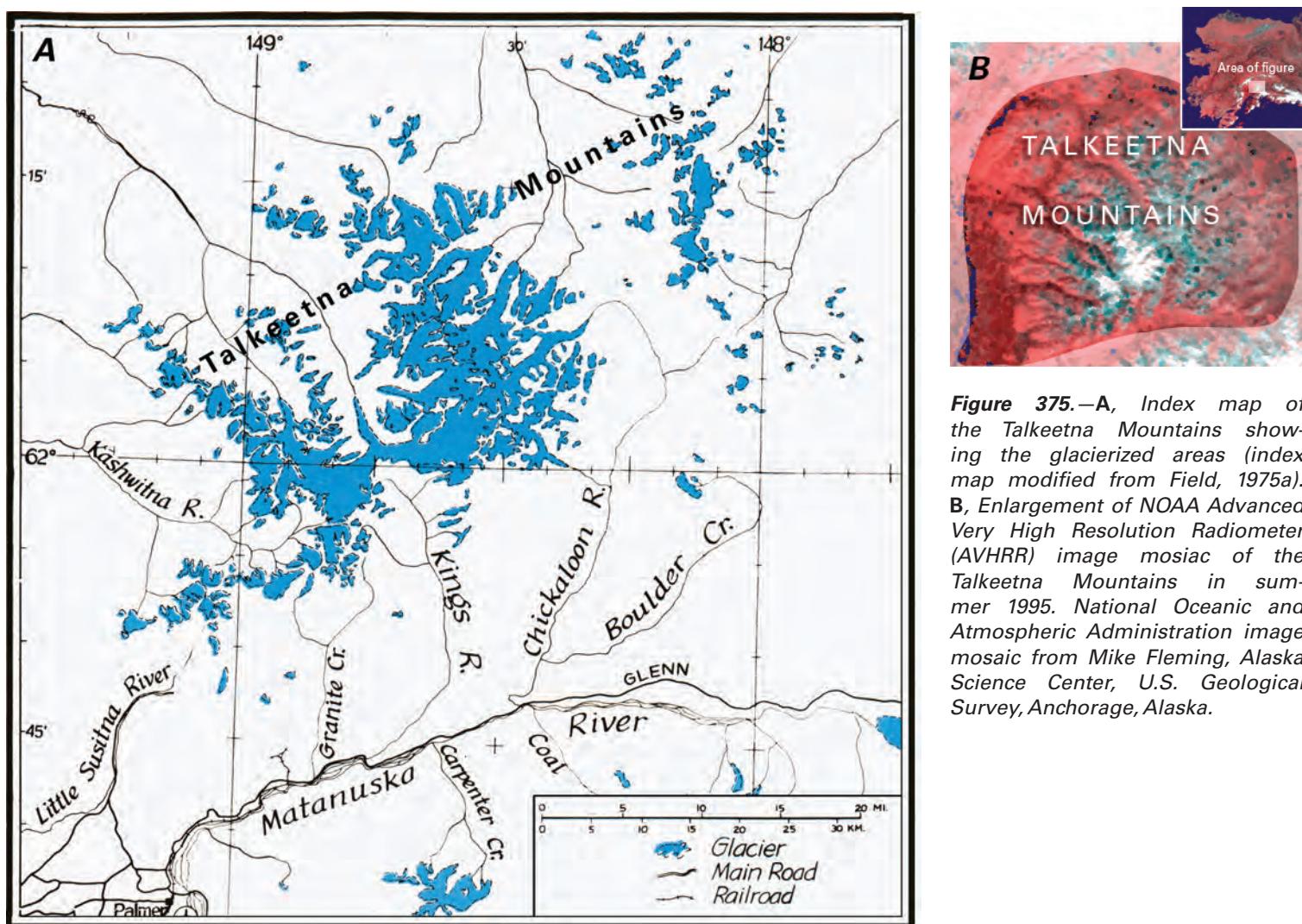
## Summary

During the period of the Landsat baseline (1972–81), all of the valley and outlet glaciers within the Wrangell Mountains were retreating, thinning, or stagnant, with the exception of *Athna Glacier* and *South and Center MacKeith Glaciers*, which were advancing.

Through the end of the 20th century and into the 21st century, no additional information was available about the continued advance of *Athna Glacier* and *South and Center MacKeith Glaciers*. All other valley and outlet glaciers in the Wrangell Mountains continued to thin, retreat, or stagnate.

## Talkeetna Mountains

The Talkeetna Mountains are named for the Talkeetna River, which means “river of plenty” in the language of the Tanaina Indians (Collins, 1975, p. 543). The long axis of the 160×130-km Talkeetna Mountains is oriented north-south (figs. 1, 375). The mountains are bounded on the north by the Nenana River and Broad Pass, on the east by the Susitna and Tyone Rivers, on the west by the Chulitna and Susitna Rivers, and on the south by the Matanuska River. Many peaks have summit elevations greater than 2,000 m; the highest, an unnamed peak, reaches an elevation of 2,550 m.

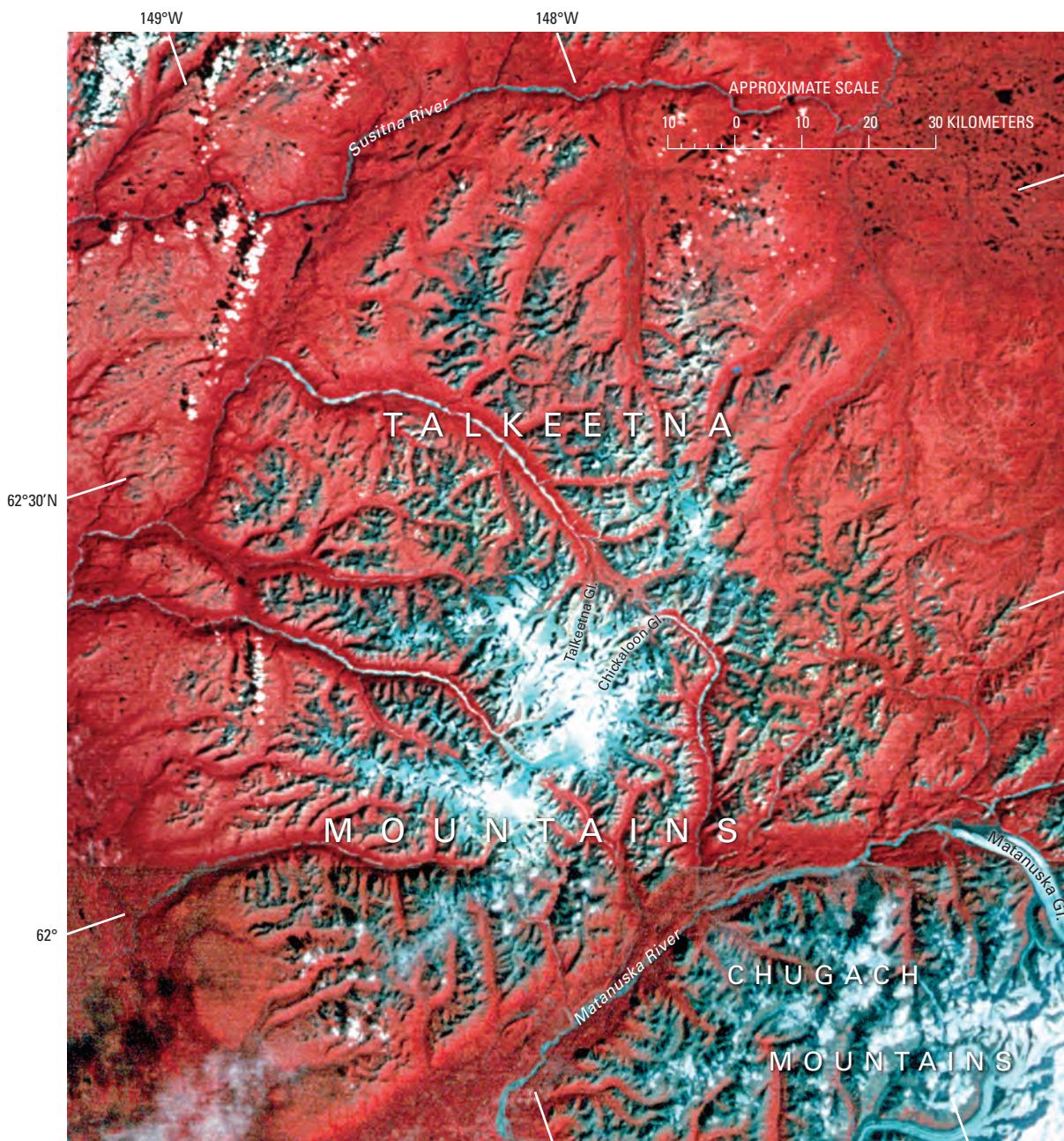


**Figure 375.**—A, Index map of the Talkeetna Mountains showing the glacierized areas (index map modified from Field, 1975a). B, Enlargement of NOAA Advanced Very High Resolution Radiometer (AVHRR) image mosaic of the Talkeetna Mountains in summer 1995. National Oceanic and Atmospheric Administration image mosaic from Mike Fleming, Alaska Science Center, U.S. Geological Survey, Anchorage, Alaska.

Landsat MSS images that include the glacier-covered Talkeetna Mountains have the following Path/Row coordinates: 74/16, 74/17, and 75/16 (figs. 3, 376; table 1). The southwestern part of the Talkeetna Mountains is shown on a 1:250,000-scale satellite image map of the Anchorage quadrangle made from 4 September 1980 Landsat 3 MSS data (USGS, 1980). The glacier-covered part of the Talkeetna Mountains is mapped on the Anchorage (1962) and Talkeetna Mountains (1954) USGS 1:250,000-scale topographic maps of Alaska (appendix A).

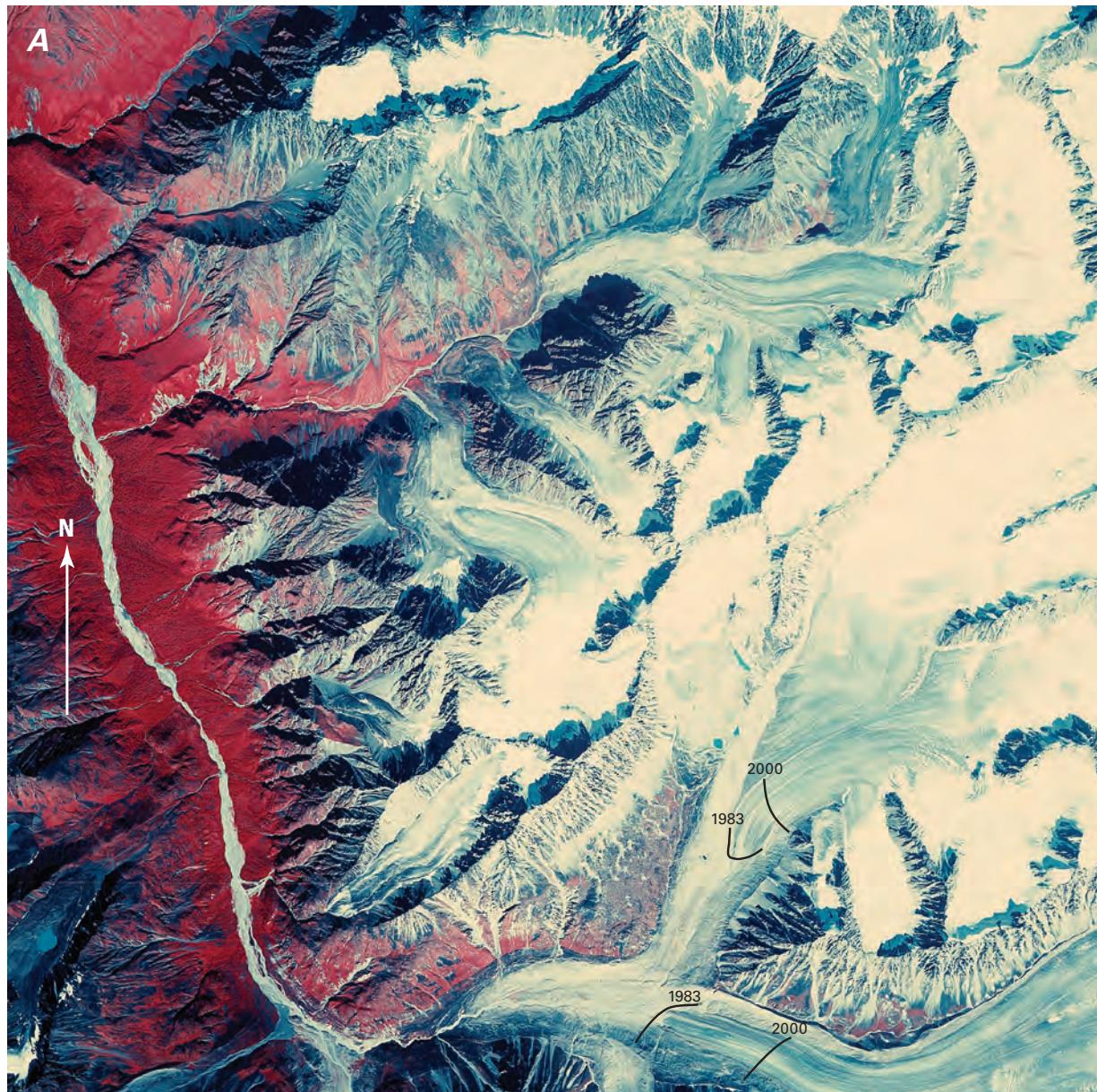
Photographs of glaciers in the Talkeetna Mountains taken by Capps between 1913 and 1917 show many retreating glaciers (9 August 1917 Capps photograph, USGS Photo Library photograph Capps 435; summer 1913 Capps photograph, USGS Photo Library photograph Capps 876). This trend has continued through the early 21st century. Comparing Capps' photographs with aerial observations, shows that one unnamed glacier at the head of Iron Creek retreated approximately 4 km between August 1917 and August 2000. Collins (1945, p. 544) stated that "It can reasonably be deduced that general recession has been the rule here in recent decades, and that

**Figure 376.**—Annotated Landsat 3 MSS false-color composite image mosaic showing the Talkeetna Mountains and part of the northern Chugach Mountains. Shown are the locations of Chickaloon and Talkeetna Glaciers in the Talkeetna Mountains; and Matanuska Glacier in the Chugach Mountains. Landsat images (30175-20342, bands 4, 5, 7; 27 August 1978; Path 74, Row 16 and 2531-20322, bands 4, 5, 7; 9 September 1979; Path 74, Row 17) are from the USGS, EROS Data Center, Sioux Falls, S. Dak.



climatic changes have caused a significant rise in the lower limit at which accumulation can take place. At present this lower limit of accumulation seems to be generally higher than 1850 m."

When the area was mapped between 1951 and 1954, more than 100 glaciers were located on the southwestern flank of the mountains, generally heading at elevations above 1,800 m. Seven had lengths of more than 8 km. The longest, an unnamed glacier located above the headwaters of the northwest-flowing Sheep River, had a length of 17.7 km, and an area of 77 km<sup>2</sup> (Collins, 1975, p. 546); it has retreated since it was last mapped (fig. 377). Both Chickaloon Glacier, which is 14.5 km long and 33 km<sup>2</sup> in area (Collins, 1975, p. 546) (fig. 378), and Talkeetna Glacier, which is 11.6 km long and

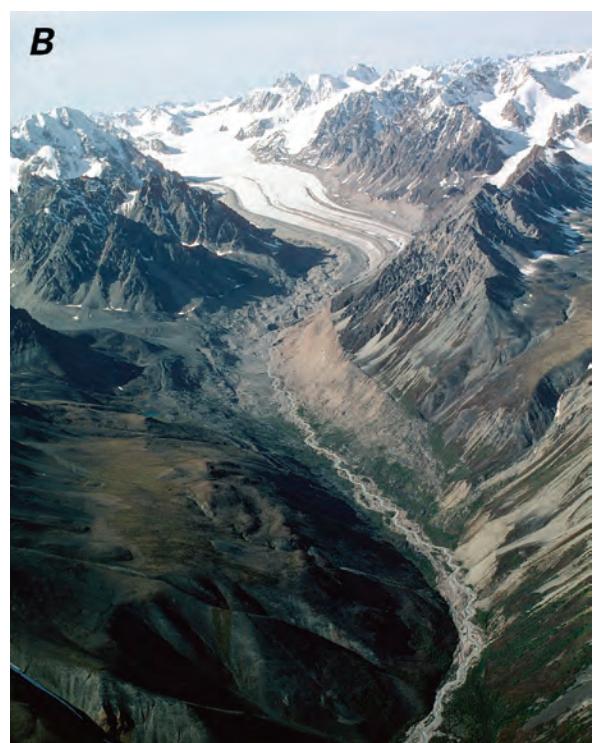


**Figure 377.**—Two photographs of glaciers at the head of the Sheep River. This area contains the largest concentration of glacier ice in the Talkeetna Mountains. **A**, 3 August 1983 AHAP false-color infrared vertical aerial photograph of the area showing a number of retreating glaciers. All of the unnamed glaciers have their margins surrounded by combinations of stagnant ice, unvegetated ground moraine, elevated trimlines, or relict lateral and medial moraines, all evidence of retreat, thinning, or stagnation. When mapped

in 1954, the ice margin of the unnamed glacier at the southern edge of the photograph, longest in the area, sat about 2 km further downvalley. The area between the two terminus positions is covered by stagnant ice and ice-cored moraine. The locations of the debris-free ice margin in 1983 and 2000 are shown. The 2000 termini positions are based on photographs by the author. AHAP photograph no. L99F5175 from the GeoData Center, Geophysical Institute, University of Alaska, Fairbanks, Alaska. **B**, see following page.



**Figure 377.—B,** 31 August 2000 east-looking oblique aerial photograph of the long unnamed glacier described in A. Now separated into two distinct ice tongues, the glacier retreated more than 3 km during the 20th century. Photograph by Bruce F. Molnia, U.S. Geological Survey.



**Figure 378.**—Two photographs of Chickaloon Glacier and its surrounding area. **A**, Annotated 3 August 1983 AHAP false-color infrared vertical aerial photograph of the area showing the retreating Chickaloon Glacier and a number of retreating glaciers located in a small drainage basin to the north. All of the unnamed glaciers in the photograph north of Chickaloon Glacier have their margins surrounded by combinations of stagnant ice, unvegetated ground moraine, elevated trim-lines, or relict lateral and medial moraines, all evidence of retreat, thinning, or stagnation. When mapped in 1954, the

ice margin of Chickaloon Glacier was located approximately 3 km downvalley from its 1983 position. The tributary glaciers south of Chickaloon Glacier also show evidence of retreat, thinning, or stagnation. AHAP photograph no. L99F5172 from the GeoData Center, Geophysical Institute, University of Alaska, Fairbanks, Alaska. **B**, 31 August 2000 west-looking oblique aerial photograph of Chickaloon Glacier and its valley. Chickaloon Glacier retreated more than 5 km during the 20th century. Photograph by Bruce F. Molnia, U.S. Geological Survey.



**▲ Figure 379.**—A 31 August 2000 oblique aerial photograph of Talkeetna Glacier and its surrounding area. The view is northeast, downglacier, of the lower approximately 5 km of the glacier. Elevated trimlines, relict lateral and medial moraines, the low gradient, and generally featureless surface are all evidence of rapid retreat and thinning. Photograph by Bruce F. Molnia, U.S. Geological Survey. A larger version of this figure is available online.



**Figure 380.**—31 August 2000 oblique aerial photograph of several large rock glaciers located south of Talkeetna Glacier. Many are located at the foot of cirques or on the flanks of glacier valleys. Also note the thick end-and-ground-moraine complex left by the retreat of the unnamed valley glacier in the valley to the left of the cirque. Photograph by Bruce F. Molnia, U.S. Geological Survey.

32 km<sup>2</sup> in area (Collins, 1975, p. 546) (fig. 379), had retreating termini that were covered with thick ablation moraines. Recent observations made by the author suggest that these long glaciers have lost as much as 5 km of their lengths since 1951–54.

McCauley (1958) made planimetric measurements of all of the glaciers in the Talkeetna Mountains, using USGS 1:63,360-scale topographic maps prepared between 1948 and 1958. She calculated that the total glacierized area was about 300 km<sup>2</sup>. The seven largest glaciers had a cumulative area of 212 km<sup>2</sup>, accounting for approximately two-thirds of the total area. These seven glaciers had termini elevations at between 1,460 and 885 m. Recent observations made by the author show that every one of these glaciers has retreated, some more than 3 km; it is estimated that the Talkeetna Mountains have lost as much as 15 percent of its glacier cover since 1948–58. However, Post and Meier (1980, p. 45) reported the total area of glaciers in the Talkeetna Mountains at 800 km<sup>2</sup>.

Limited revisions made in 1983 by the USGS to the 1954 Talkeetna Mountains 1:250,000-scale topographic map (appendix A) were based on aerial photography obtained in 1978, 1980, and 1981. These revisions showed that at least 50 glaciers east of the Talkeetna and Chickaloon Rivers either decreased significantly in area or melted completely away. Similarly, almost all of the large glaciers west of the two rivers show retreat and shrinkage.

A survey of the glacierized Talkeetna Mountains made by the author from the air on 31 August 2000 documented that glaciers descending below an elevation of about 1,500 m were conspicuously thinning and retreating. Several large glaciers had retreated to the point that primary lobes had separated into several distinct tributary glaciers. On the southern and southwestern sides of the mountains, many of the cirques and valleys were ice free. Many glacier-free cirques and valleys hosted large lobate rock glaciers (fig. 380).

## Summary

During the period of the Landsat baseline (1972–81), all available evidence suggests that the glaciers of the Talkeetna Mountains were thinning and retreating. These conclusions are based on a comparison of the size and number of glaciers shown on topographic maps made from data acquired between 1948 and 1952 with AHAP photography from the middle of the baseline period (1977) and just after the baseline interval (1983). When they were observed at the end of the 20th century, every glacier examined showed significant evidence of thinning and retreat, and many smaller glaciers had completely disappeared.