Glaciers Along Proposed Routes Extending The Copper River Highway, Alaska

By Roy L. Glass

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BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
GORDON P. EATON, Director

For additional information write to:

District Chief
U.S. Geological Survey
4230 University Drive, Suite 201
Anchorage, AK 99508-4664

Copies of this report may be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre-foot (acre-ft)	1,233	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
cubic yard (yd^3)	0.7646	cubic meter
foot per second (ft/s)	0.3048	meter per second
foot per day (ft/d)	0.3048	meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
mile per hour (mi/h)	1.609	kilometer per hour

Sea level:

In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)-- a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Note:

In this report the term "mile" refers to the distance along the Copper River and Northwestern Railway alignment starting at Cordova and "milepost" refers to a distance along a road. The milepost distances for the Copper River Highway start at Cordova. The Million Dollar Bridge is at mile 49 of the railway alignment and is at milepost 48 of the Copper River Highway, reflecting a shortening of the route by 1 mile. The milepost distances for the Richardson Highway start at the old town of Valdez.

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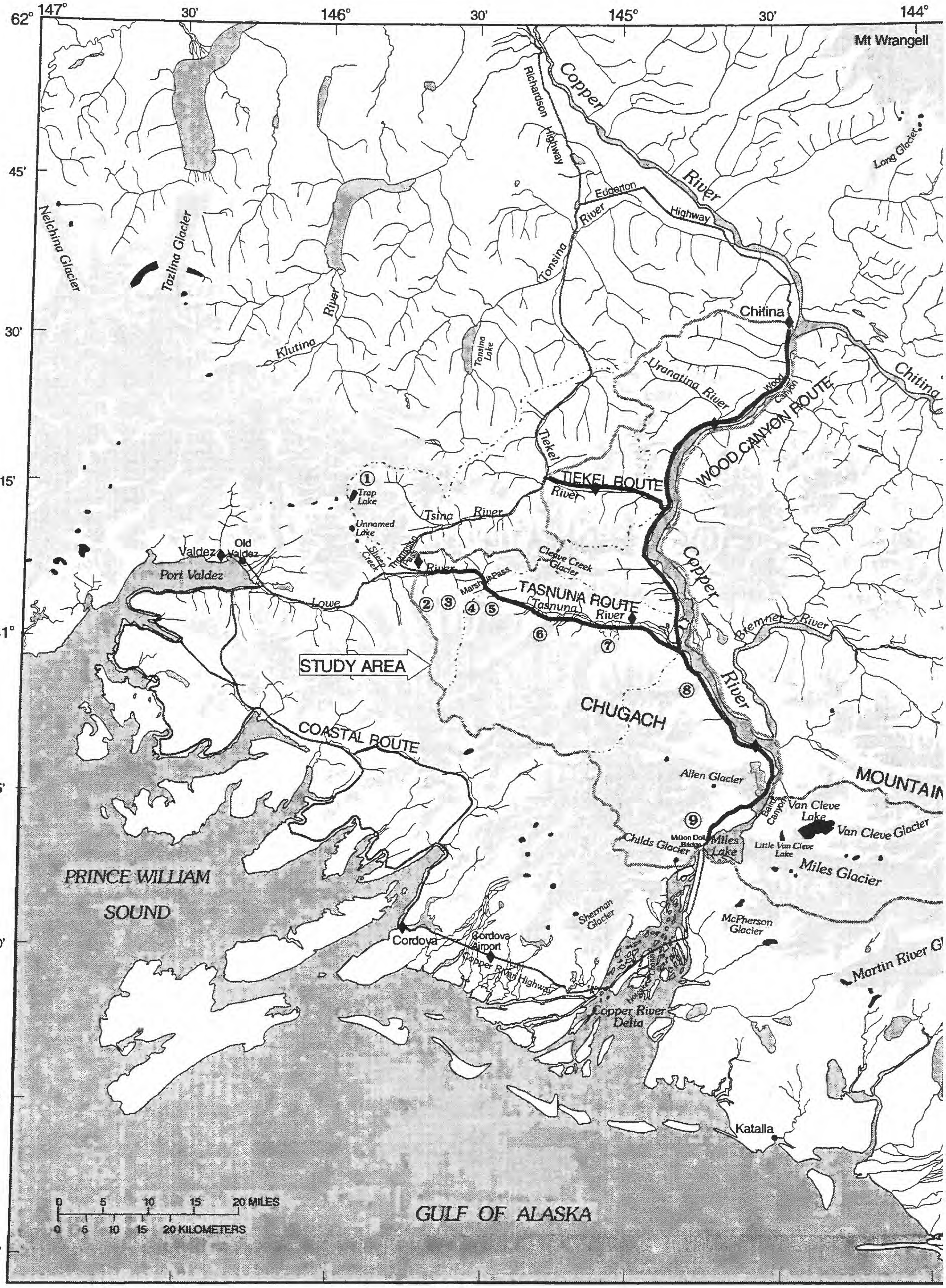
ABSTRACT

Three inland highway routes are being considered by the Alaska Department of Transportation and Public Facilities to connect the community of Cordova in southcentral Alaska to a statewide road system. The routes use part of a Copper River and Northwest Railway alignment along the Copper River through mountainous terrain having numerous glaciers. An advance of any of several glaciers could block and destroy the roadway, whereas retreating glaciers expose large quantities of unconsolidated, unvegetated, and commonly ice-rich sediments. The purpose of this study was to map historical locations of glacier termini near these routes and to describe hazards associated with glaciers and seasonal snow. Historical and recent locations of glacier termini along the proposed Copper River Highway routes were determined by reviewing reports and maps and by interpreting aerial photographs.

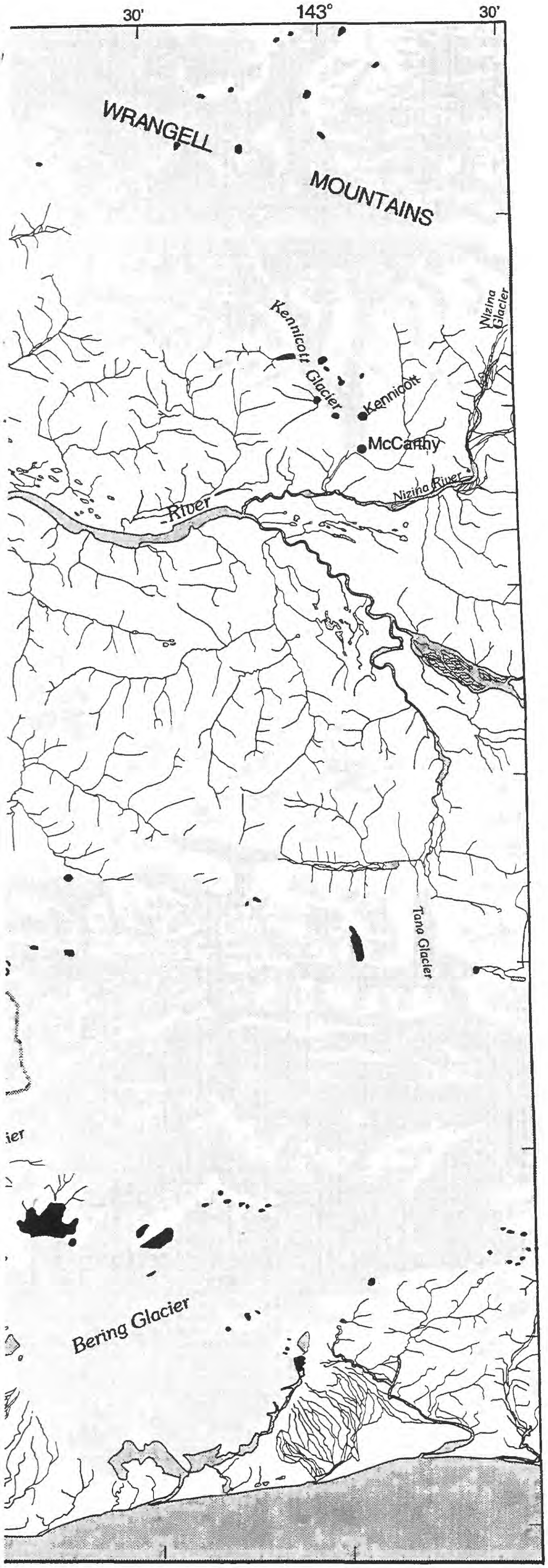
The termini of Childs, Grinnell, Tasnuna, and Woodworth Glaciers were 1 mile or less from a proposed route in the most recently available aerial photography (1978-91); the termini of Allen, Heney, and Schwan Glaciers were 1.5 miles or less from a proposed route. In general, since 1911, most glaciers have slowly retreated, but many glaciers have had occasional advances. Deserted Glacier and one of its tributary glaciers have surge-type medial moraines, indicating potential rapid advances. The terminus of Deserted Glacier was about 2.1 miles from a proposed route in 1978, but showed no evidence of surging. Snow and rock avalanches and snowdrifts are common along the proposed routes and will periodically obstruct the roadway. Floods from ice-dammed lakes also pose a threat. For example, Van Cleve Lake, adjacent to Miles Glacier, is as large as 4.4 square miles and empties about every 6 years. Floods from drainages of Van Cleve Lake have caused the Copper River to rise on the order of 20 feet at Million Dollar Bridge.

INTRODUCTION

In August 1992, under a cooperative water resources agreement with the State of Alaska Department of Transportation and Public Facilities, the U.S. Geological Survey began a reconnaissance study of glaciers along three proposed Copper River Highway routes in southcentral Alaska (fig. 1). The objectives of the study were to map historical locations of glacier termini and to describe glacier and seasonal snow-related hazards along these three routes. Historical positions of glacier termini near the routes were delineated using aerial photographs, maps, and reports, but were not field checked or ground surveyed. Glaciers and hazards along the existing Copper River Highway from Cordova to the Copper River Delta and along a proposed coastal route are not included in this study.



Base modified from U.S. Geological Survey, Valdez and McCarthy, Alaska, 1:250,000, 1960, Cordova and Bering Glacier, Alaska, 1:250,000, 1959.



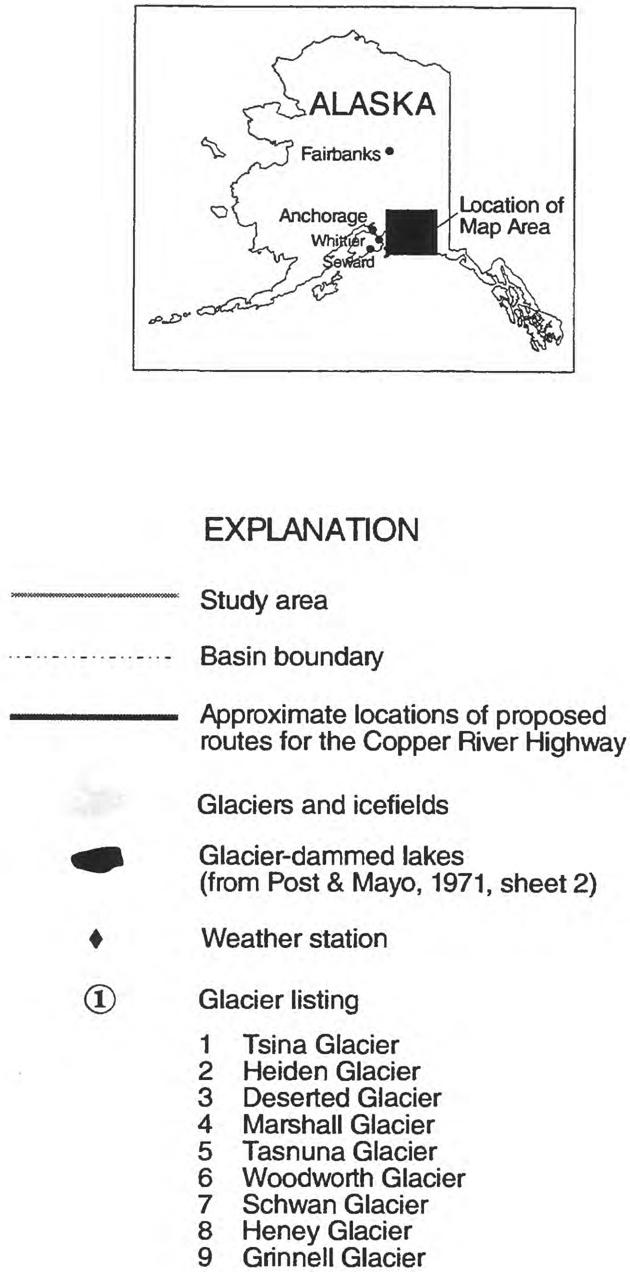


Figure 1. Location of Copper River, Alaska, proposed highway routes, and glacier-dammed lakes.

Description of Area

Cordova (fig. 1) is a community of about 2,600 people on the southeast side of Prince William Sound. Commercial fishing, government activities, and tourism are the area's major economic bases. The community is connected to the statewide road system only by the Alaska State Ferry System, and so must rely on water and air for transport of goods and people. The town was once the ocean shipping port for copper ore transported by railroad from the Kennecott mines near McCarthy in the Wrangell Mountains, about 112 mi northeast of Cordova.

The Chugach Mountains in southcentral Alaska are rugged and contain the highest concentration of glaciers in the State. Glaciers cover about 8,200 mi^2 in the mountains. The study area (fig. 1) is in the central and eastern parts of the Chugach Mountains where peaks rise to altitudes greater than 7,000 ft above sea level. Several glaciers in the study area are more than 10 mi long and have areas of more than 30 mi^2 (table 1). The study area is limited to drainage areas adjacent to the three proposed inland highway routes in the Tiekel, Lowe, Tasnuna, and Copper River valleys.

The Lowe River flows westward into Port Valdez, whereas the Tiekel and Tasnuna Rivers flow eastward into the Copper River below Wood Canyon. The Copper River basin covers an area of approximately 24,000 mi^2, of which about 20,600 mi^2 are upstream from Wood Canyon, a constriction about 6 mi downstream from Chitina. The valley of the Copper River below Wood Canyon, the lower two-thirds of the Tasnuna River valley, and about a mile-long section of the Tiekel River valley near its mouth generally have broad valley floors of glacial and fluvial silt, sand, and gravel. These valley floors are bordered by steep rocky mountain slopes that rise 4,000 to 5,000 ft. In Wood Canyon, in the upper one-third of the Tasnuna River valley, and throughout most of the Tiekel and Lowe River valleys, the rivers are cut into bedrock and have narrow valley floors. Marshall Pass separates the Lowe and Tasnuna River valleys.

Climate

The climate within the study area varies widely because of large altitude ranges. Climate data are collected at Chitina, Cordova, Cordova Airport, and Valdez (fig. 1) and are published monthly by National Oceanic and Atmospheric Administration. Climate data for Thompson Pass are available for 1952-74. Temperature and precipitation data for these weather stations are summarized intermittently by Alaska Environmental Information and Data Center (Leslie, 1989). Mean monthly precipitation and snowfall data are shown in table 2 for weather stations at Chitina, Cordova, Cordova Airport, Thompson Pass, and Valdez.

A generalized mean annual precipitation map (fig. 2) developed by Charles B. Fahl, Alaska Pacific University, Anchorage, Alaska, shows the areal distribution of precipitation over the study area for 1951-80 (Jones and Fahl, 1994). The coastal communities of Cordova and Valdez have much more rain, warmer winters, and cooler summers than areas north of the Chugach Mountains. The average annual precipitation for Cordova is more than 170 in., whereas Chitina receives slightly less than 12 in. Coastal areas of the Chugach Mountains west of Copper River commonly receive more than 200 in. of precipitation annually. Although precipitation may fall as rain for much of the year at sea level, the moist warm air cools as it rises up the steep mountains and drops enormous quantities of snow on seaward-facing slopes. At Thompson Pass, 2,500 ft above sea level, the mean annual snowfall is 540 in. or 45 ft (Leslie, 1989). More snow falls at higher altitudes

Table 1. Information on selected glaciers in the Chugach Mountains near the Copper River, Alaska

Glacier name	Drainage	Length[1] (miles)	Area[1] (square miles)	Altitude of terminus[1] (feet)	Approximate distance from terminus to proposed highway route (miles)	Map reference (USGS 1:63,360)	Source for terminus positions[2]
Deserted	Lowe River	11	14	1,700-1,800	2.1	Valdez A-5 (Terminus) Cordova D-5	August 1950--B&W, M384, 180 August 1978--CIR, 2664, 7306
Heiden	Lowe River	3.5	1.5	3,300	3.1	Valdez A-5	August 1950--B&W, M384, 180 August 1978--CIR, 2664, 7307
Marshall	Tasnuna River	5	4	2,100-2,200	2.0	Valdez A-5 (Terminus) Valdez A-4	August 1950--B&W, M384, 130 August 1978--CIR, 2664, 7305
Tasnuna	Tasnuna River	8	12	1,000-1,100	1.0	Valdez A-4 (Terminus) Cordova D-4, D-5	August 1950--B&W, M384, 130 August 1978--CIR, 2664, 7305
Woodworth	Tasnuna River	14	71	400-500	1.0	Valdez A-4 (Terminus) Cordova D-4, D-5	August 1950--B&W, M384, 65 August 1978--CIR, 2664, 7292
Schwan	Tasnuna River	14	55	300-400	1.5	Valdez A-3 (Terminus) Cordova D-3, D-4	August 1950--B&W, M384, 1 July 1978--CIR, 2630, 6221 August 1978--CIR, 2654, 7293
Cleave Creek	Copper River	6	12	1,000	6.1	Valdez A-3 (Terminus) Valdez A-4	August 1950--B&W, M384, 5 July 1978--CIR, 2630, 6218 August 1978--CIR, 2664, 7302
Heney	Copper River	12	28	200-300	1.5	Cordova D-3	1910--Tarr and Martin (1914, pl. CLXXVIII) August 1950--B&W, M372, 91 August 1978--CIR, 2657, 6225
Allen	Copper River	19	89	200-300	1.3	Cordova D-2 (Terminus) Cordova D-3 Cordova C-3	1910--Tarr and Martin (1914, map 9) 1913 and 1931--Wentworth and Ray (1936, fig.15, p. 922) August 1950--B&W, M372, 71 1961 to 1965--Post (1967, p. D22) July 1982--B&W, 3093,1499 July 1982--CIR, 3092, 9310 July 1985--CIR, 3481, 54
Miles	Miles Lake Copper River	32	100	100-200	4.0	Cordova C-2 (Terminus) Bering Glacier	1908--Tarr and Martin (1914, fig. 65, p. 431) 1910--Tarr and Martin (1914, map 9) 1931--Wentworth and Ray (1936, fig. 18, p. 928) August 1950--B&W, M372, 74 August 1950--B&W, M345, 88 August 1978--CIR, 2657, 6156 July 1982--B&W, 3482, 1552 August 1985--CIR, 3481, 51

Table 1. Information on selected glaciers in the Chugach Mountains near the Copper River, Alaska--Continued

Glacier name	Drainage	Length[1] (miles)	Area[1] (square miles)	Altitude of terminus[1] (feet)	Approximate distance from terminus to proposed highway route (miles)	Map reference (USGS 1:63,360)	Source for terminus positions[2]
Grinnell	Copper River	5	4	200-300	1.0	Cordova C-2 (Terminus) Cordova C-3	1910--Tarr and Martin (1914, map 9) 1931--Wentworth and Ray (1936, p. 919) August 1950--B&W, M345, 24 August 1978--CIR, 2657, 6156 July 1982--B&W, 3482, 1552 August 1985--CIR, 3481, 52
Childs	Copper River	12	39	50-360	0.5	Cordova C-3	1909--Tarr and Martin (1914, fig. 59, p. 404) 1910--Tarr and Martin (1914, map 9) 1931--Wentworth and Ray (1936, fig. 16, p. 924) August 1950--B&W, M345, 26 August 1978--CIR, 2657, 6155 July 1982--B&W, 3482, 1552 August 1985--CIR, 3481, 51 August 1991--COLOR, 590, 17

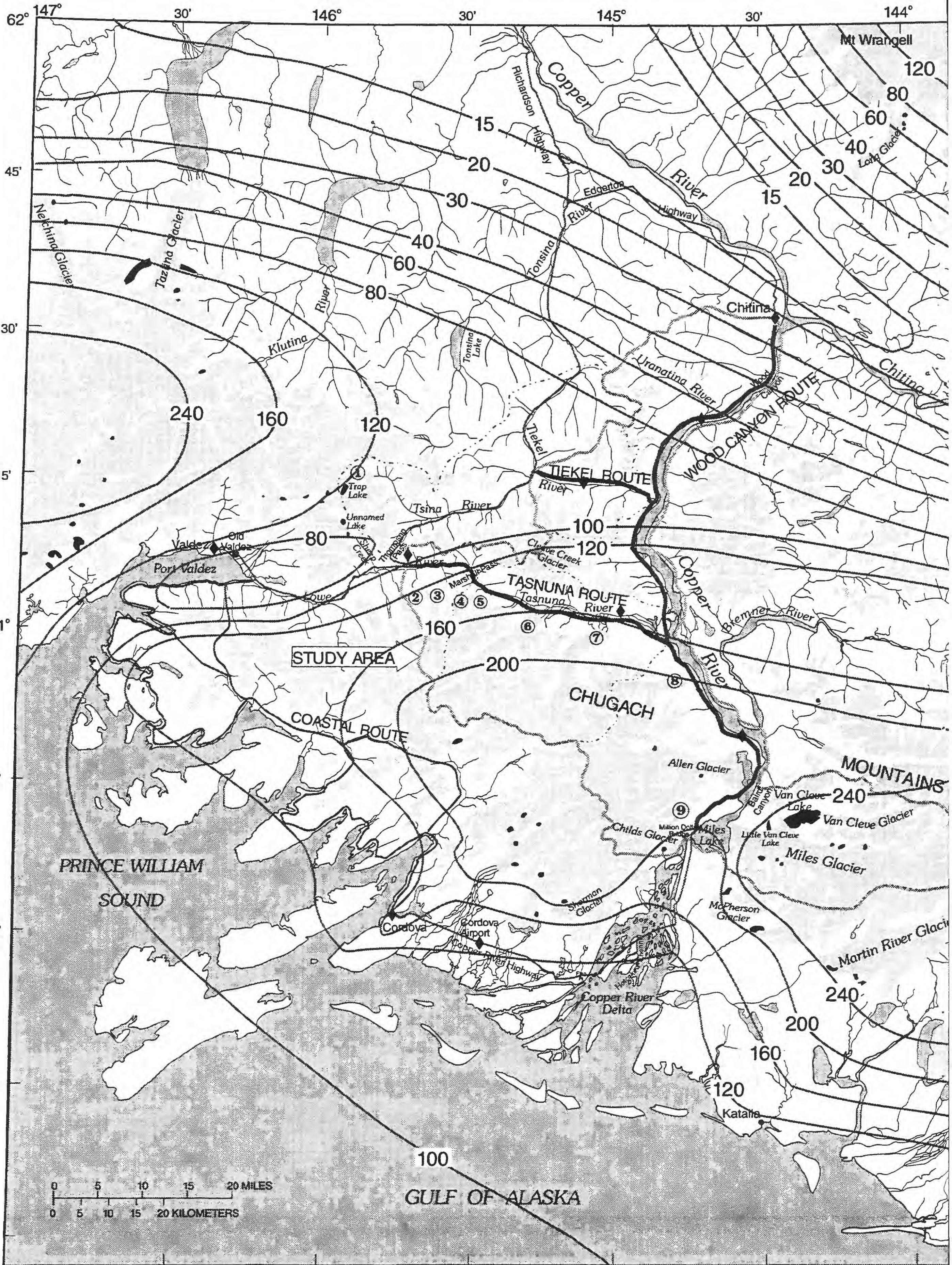
[1]Lengths, areas, and altitudes of termini are based on the glacier extents shown on the maps referenced, generally 1:63,360 scale topographic maps based on 1950 aerial photography

[2]Source for terminus position: Date of position described--cited reference or description of aerial photographic used: B&W, black and white; CIR, color infrared; COLOR, true color; roll number; frame number of photograph. Aerial photographs can be purchased from U.S. Geological Survey, Earth Science Information Center, 4230 University Drive, Suite 101, Anchorage, Alaska 99508-4664.

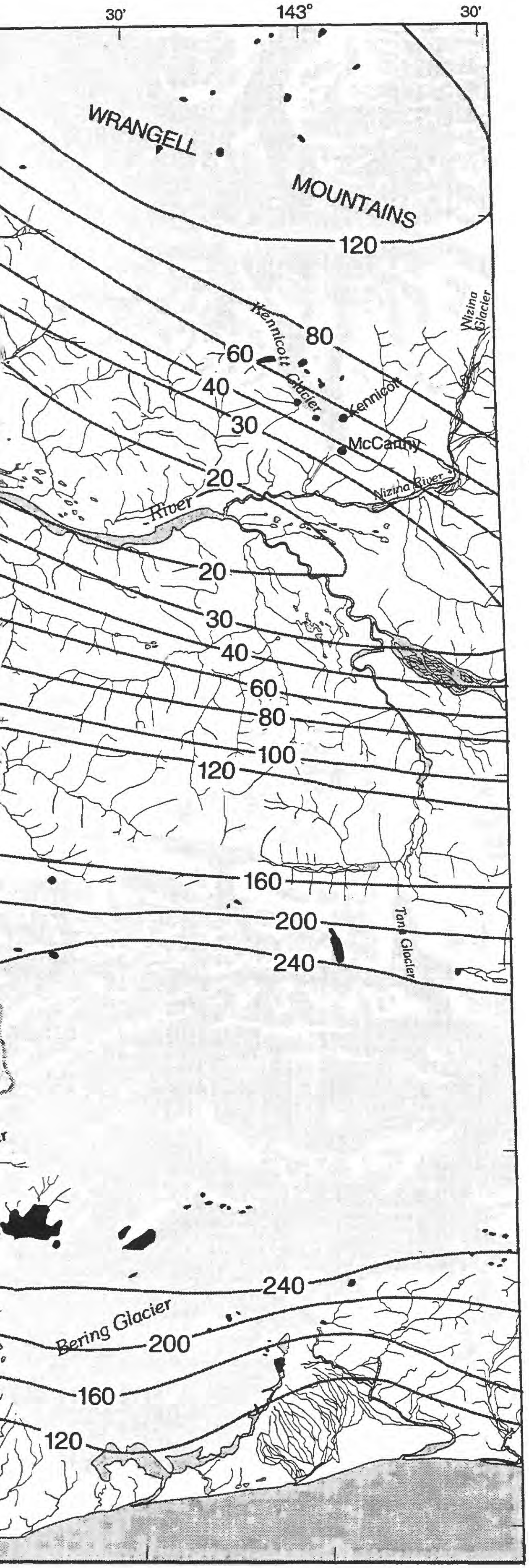
Table 2. Climatological data for selected locations near the proposed Copper River Highway routes

[Data from Leslie, 1989]

Location	Period of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mean precipitation (water equivalent in inches)														
Chitina	1922-71	0.86	0.89	0.38	0.19	0.38	0.58	1.36	1.35	1.65	1.20	1.48	1.47	11.79
Cordova	1955-66 1968-71 1986-87	12.16	9.60	10.53	9.63	16.72	8.56	12.42	13.94	19.99	24.06	18.06	17.73	173.36
Cordova Airport	1949-87	6.09	6.33	5.23	5.33	5.84	5.09	6.39	8.70	12.92	12.71	8.37	7.97	91.05
Thompson Pass	1952-74	6.18	8.41	7.11	6.40	2.02	2.87	3.36	4.14	5.55	10.82	9.84	9.89	76.58
Valdez	1964-69 1971-73 1975-87	5.63	5.08	4.06	2.89	2.74	2.64	3.77	5.73	7.99	8.23	6.09	6.65	61.50
Mean snowfall (inches)														
Chitina	1922-71	9.8	7.7	4.9	0.4	0.0	0.0	0.0	0.0	0.3	2.9	9.1	8.2	43.2
Cordova	1955-66 1968-71 1986-87	14.4	21.0	14.8	9.9	0.0	0.0	0.0	0.0	0.0	2.3	9.0	28.1	99.5
Cordova Airport	1949-87	19.3	22.1	24.6	14.0	1.2	0.0	0.0	0.0	0.0	3.5	11.2	25.9	121.9
Thompson Pass	1952-74	61.9	92.4	65.9	58.1	13.4	0.0	0.0	0.0	8.7	59.4	83.8	97.0	540.5
Valdez	1964-69 1971-73 1975-87	47.3	46.4	48.5	19.1	0.7	0.0	0.0	0.0	0.0	9.5	34.9	62.9	269.2



Base modified from U.S. Geological Survey, Valdez and McCarthy, Alaska, 1:250,000, 1960, Cordova and Bering Glacier, Alaska, 1:250,000, 1959.



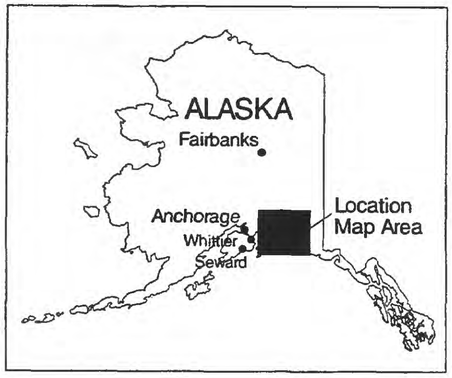


Figure 2. Generalized mean annual precipitation, 1951-80, for the Copper River area. Modified from Jones and Fahl, 1994.

and the mean annual maximum snowpack may be greater than 240 in. over high coastal areas of the Chugach Mountains (Blanchet, 1983, map 6b). This heavy snowfall maintains glaciers in the area, supplies large quantities of water for summer runoff, and helps produce large snow avalanches.

The Copper River valley is windy, as air flows between the north and south sides of the Chugach Mountains. The Alaska Department of Natural Resources has collected wind velocity and direction data at four sites near proposed inland highway routes (fig. 1). Wind data from 36-foot tall wind towers near Uranatina River, Marshall Pass, Allen Glacier, and Tiekel River for July 30 to September 30, 1992 are summarized by Carrick and others (1992). Measurable winds were observed from 89 percent of the time at Allen Glacier to 96 percent of the time at the Tiekel River station. Wind velocities as great as 86 mi/h were observed at Marshall Pass. Average wind velocities ranged from 3.7 mi/h at Uranatina River to 8.1 mi/h at Allen Glacier. In summer, high velocity winds, combined with the abundance of glacial silt and sand on bars of the Copper River, create great dust and sand storms along the Copper River. In winter, strong winds commonly cause snow to drift to great depths.

History of Transportation Routes

Descriptions of early transportation routes, including proposed railway routes can be found in reports by Schrader and Spencer (1901), Mendenhall and Schrader (1903), Mendenhall (1905, p. 91 and map 11), Brooks (1906), Moffit and Maddren (1909, p. 13-18), Johansen (1975), and Janson (1975). Before the Copper River and Northwest Railway (CR&NWR) was completed in 1911, supplies bound for interior Alaska were commonly hauled overland on sleds during winter when the surfaces of rivers and wetlands were frozen. A heavily traveled winter trail led from Valdez up the Lowe River to Marshall Pass, down the Tasnuna River and up the Copper River (fig. 3). Three stern-wheeled steamboats were hauled over this route (in pieces) by horse-drawn sleds before they were assembled and put into service on the Copper and Chitina Rivers.

Numerous competing railway routes were started in a race to bring minerals from the Copper River basin and interior Alaska to seaports at Cordova, Valdez, and Katalla (Janson, 1975). Katalla (fig. 1) had coal for locomotives and smelters, but its harbor is exposed to storms. Two railroad companies began laying track from Katalla, but a series of storms during the fall of 1907 destroyed railroad trestles and breakwaters within the harbor and led to abandonment of this route. Both Valdez and Cordova have deep, protected harbors, but routes from Valdez through Thompson or Marshall Pass are steep, whereas a route from Cordova required a long bridge across the Copper River near two glaciers. Tracks were also laid beginning in both Valdez and Cordova. Eventually, a standard-gauge railroad was completed by the Copper River and Northwestern Railway from Cordova to copper mines near McCarthy in 1911. The railway went from Cordova, across part of the Copper River Delta, followed the Copper River valley to Chitina, and then headed east to McCarthy. The railroad crossed the Copper River three times. A history of the CR&NWR is reported by Johansen (1975) and Janson (1975). The railroad ceased operating in 1938 when the copper mines shut down because the mines were no longer profitable and some of the rails were salvaged for scrap metal during World War II. However, the railroad between Cordova and an airport at mile 13 was used during World War II by the U.S. Army and later by the Civil Aeronautics Administration.

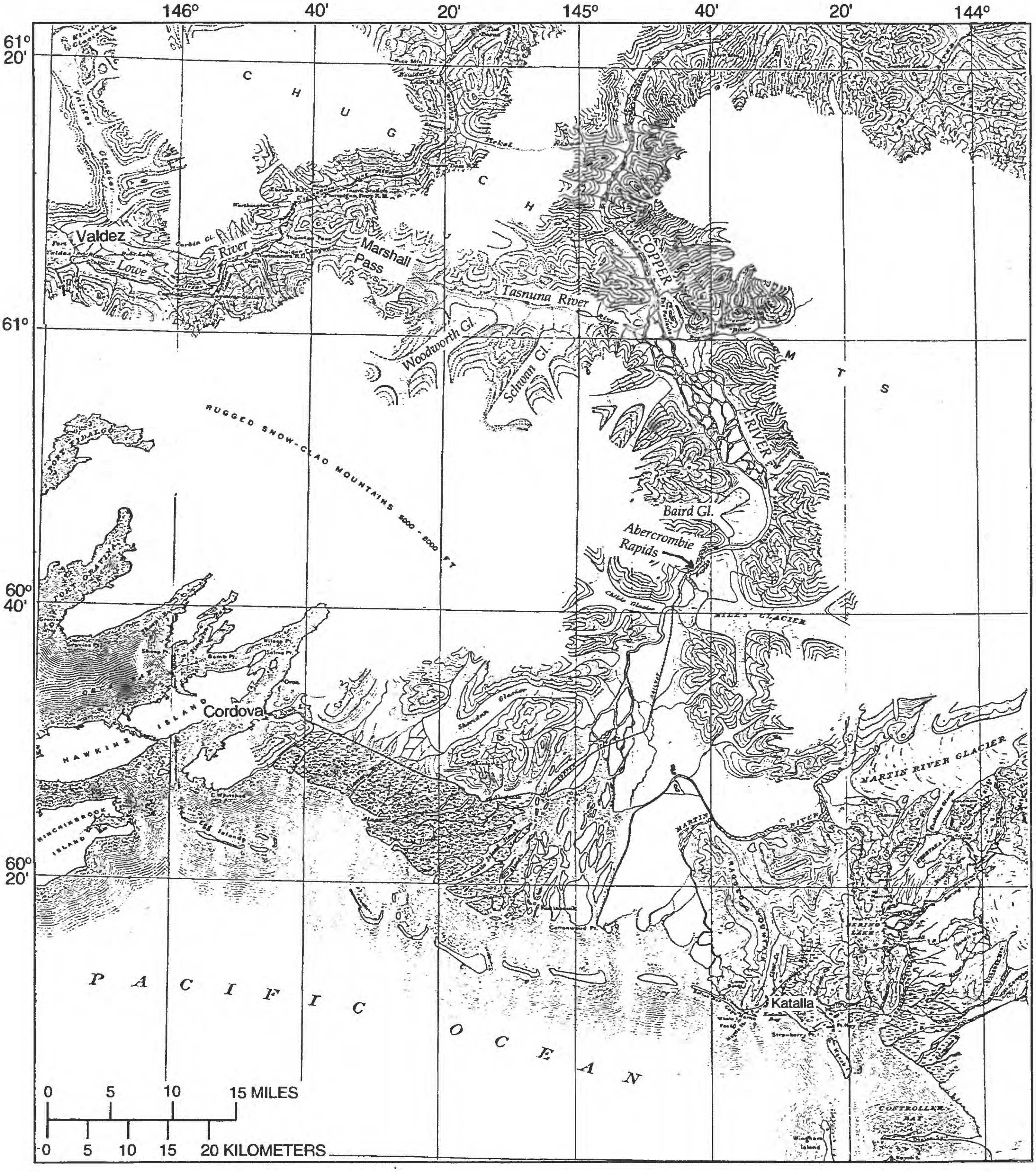


Figure 3. Part of the Chitina quadrangle, Copper River region in 1908. (From Moffit and Maddren, 1909.)

In 1945, the U.S. Forest Service built a road from Cordova to the airport and by 1958 the road had reached Million Dollar Bridge, which crosses Copper River between Miles and Childs Glaciers. On March 27, 1964, an earthquake knocked one end of the north span of the bridge into the river. The bridge was modified to allow vehicles to cross the bridge over an inclined ramp from the undamaged bridge span to the middle of the deck of the fallen span. During summer, the Alaska Department of Transportation and Public Facilities currently (1996) maintains the Copper River Highway from Cordova to the Million Dollar Bridge and from Chitina to about 4 mi south of Chitina. During winter, the highway is maintained only from Cordova to Flag Point, about 23 mi from Cordova.

Proposed Highway Routes

The Alaska Department of Transportation and Public Facilities is studying four alternative routes (fig. 1) to tie Cordova to the statewide interconnected road system (Alaska Department of Highways, 1967 and 1973). One route begins at Cordova and parallels the coast northwestward toward Valdez to join the Richardson Highway near milepost 3. This coastal route, which varies in length from approximately 63 to 165 mi, depending on the extent of tunneling, was not included in this study. The three potential inland routes described below start at Million Dollar Bridge (mile 49) and generally follow the CR&NWR alignment for 33, 52, or 81 mi.

1. Tasnuna Route would leave the CR&NWR alignment at mile 82 and follow the Tasnuna River valley to Marshall Pass and then follow the northern side of the Lowe River valley to join the Richardson Highway at milepost 22.5 near Thompson Pass. The length of the route between the railway alignment and the Richardson Highway is 31 mi.
2. Tiekel Route would depart the CR&NWR alignment at mile 101 and follow the northern side of the Tiekel River valley west to join with the Richardson Highway near milepost 46 near the confluence of the Tsina River with the Tiekel River. The length of this route between Copper River and Richardson Highway is 17 mi.
3. Wood Canyon Route would follow the CR&NWR alignment north to Chitina (mile 130.6) and intersect the Edgerton Highway approximately 30 mi east of milepost 94.1 on the Richardson Highway. The distance between the Tiekel River and Chitina is about 30 mi.

Previous Glacier and Snow Studies

Many reports are available that describe the snow and glacier conditions within the study area. Blanchet (1983) produced maps that show areal distributions of mean annual temperature, mean annual precipitation, and maximum snowpack. A 1:250,000 scale topographic map in a mineral resources report by Moffit and Maddren (1909, map 1) shows general glacier termini positions during 1900-08 (fig. 3). Tarr and Martin (1914), Wentworth and Ray (1936), Field (1975), Lethcoe (1987), Krimmel and Meier (1989), and Molnia (1993) describe some of the glaciers within the study area. Observations of the fluctuations of the termini of many glaciers within the study area are periodically tabulated in reports published by International Commission of Snow and Ice (Kasser, 1967 and 1973; Müller, 1977; Haeberli, 1985; Haeberli and Müller, 1988; Haeberli and Hoelzle, 1993).

CHARACTERISTICS OF GLACIERS

A glacier (fig. 4) is a perennial mass of ice formed on land by the compaction and recrystallization of snow that moves slowly downslope under the influence of gravity. In the upper part of a glacier, the amount of snow added to the surface each year exceeds the amount lost by melting, evaporation, and calving (Paterson, 1969). In the lower part, some ice and all of the previous winter's snow are lost each summer. The profile of the glacier does not change much from year to year, however, because ice flows from the "accumulation area" to the "ablation area." How fast a glacier moves depends in part on ice thickness and the glacier's slope. Under steady-state conditions, accumulation, ablation, and ice flow balance so that the geometry of the glacier remains constant. However, such conditions are rare; thus, glaciers are constantly adjusting to changes in snow accumulation and ablation. Usually, the main components of ablation are surface melt and evaporation, but for a glacier reaching a river, lake, or ocean, calving of icebergs is an additional component. Calving is influenced by water depth, ice thickness, and the geometry of the bed of the water body. Calving can significantly influence the rate of advance or retreat of a glacier.

The rate of glacier movement is not constant, but exhibits seasonal variations and longer term climatic fluctuations. During fall and winter, most glaciers move more slowly than in spring and summer. During summer, surface melting and rain help increase their rates of sliding. The future advance or retreat of a glacier depends on future short- and long-term changes in climate. Worldwide air temperatures were lower from the 16th century through the late 19th century than they were before that period, and the terminus positions of many glaciers advanced (O'Connor and Costa, 1993). Between about 1885 and 1940, and from 1970 to present, have been periods of warming global surface air temperatures and glacier termini have generally retreated upvalley. However, glaciers now retreating may not continue to retreat in the future if melt seasons become shorter and cooler and if snow accumulation increases.

Some glaciers periodically have flow instabilities known as "surges" (Post, 1969). A surge is a sudden, brief, large-scale ice movement which is 10 to 100 times faster than the normal flow rate of the glacier. Surges may occur at intervals ranging from about 15 to more than 100 years and can last from a few months to a few years. Bering Glacier (fig. 1), southeast of the study area, is one of the largest (about 2,000 mi^2 if tributary glaciers are included) and longest (about 120 mi) glaciers on the North American continent. This glacier has had surges that affected the its terminus in around 1900, about 1920, about 1940, from 1957-60, from 1965-67, and one that began in 1993. During the 1957-60 surge, ice was displaced by as much as 5.6 mi.

NATURE OF GLACIER AND SNOW HAZARDS

Many hazards exist in areas having glaciers, snow, and human use (Benson and others, 1986; Costa and Schuster, 1988; Coffin and others, 1990; Jones and Glass, 1993; O'Connor and Costa, 1993). These hazards include glacial ice, snowslides, and rockslides over-riding transportation routes; subsiding sediments caused by melting of internal ice; mass wasting of moraine materials; calving glaciers; floating icebergs; migrating stream channels; and flooding. Flooding may result from (1) precipitation; (2) the rapid melting of snow and ice; (3) the sudden release of water (outburst) stored on, within, and beneath a glacier; or (4) the rapid release of moraine-, landslide-, and glacier-dammed lakes. When an outburst occurs, the flood waters can pick up and carry large quantities of loose glacial and outwash materials, which can evolve into debris flows. These materials are transported downstream, can increase flood heights, and may possibly block transportation routes and reroute streams.

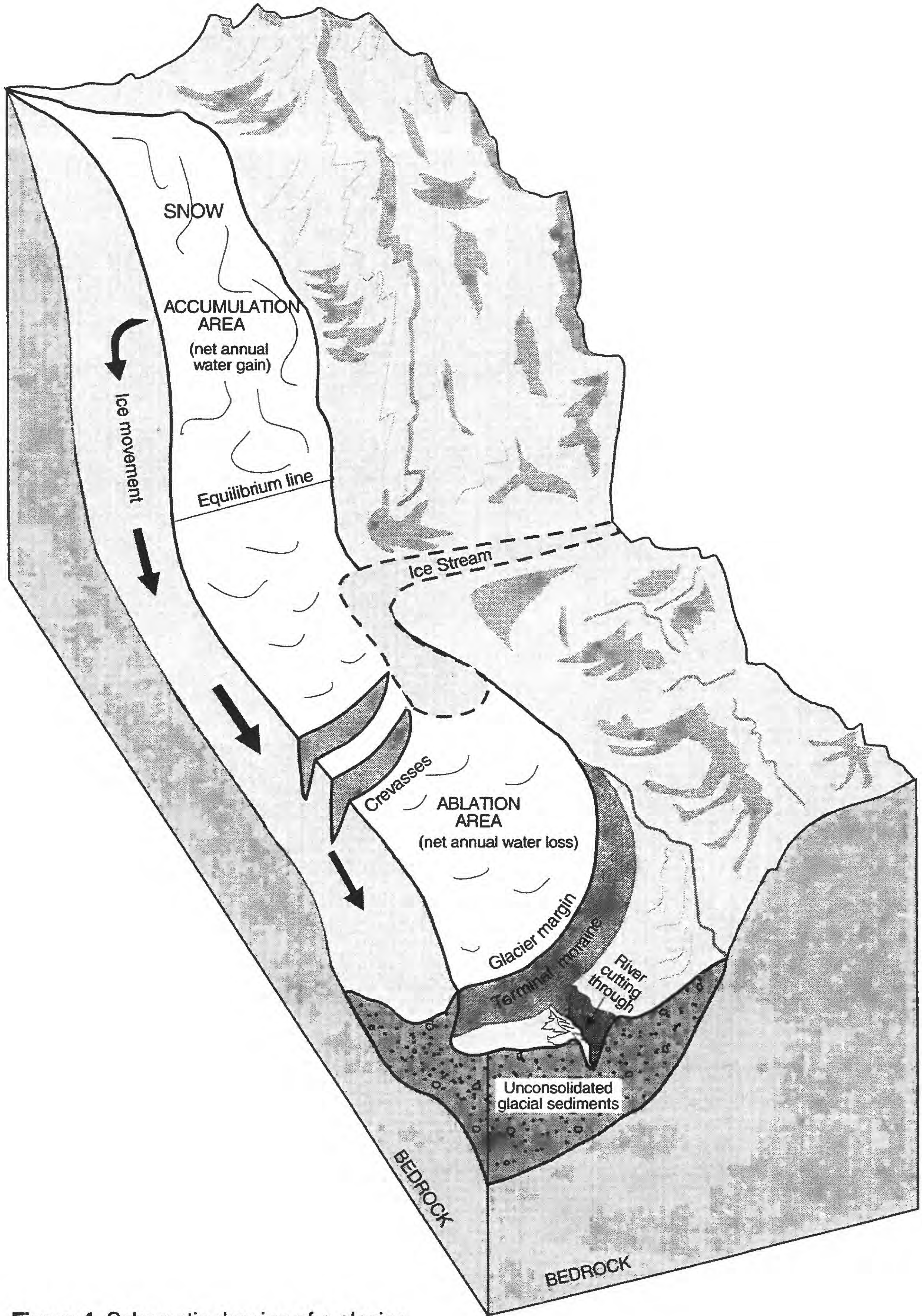


Figure 4. Schematic drawing of a glacier.

Glacier Hazards

An advancing glacier can override and destroy roadbeds and bridges, block valleys, and impound water. Most glaciers in the central and eastern parts of the Chugach Mountains have receded during this century, but this pattern has been interrupted by a number of significant short-term advances (Field, 1975, v. 2, p. 331). Many of the larger glaciers in the study area (Woodworth, Schwan, Heney, Allen, Miles, and Childs Glaciers) have advanced sometime within the last 100 years and in some instances nearly blocked the full width of their trunk valley. Some of the termini of these glaciers are presently within 1 mi of proposed highway routes.

A retreating glacier exposes large quantities of unconsolidated, unvegetated, and commonly ice-cored glacier sediment (O'Connor and Costa, 1993). These loose sediments are commonly emplaced on steep slopes and are readily transported downslope. Terminal and lateral moraines left by retreating glaciers can be large and commonly have steep slopes of uncompacted and noncohesive sediments. When topographic conditions are appropriate, lakes can form behind the moraines. Melting of ice within a moraine dam can lead to the collapse and failure of a morainal dam and cause a large flood and debris flow. Where they are ice-cored, glacial and outwash materials make poor roadbed foundations because their surfaces subside as the isolated pockets of glacial ice melt. The CR&NWR laid 5.5 mi of track on the ice-cored terminal moraine of Allen Glacier. Because the moraine's internal ice was melting, this stretch of track had to be repaired frequently (Janson, 1975, p. 99). Ice is still visible in the banks of many of the small lakes in glacial sediments in front of Allen Glacier.

Hazards from rockfalls and landslides are great where steep, narrow valleys are bordered by rugged mountains because even small mass movements present a potential to cover transportation routes, destroy structures, and form high dams in stream channels. As glaciers advance, they erode the surfaces they contact. When they retreat, the loss of buttress support of valley walls causes dangerously steep conditions, which can contribute to the initiation of rockfalls and landslides. Many huge rock avalanches in the Copper River area were induced by the March 27, 1964 earthquake (Post, 1967). One very large rockslide came to rest on the lower part of the Sherman Glacier about 8 mi south of the study area, but about 6 mi north of the existing Copper River Highway. This rock avalanche was 3.5 mi long, was as much as 2.5 mi wide, had an average thickness of about 16 ft, and contained about 33 million yd^3 of shattered rock debris and minor amounts of ice and snow (Post, 1967). Post also documented rockslide avalanches on Childs, Allen, Schwan, and Miles Glaciers. One rockslide avalanche on Schwan Glacier covered about 3.3 mi^2. A very large rockslide avalanche has occurred since the 1964 earthquake and its debris rests on Allen Glacier. This rockslide travelled about 4.7 mi, has a maximum width of about 0.9 mi, and covers 2.9 mi^2 (Post, 1967).

A landslide ending up on a glacier can also influence the glacier's melting and its movement. A thin (less than about 1 in.) layer of rock debris could absorb more energy from the sun and increase glacier melting, whereas a thick layer of debris could insulate the glacier and decrease melting (Driedger, 1981).

Glaciers can present hazards to people. Blocks of ice calving from glaciers, either onto land or into water, create hazardous conditions for glacier observers. The terminus of glaciers in the study area can be higher than 250 ft. Many glaciers are within easy walking distances from the currently maintained highway and from proposed routes. Hikers may be susceptible to being crushed by an icefall or falling into a crevasse. A tourist at Exit Glacier near Seward (about 130 mi south-west of Cordova) was killed when a block of ice fell from the glacier and crushed the person. Schwan, Childs, and Miles Glaciers have their termini in water. Massive blocks of ice calving from these glaciers produce large waves that can topple boats and can travel across the water body and run up the banks, soaking observers with cold water or crushing them with blocks of ice. Large icebergs can also travel long distances before melting and can damage boats and bridges far away from the terminus of a glacier. Icebergs from Miles Glacier as large as 50 by 100 ft, rising 8 ft out of the water have been observed in the Copper River at Million Dollar Bridge travelling at a velocity greater than 10 ft/s while dragging on the river bottom (Johansen, 1975, p. 29). During the summer of 1993, several people were seriously injured while viewing glaciers in Alaska. A kayaker in Blackstone Bay near Whittier (about 100 mi west of Cordova) was killed when a block of ice from Blackstone Glacier fell onto the kayaker. Two people viewing Childs Glacier were seriously injured when a large piece of ice calved from the glacier and fell into the Copper River. A wave crossed the river, lifted them up and carried one of them about 250 ft. Slabs of ice the size of desks were reported to be scattered around the popular glacier-viewing area (Anchorage Daily News, July 25, 1993).

Even though the position of a glacier's terminus may appear relatively stationary, conditions at the terminus are always changing because glacier ice is continually moving downslope. Water drainage from and near a glacier may change as a result of ice advancing terminal moraines, scouring and filling of materials in adjacent lakes and stream channels, and melting of ice within moraines and glacier deposits. Roadbeds built near the terminus of a glacier may require frequent maintenance and new bridges as topographic and hydrologic conditions change.

Glaciers terminating in a lake or river can change water-flow patterns as the glaciers advance or retreat. Until 1951, the terminal moraine of Miles Glacier constricted the Copper River into a narrow channel known as "Abercrombie Rapids" (fig. 3). As the glacier retreated, the river cut into the glacial deposits, forming a new channel and leaving the old channel dry. The lake in front of Miles Glacier may be filling with sediments transported by Miles Glacier and by glacial-silt laden Copper River as it passes through the lake. A potential exists for the lake to fill with sediment to a level that would cause all or part of the Copper River to flow to the south in a new channel, bypassing Million Dollar Bridge and washing out part of the existing Copper River Highway.

Liquid water can be stored in glaciers, adjacent to them, or behind their moraines. Rapid draining of this stored water (an outburst) can cause extensive flooding and mass wasting of morainal materials. Lakes adjacent to or on top of glaciers and behind moraines can be very large and are signs of potential hazards; however, water stored beneath and within a glacier can not be seen, even though internal water storage and the hazards associated with its release could be great.

Outbursts from Glacier-Dammed Lakes

Post and Mayo (1971) mapped the locations of glacier-dammed lakes throughout Alaska, including about 60 in the Copper River basin (fig. 1). Many of these lakes periodically drain, causing catastrophic floods. In the Copper River basin, breakouts are known to have occurred from lakes adjacent to Nelchina, Tazlina, Long, Kennicott, Nizina, Tana, Tsina, Miles, and McPherson Glaciers. Glacier-dammed lakes commonly drain whenever they fill to critical levels, regardless of the time of year. Winter outbursts of lakes are less common than summer outbursts, but can be devastating because winter flood waters incorporate river ice and form ice jams that may inundate large areas with freezing water and ice.

Local effects of flooding caused by the outburst of even a small lake may be devastating. During September 1945, a bridge on the Richardson Highway (milepost 18.6) over Sheep Creek (fig. 1) in the Lowe River basin was buried by debris about 25 ft thick resulting from a glacier-outburst flood from a tiny lake. Bridges at this site were also destroyed by outburst floods during 1913 and 1959 (Post and Mayo, 1971). In the upper Copper River basin, the CR&NWR bridge near Chitina was destroyed in August 1932 by flooding, probably originating from lakes dammed by Tazlina Glacier. A bridge across Nizina River near McCarthy was destroyed in June 1934 by flooding originating at Lower Skolai Lake adjacent to Nizina Glacier (fig. 1).

Van Cleve Lake (fig. 1), on the north side of Miles Glacier, has a surface area of about 4.4 mi^2, an average depth of about 380 ft, and a volume of about 1.1 million acre-ft at its maximum capacity (T.P. Brabets, U.S. Geological Survey, oral commun., 1992). Generally, when the lake surface rises to the altitude of the strandline surrounding the edge of the lake, the lake drains under the glacier. The lake drains about every 6 years (T.P. Brabets, oral commun., 1996). A breakout on February 10, 1909 caused a 20-foot rise in the water surface of Copper River at Million Dollar Bridge (fig. 5). A similar catastrophic flood occurred on August 16, 1912, when the water rose 12 ft at the Million Dollar Bridge and swept away 1,600 ft of railway trestle east of Flag Point near mile 26, drowning a repair crew foreman (Tarr and Martin, 1914, p. 432). The draining of Van Cleve Lake during August 4-10, 1992 produced an 8 ft rise in the water surface at Million Dollar Bridge (fig. 5). Another lake on the north side of Miles Glacier, locally known as Little Van Cleve Lake, also outbursts intermittently. Its maximum area is about 0.3 mi^2.

Trap Lake (fig. 1) along the edge of Tsina Glacier has a maximum area of about 0.4 mi^2 and generally drains subglacially into the Tsina River at irregular intervals but it may also be possible for the lake to drain to Sheep Creek (Post and Mayo, 1971). The Tsina River flows into the Tiekel River at the western end of the proposed Tiekel route. Ellsworth and Davenport (1915, p. 65) report that the "Tsina River, like many other glacial streams, is subject to extreme floods caused by the release of water that has been stored in the glaciers. On October 16, 1913, the river was discharging at least 1,500 second-feet [ft^3/s], but two days later, without appreciable change in the weather, the flow had decreased to 87 second-feet. People living along the stream stated that the river commenced to rise rapidly on October 14." Hoffman (1970, p. 36) reported a flood in the summer of 1915: "***a glacier reservoir on the headwaters of Tsina River caused a flood of unprecedented magnitude that carried away a bridge over the Tsina River. It also flooded the roadhouse and telegraph station at Beaver Dam***," near mile 42 of the Richardson Highway about 4 mi above the confluence of the Tsina and Tiekel Rivers. Hoffman also reported that the roadhouse and telegraph station were flooded in 1919.

Snow Hazards

Snow avalanches and drifted snow can block roadways and may temporarily block stream channels which could create inundations and floods. Deep snow was a constant problem during winter operation of the Copper River and Northwest Railway (Janson, 1975 and Johansen, 1975). Four rotary snowplows were used to keep the tracks clear of snow and several snow sheds were built to protect tracks along Abercrombie Canyon between Million Dollar Bridge and Allen Glacier. The rotary plows of the railroad were about 14 ft tall, but snow depths caused by drifting snow or avalanches were commonly greater (Janson, 1975, p. 101). Work crews shoveled the drifts down to a level that the rotary plows could handle. The crews also had to reduce the heights of snowdrifts

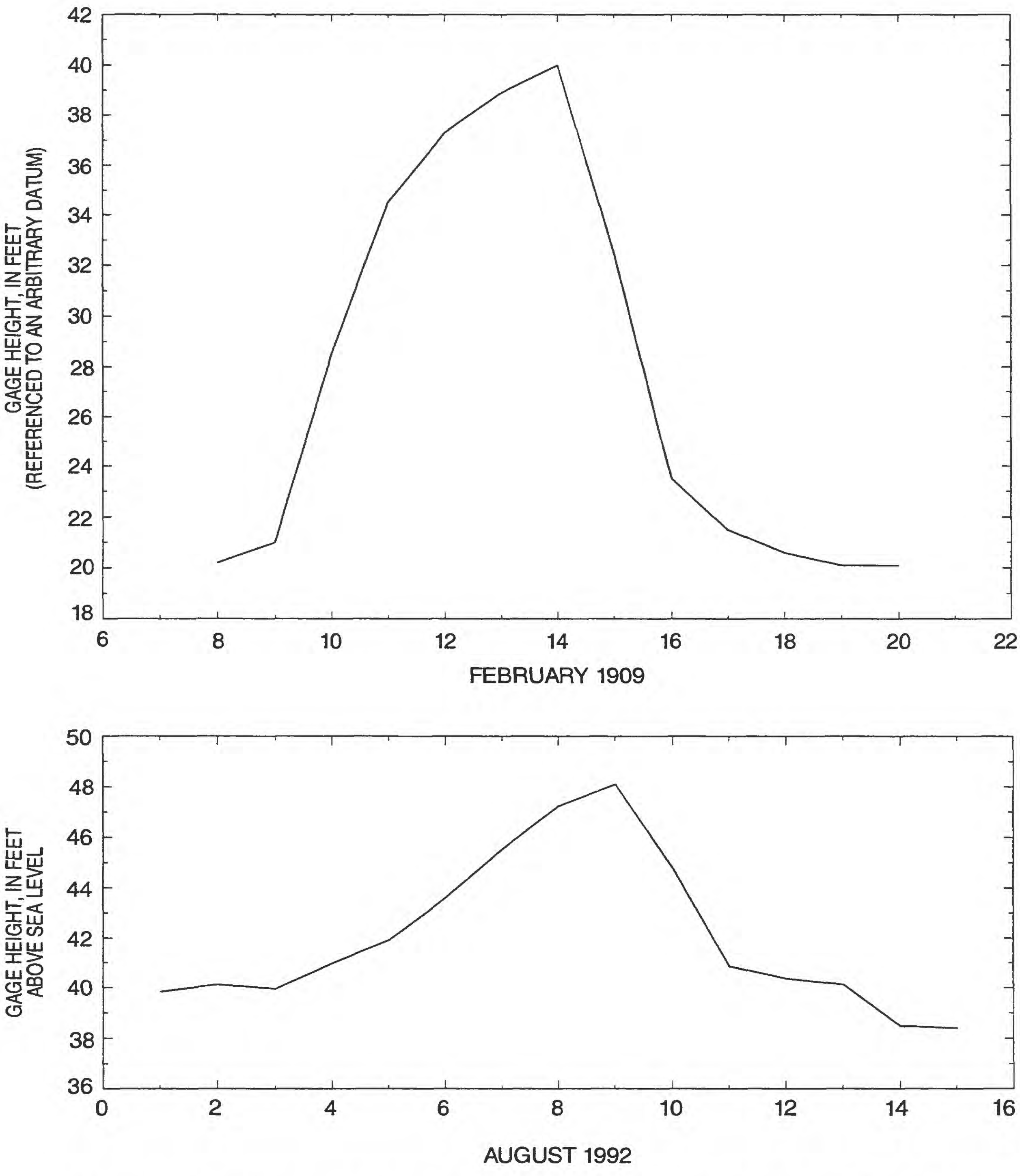


Figure 5. Hydrographs of two outburst floods on the Copper River at Million Dollar Bridge, February 1909 (data from Ellsworth and Davenport, 1915) and August 1992 (unpublished data from U.S. Geological Survey files).

on the river side of the tracks so that the plows could throw the snow away. High velocity winds created drifts that the railroad's rotary plows and work crews could not quickly remove. Trains were stranded for extended periods twice near Hotcake Channel (mile 34) in the Copper River Delta because of drifting snow and a slight depression in the tracks. A 160-man work crew was snowed in at this site from February 17 through March 10, 1909 (Johansen, 1975, p. 24-25; Janson, 1975, p. 82-86). The railroad did not operate during the winter months of 1933-37, because of heavy snows (Janson, 1975, p. 156).

Deep snow and high winds can also be troublesome to highway maintenance crews and travellers. However, road closures can be kept to a minimum with large snow-removal equipment, a road having a high road prism, wide ditches, snow fences, and an avalanche-control program. During 1982-92, the Richardson Highway over Thompson Pass has been closed an average of less than two days a year (George Levasseur, Alaska Department of Transportation and Public Facilities, Valdez area manager, oral commun., 1993).

Rain falling on snow and alternating periods of freezing and thawing of snow can create large masses of ice and slush that can impede traffic flow. Such conditions sometimes caused CR&NWR great problems. During the winter of 1909-10, rain penetrated a deep snow and froze at the bottom causing the track of the railroad to be covered by 0.5 to 2 ft of ice. As a result, it took 31 days for a train with two locomotives pushing a rotary snowplow to advance 50 mi from Million Dollar Bridge to the Tiekel River. During that project, the train had been off the track about 1,500 times (Janson, 1975, p. 92; Johansen, 1975, p. 25-26).

The small potential for flooding from subglacial thermal activity also exists. Mount Wrangell (14,163 ft), a glacier-clad, dormant volcano about 40 mi northwest of Chitina, intermittently vents steam and small amounts of ash from its summit crater. Rapid melting of this snow and glacial ice from a large eruption could lead to flooding along Copper River. A large eruption could also shower the study area with ash, depending on wind direction at the time. A trace covering of ash on snow would greatly enhance snowmelt, thus increasing rates of stream runoff.

GLACIERS ALONG PROPOSED ROUTES

Methods of Mapping

Locations of termini were determined by interpreting aerial photographs and maps in published reports listed in table 1. Stereo pairs of vertical aerial photographs used were generally either black-and-white (B&W) at a scale of about 1:40,000 taken in August 1950, or color-infrared (CIR) at a scale of about 1:60,000 taken in August 1978. Only glaciers in the lower Copper River area had aerial photographs more recent than 1978. In general, the margin of a glacier was defined by a change in slope at the glacier/ground surface or a change in the color or texture of the surface. Snow-covered areas having crevasses were considered to be moving and were mapped as being glacial ice. Areas thought to be rock debris covering ice and moving downslope, were also considered to be glacial. Sediments near glaciers that may contain high proportions of ice, but not considered to be moving, were mapped as containing "potentially ice-rich materials," and were also considered to be glacial. These areas commonly had hummocky topography, had ice visible in cliff walls, or had steep cliff walls bordering streams.

The glacier margins were identified on aerial photographs (table 1) and were transferred to 1:63,360 scale topographic maps (fig. 6) using a zoom-transfer scope. Identification and placement of glacier termini were most accurate where glaciers had well-defined snouts, such as Childs Glacier, a thick glacier that calves into the Copper River. At best, the accuracy of the glacier margins depicted on maps in this report is ±0.2 mi because of the following inherent difficulties: (1) identifying and depicting an ice/rock contact that may actually be gradational, (2) identifying and projecting features in steep terrain using vertical photographs, and (3) transferring features from one map scale to another. Where glaciers grade into ice-free areas, it is difficult to discern a contact between glacier and rock. On aerial photographs, areas of debris-covered ice are commonly hummocky; however, if they are vegetated, they cannot always be distinguished from ice-free rock. For most glaciers in the study area, the most recent aerial photographs available are from August 1978. No field checking or ground surveying were made to verify the margins of the glaciers, to determine the ice content of sediments downvalley from the termini, or to determine whether the ice and sediments were stationary or seasonally moving. Areas and lengths are vertically projected values. The approximate distances from the termini to proposed highway routes shown in table 1 are based on the most recent aerial photographs available, whereas lengths and areas of glaciers were determined from topographic maps.

Tiekel River Area

The Tiekel River area consists of lands adjacent to the proposed highway route that drain into the Tiekel River east of the Richardson Highway. Approximately 21 percent of the 155-mi^2 area is shown on 1:63,360 topographic maps as being covered by glaciers. The margins of the termini of all glaciers within the corridor area have changed only slightly between August 1950 and August 1978, generally less than 2,500 ft. The termini of all glaciers were more than 2 mi upvalley from the proposed Tiekel route (figs. 7, 8, and 11) in 1978.

Lowe and Tasnuna Rivers Area

The Lowe and Tasnuna Rivers area consists of lands adjacent to the proposed Tasnuna route east of the Richardson Highway and that drain into the Lowe or Tasnuna Rivers. Approximately 43 percent of this 460-mi^2 area is shown on 1:63,360 topographic maps as being covered by glaciers. Glaciers cover approximately 28 percent of the upper 80 mi^2 of Lowe River basin. The major glaciers in the Lowe River corridor area are Deserted and Heiden Glaciers: both flow northward into the Lowe River valley (fig. 9). The proposed highway route is on the north side of the valley, whereas these glaciers are on the south side. The termini of Deserted and Heiden Glaciers have retreated about 1,600 ft between August 1950 and August 1978 (fig. 9) and in 1978 were about 2 and 3 mi, respectively, from the proposed Tasnuna route. Surge-type medial moraines (bulb-like loops instead of smooth lines, more or less parallel to the valley walls) from a tributary glacier occur on the east side of Deserted Glacier (fig. 10), indicating that the flow velocity of the tributary glacier periodically changes. The frequency of the surge periods are unknown. The terminus of Deserted Glacier does not show evidence of surging; thus, this surging tributary glacier is not considered to be hazardous to this proposed highway route.

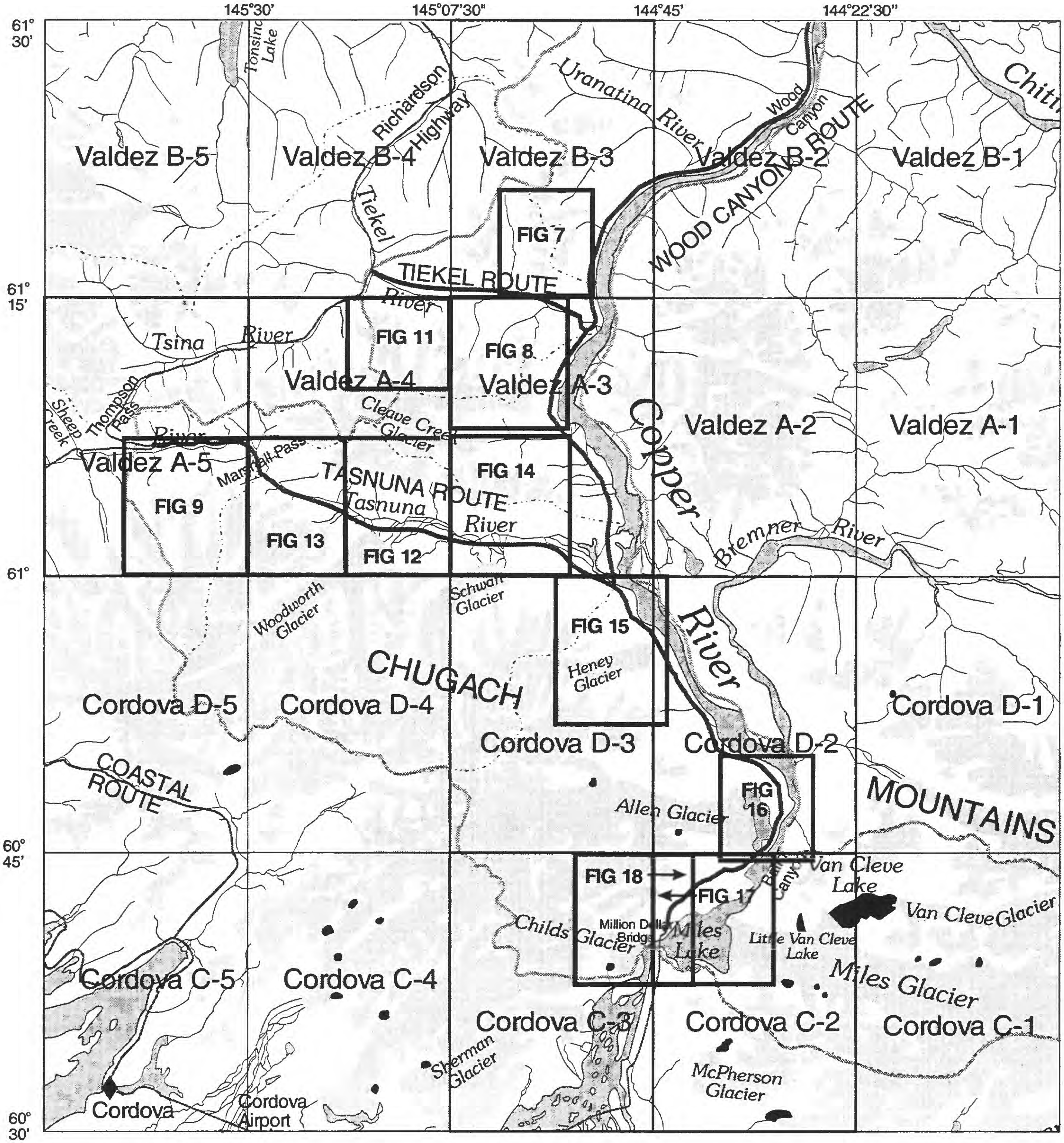


Figure 6. Index map of U.S. Geological Survey 1:63,360 scale topographic maps and map areas showing termini of glaciers.

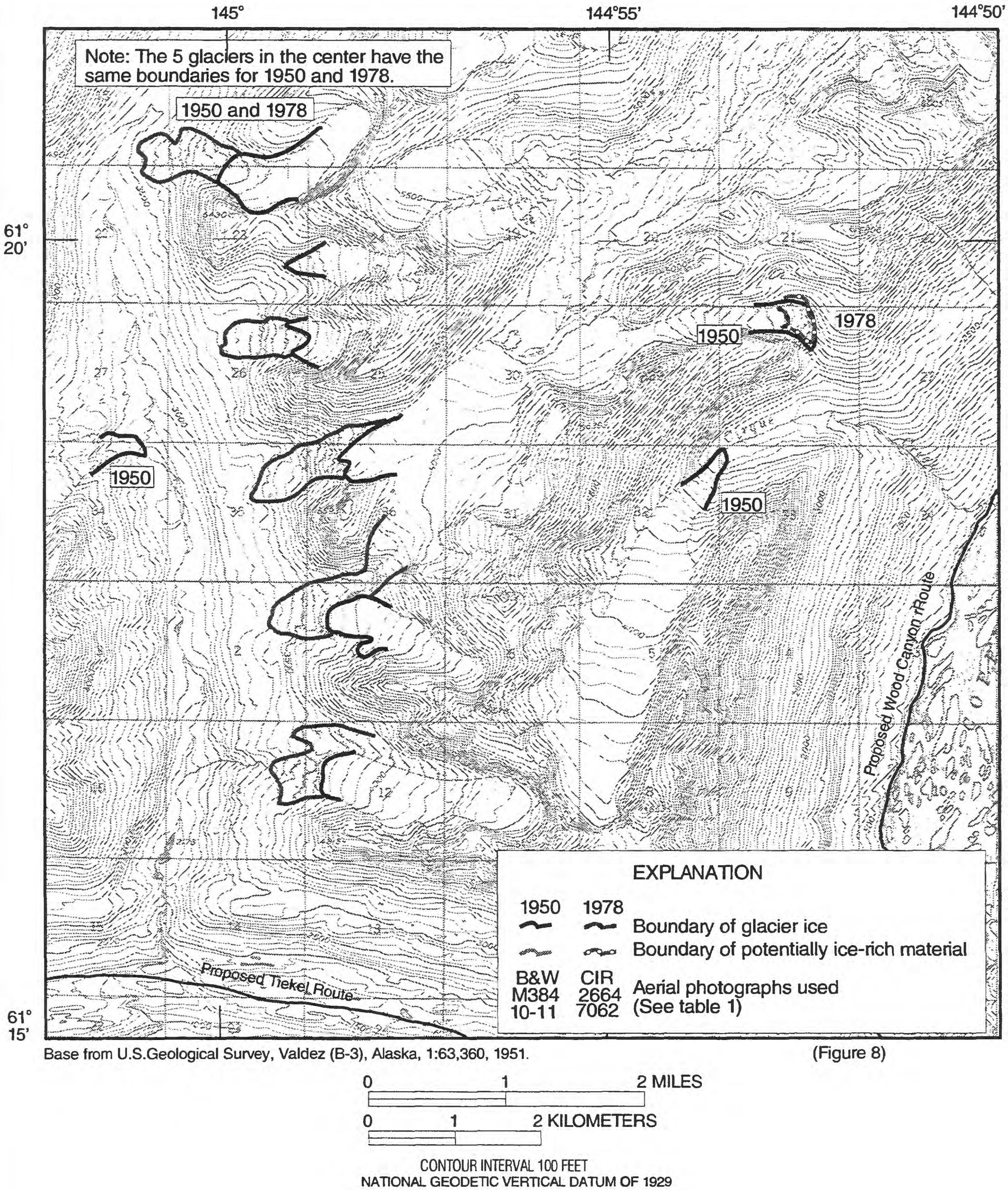


Figure 7. Selected glacier termini, 1950 and 1978, in the southern part of the Valdez B-3 quadrangle. (See figure 6 for map location.)

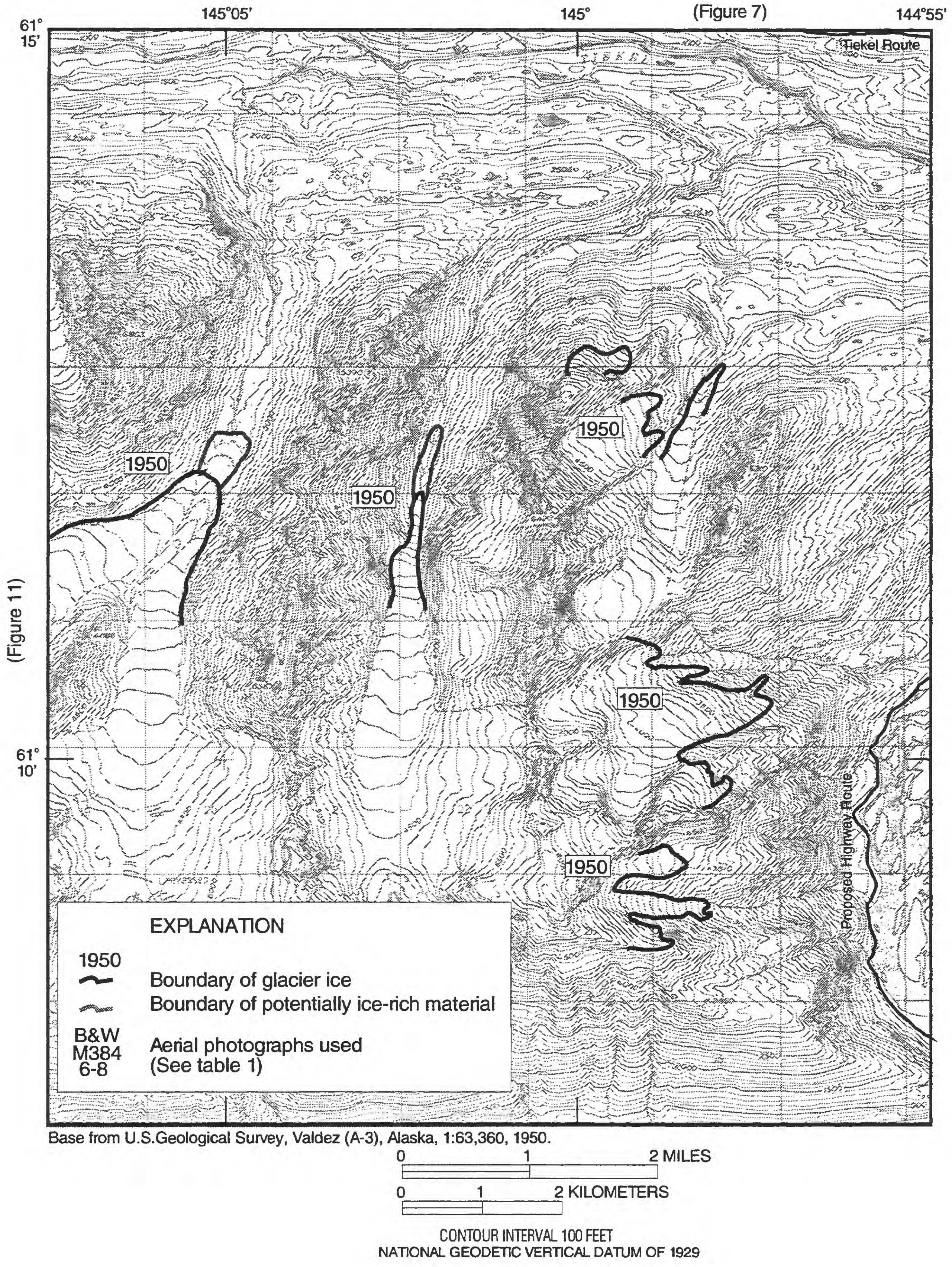


Figure 8. Selected glacier termini, 1950, in the northwestern part of the Valdez A-3 quadrangle. (See figure 6 for map location.)

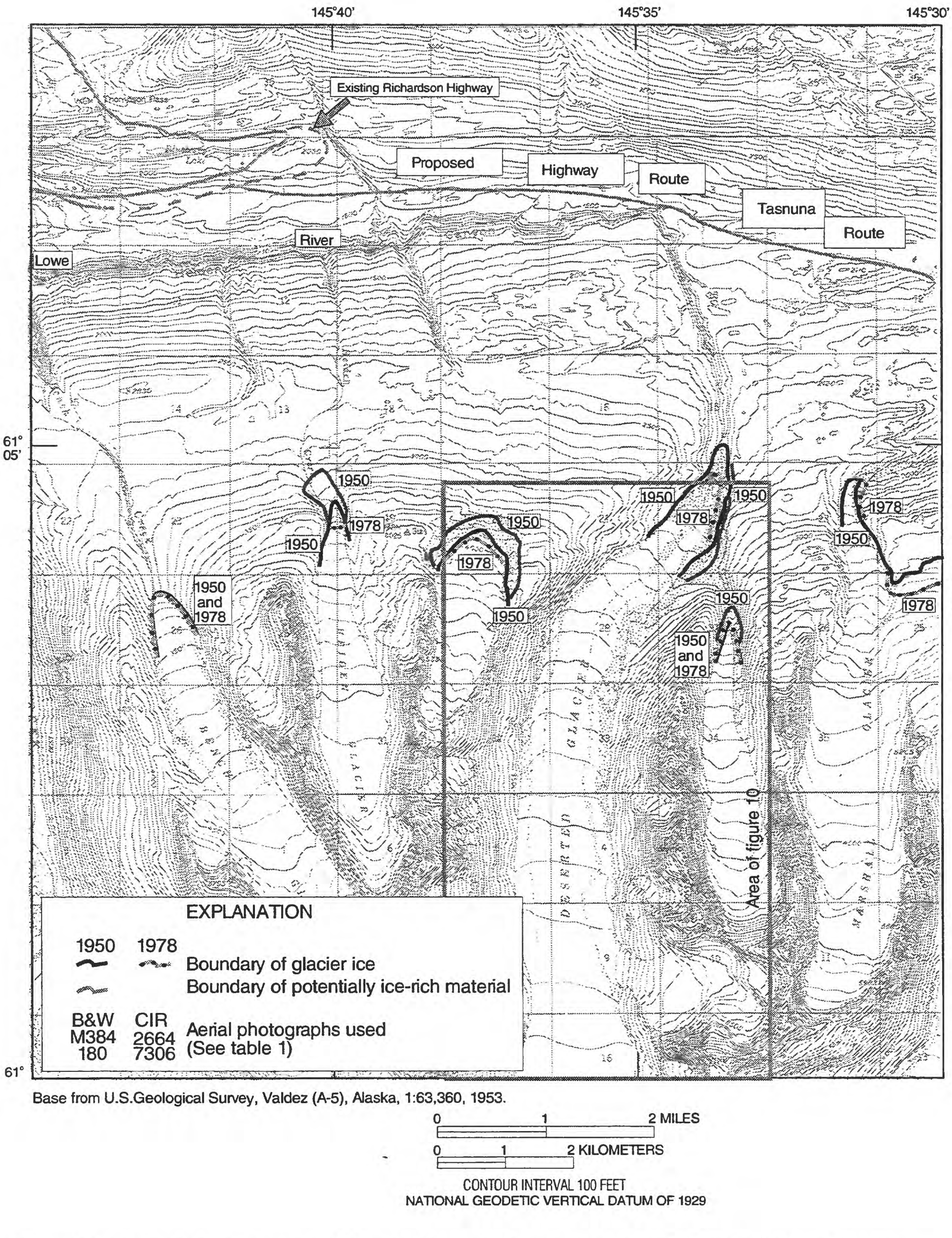


Figure 9. Selected glacier termini, 1950 and 1978, southeastern part of the Valdez A-5 quadrangle. (See figure 6 for map location.)

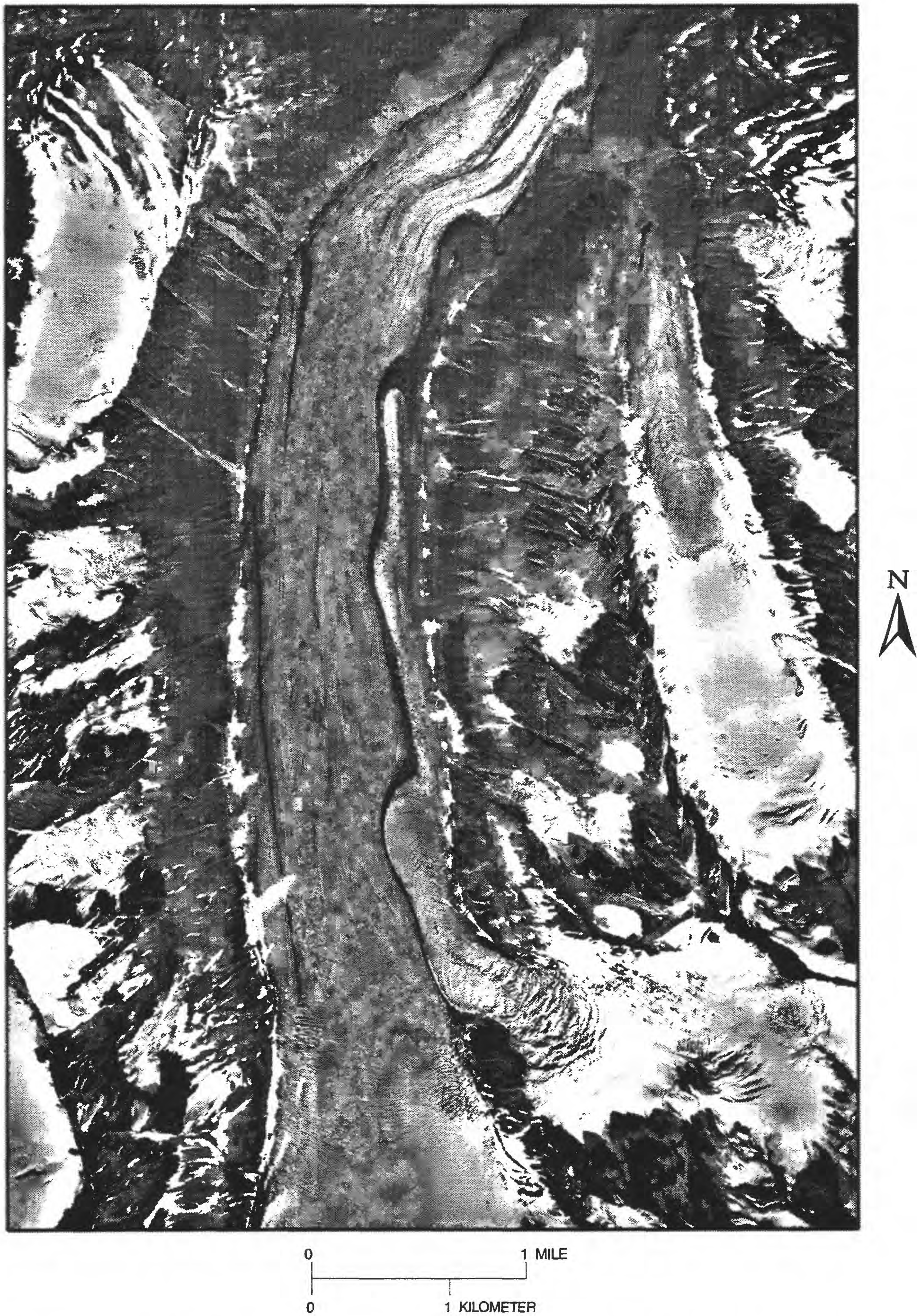


Figure 10. Aerial photograph of Deserted Glacier, August 1950. (See figure 9 for location.)

Glaciers cover almost half of the 380 mi^2 Tasnuna River basin. The major glaciers in the corridor area are Marshall, Tasnuna, Woodworth, and Schwan Glaciers: all flow northward into the Tasnuna River valley. The termini of these glaciers are shown in figures 3, 9, 12, 13, and 14. The Tasnuna and Woodworth Glaciers were about 1 mi south of the proposed route in 1978, whereas the termini of Schwan and Marshall Glaciers were about 1.5 and 2 mi south of the route, respectively. Aerial photographs taken in August 1950 and August 1978 indicate a generally slow retreat of glaciers in the Tasnuna basin. However, Post (1969, p. 231) reports that Marshall Glacier made a short-lived advance in 1960.

Woodworth and Schwan Glaciers have been described by Schrader (1900, p. 397-398) and Tarr and Martin (1914, p. 450) as large, branched valley, fan glaciers whose ice tongues were stagnant and covered with debris. Field (1975, v. 2, p. 332-333) reported that Woodworth Glacier retreated about 4,200 ft between 1898 and 1964. He reported that Schwan Glacier retreated about 8,000 ft from an outer moraine by 1938, another 1,150 ft between 1941 and 1950, and 980 ft between 1950 and 1964. A large debris slide fell on the upper part of Schwan Glacier during the 1964 earthquake (Post, 1967, p. D12-D15), but the glacier's terminus has not made a large advance or retreat. The most current photographs are from 1978, and they show Schwan Glacier calving into a shallow lake. The streams draining the lake in front of Schwan Glacier have migrated. In 1950, most of the water discharging from the glacier flowed northward from the east side of the glacier's terminus and in the easternmost channel (fig. 14). However, in 1978, the predominant flow was to the northwest from the central part of the terminus. During September 1978, water marks were detected about 14 ft above ground in alder trees below the glacier (Jon Breivogel, Copper River riverboat operator, oral commun., 1993), indicating that water may be backing up behind snow and ice or that a large outburst of water from Schwan Glacier occurred.

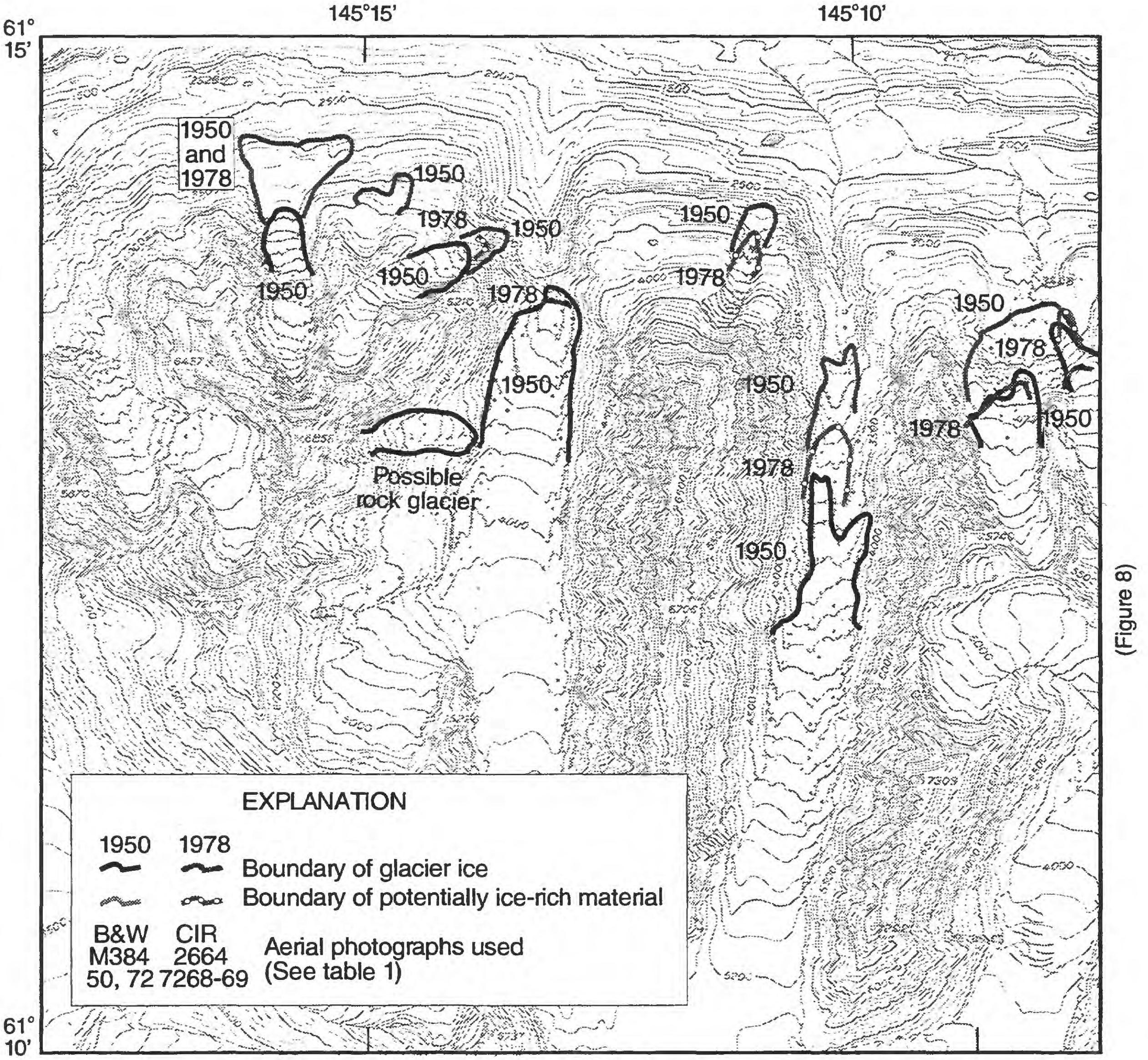
Lower Copper River Area

The lower Copper River area consists of lands south of Chitina that drain directly into the Copper River. The major glaciers are Cleave Creek, Heney, Allen, Grinnell, Miles, and Childs Glaciers. These glaciers are common to the Tiekel and Wood Canyon highway routes and all but Cleave Creek Glacier are adjacent the Tasnuna route.

Cleave Creek Glacier (fig. 1 and 14) covers about 12 mi^2 and flows eastward into Cleave Creek, a tributary to Copper River. The terminus of Cleave Creek Glacier is more than 6 mi from the proposed Tiekel and Wood Canyon routes. The terminus retreated about 3,000 ft between 1950 and 1978.

About one-half mile of the CR&NWR roadbed was built on the terminal moraine of Heney Glacier (fig. 15). Heney Glacier has been described by Tarr and Martin (1914, p. 446-450) and Field (1975, v. 2, p. 334-335). Field reports that terminus receded about 650 ft from 1937 to 1950 and about 1,000 ft from 1950 to 1964. In 1978, the terminus was about 1.5 mi west of a terminal moraine upon which the railway was constructed, but much of the vegetated glacial debris between the terminus and the old railway may be ice rich.

Allen Glacier (fig. 16) was described by Tarr and Martin (1914, p. 439-446), Wentworth and Ray (1936, p. 921-924), Field (1975, v. 2, p. 335-338), and Post (1967, p. D21-D23). Allen Glacier is a branched valley glacier that flows eastward towards the Copper River and its terminal moraine



Base from U.S.Geological Survey, Valdez (A-4), Alaska, 1:63,360, 1953.

0 1 2 MILES

0 1 2 KILOMETERS

CONTOUR INTERVAL 100 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 11. Selected glacier termini, 1950 and 1978, northeastern part of the Valdez A-4 quadrangle. (See figure 6 for map location.)

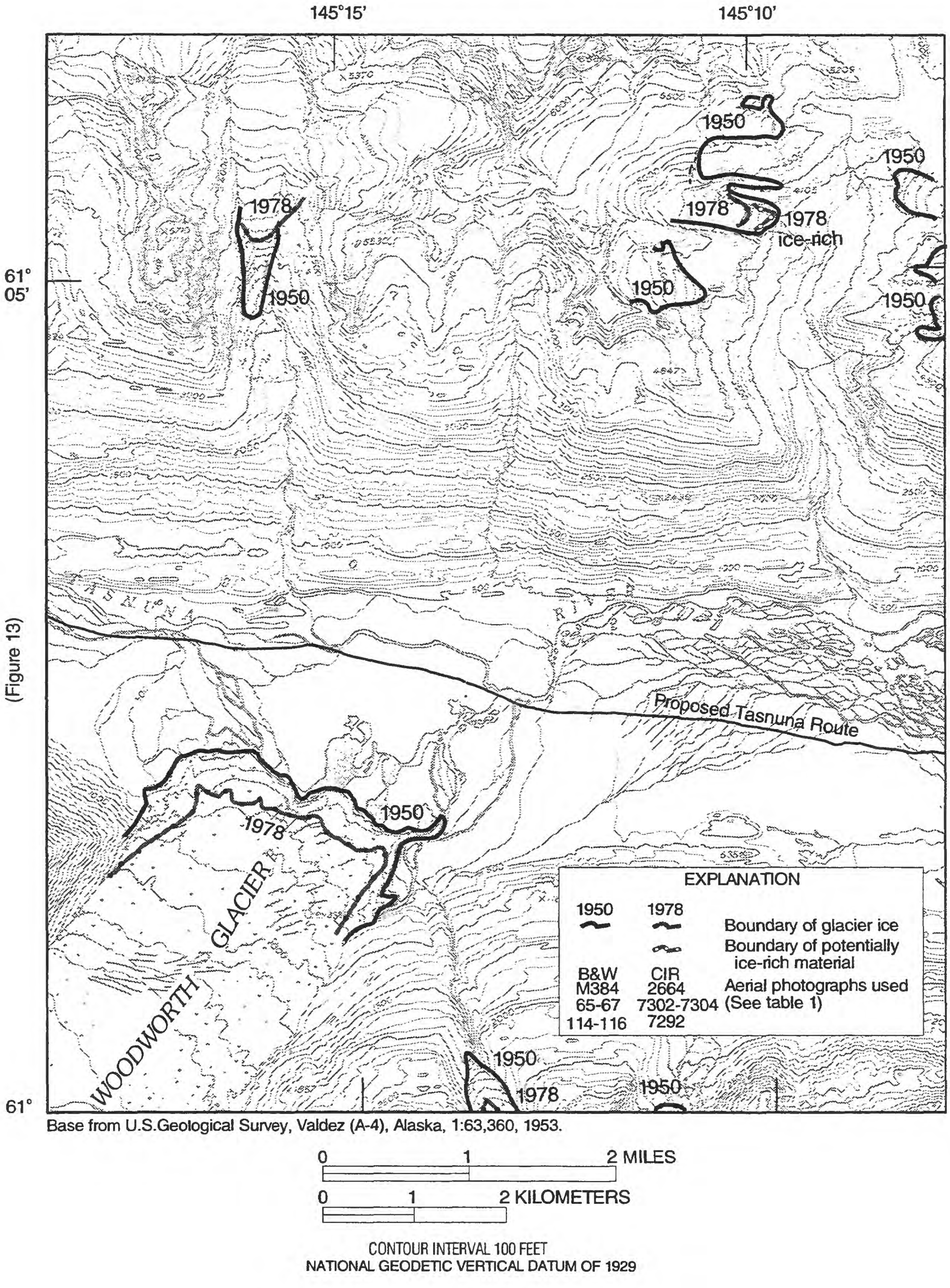


Figure 12. Selected glacier termini, 1950 and 1978, southeastern part of the Valdez A-4 quadrangle. (See figure 6 for map location.)

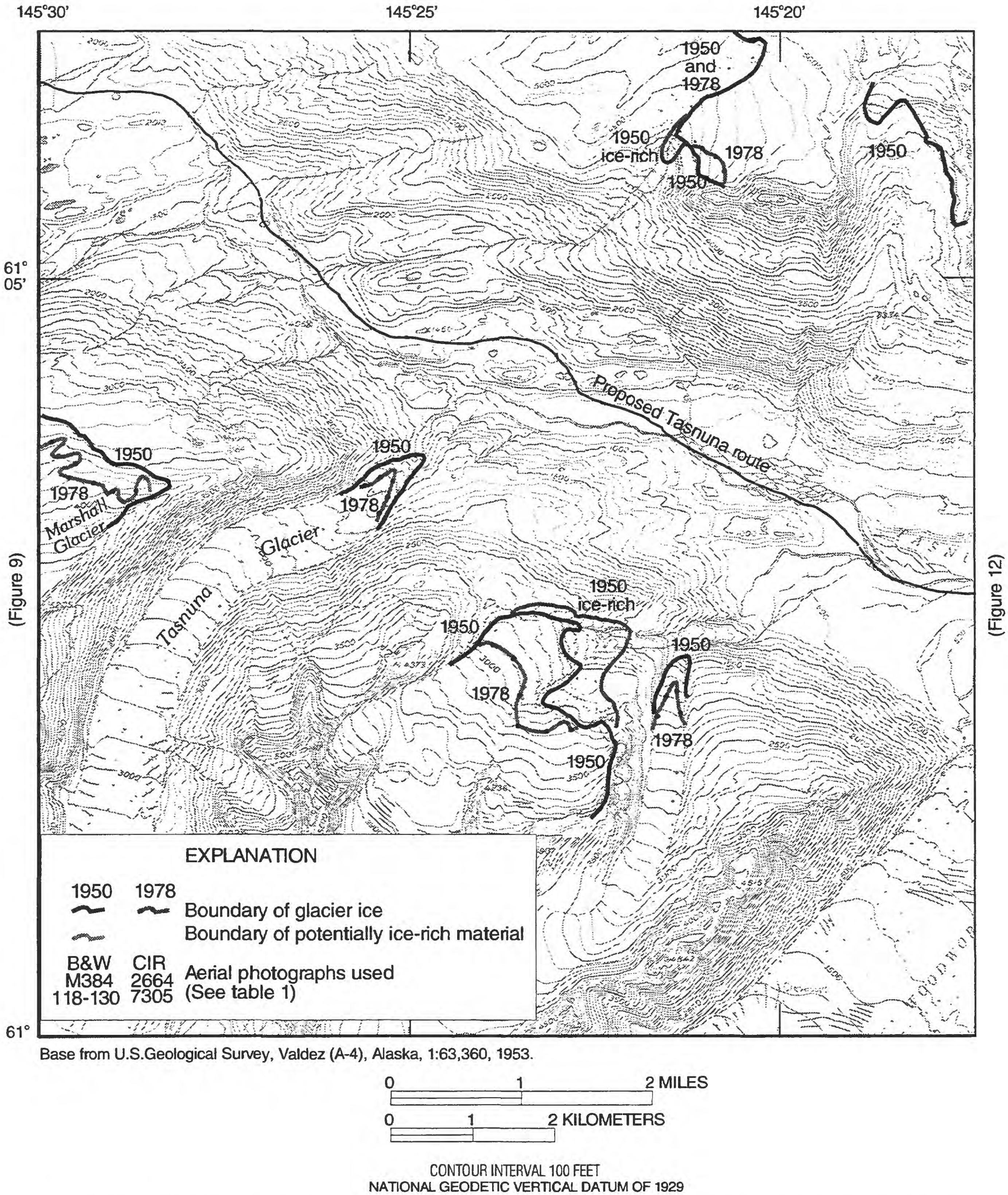
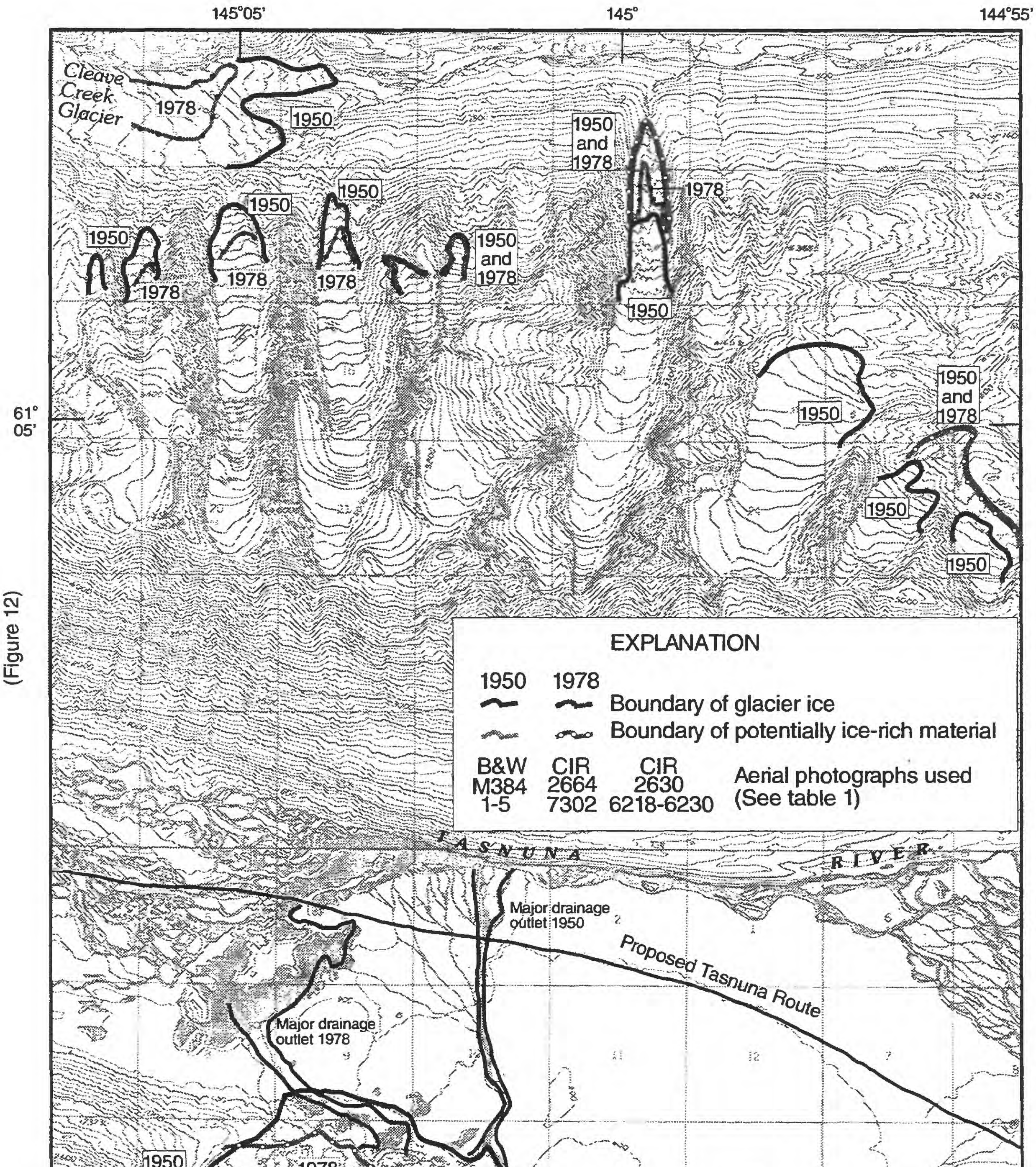


Figure 13. Selected glacier termini, 1950 and 1978, southwestern part of the Valdez A-4 quadrangle. (See figure 6 for map location.)

(Figure 12)



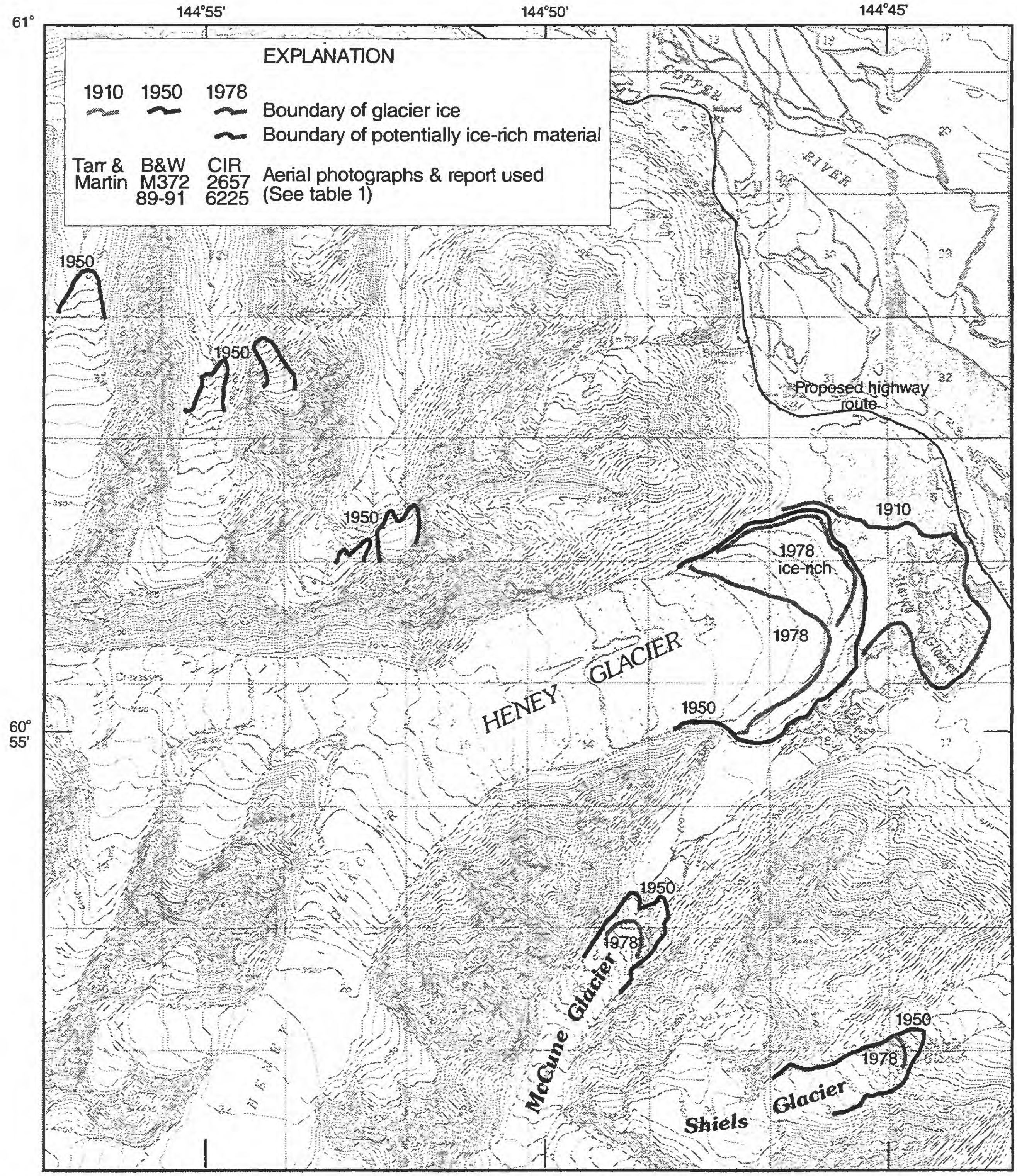
Base from U.S.Geological Survey, Valdez (A-3), Alaska, 1:63,360, 1950.

0 1 2 MILES

0 1 2 KILOMETERS

CONTOUR INTERVAL 100 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 14. Termini of Schwan Glacier and selected other glaciers , 1950 and 1978, southwestern part of the Valdez A-3 quadrangle. (See figure 6 for map location.)



Base from U.S.Geological Survey, Cordova (D-3, D-2), Alaska, 1:63,360, 1950, 1959.

0 1 2 MILES

0 1 2 KILOMETERS

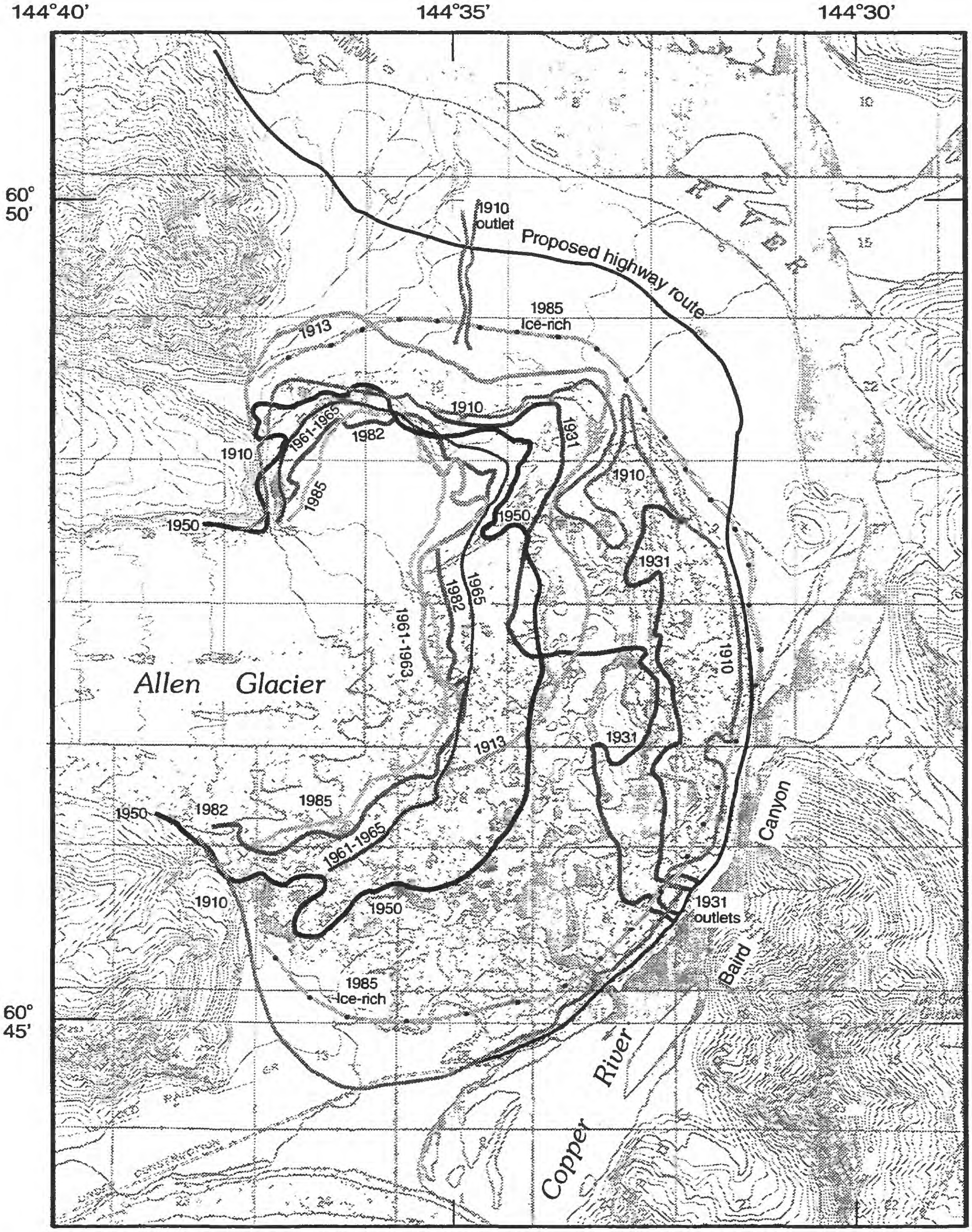
CONTOUR INTERVAL 100 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 15. Termini of Heney Glacier, 1910, 1950, and 1978, and selected other glaciers, northeastern part of the Cordova D-3 quadrangle and small area in northwestern part of D-2. (See figure 6 for map location.)

presently constricts the width of Copper River to about 400 ft, forming Baird Canyon (figs. 16 and 17). A 1908 map (fig. 3) from the report by Moffit and Maddren (1909) labels this glacier "Baird Glacier" and shows it having two lobes: its southern lobe was about 0.5 mi from the Copper River, whereas the northern lobe was about 1 mi from the river. The area between these two lobes was probably vegetated ice-rich debris. Tarr and Martin (1914) reported that during 1910, the terminus was a single convex lobe, 5 mi wide, extending to within a few hundred feet of the Copper River at its southeastern part and that the ice lobe was stagnant.

The CR&NWR laid 5.5 mi of track on the ice-cored terminal moraine of Allen Glacier adjacent to the Copper River. Because the moraine was being pushed towards the river by the glacier and its internal ice was melting, this stretch of track had to be replaced and reset frequently (Janson, 1975, p. 99). Ice was seen in several places along the river in August 1909, and many ice exposures were seen in railway cuts on the glacier terminus (Tarr and Martin, 1914, p. 444). Wentworth and Ray (1936, p. 923) reported that during 1912, the northern margin of Allen Glacier advanced 2,600 ft and that the glacier continued advancing until 1915. The positions of the terminus in 1913 and 1931 determined by Wentworth and Ray (1936, p. 922) are shown in figure 16. By 1950, the terminus had retreated about 5,000 ft from its 1913 position. Post (1967) mapped the terminus positions during 1961-65 and noted an advance of 980 ft from 1963 to 1964, and another 980 ft from 1964 to 1965. By July 1982 and August 1985, the terminus appears to have retreated about 10,000 ft from its 1910 position, but much of the material in this area is still ice rich—many lakes in this area have ice in their banks. The terminus of Allen Glacier was as close as 1.3 mi to the proposed highway route in 1985, but much of the material between the terminus and proposed routes is ice rich.

Miles Glacier (fig. 17) was described by Tarr and Martin (1914, p. 414-434), Wentworth and Ray (1936, p. 927-929), and Field (1975, v. 2, p. 320-322). It is about 32 mi long, covers an area of about 100 mi^2, and flows westward into the Copper River at Miles Lake (fig. 17). When Lt. W.R. Abercrombie ascended the Copper River in 1884, the northern part of Miles Glacier constricted the Copper River to a width of about 150 ft, forming the "Abercrombie Rapids" (fig. 3). Schrader (1900, p. 399) states that by 1898, the glacier had retreated but a moraine "remained as a huge dam across the channel, over which the river now tumbles, forming the impassable rapids." Tarr and Martin (1914, p. 433) reported that between 1885 and 1888, the southern terminus of the glacier was within 0.1 mi of the site of the future Million Dollar Bridge, but that by 1908, the southern terminus had retreated to about 1.5 mi east of the bridge. They also reported that by 1908, the northern part of the glacier near Abercrombie Rapids was stagnant, its moraine was vegetated, and it was in the process of being undermined by slumping due to ice melting. Miles Glacier advanced about 0.7 mi during 1909-10, but has generally retreated since 1910. Wentworth and Ray (1936) showed that the terminus was about 2.8 mi east of the bridge during 1931. By August 1950, the southern part of the terminus advanced to about 2.7 mi from the bridge while the northern part of the terminus retreated. As the northern part of the glacier terminus receded, the Copper River became less constricted and during 1951, the river changed it course away from the western bank and cut through debris left by the glacier leaving the boulder-strewn Abercrombie Rapids high and dry (Janson, 1975, p. 163). In August 1978 and in August 1985, the glacier terminus was about 4 mi from the bridge. However, much of the sediment exposed since 1910 is probably ice rich.



Base from U.S.Geological Survey, Cordova (D-2, C-2), Alaska, 1:63,360, 1959, and 1951. (Figure 17)

0 1 2 MILES

0 1 2 KILOMETERS

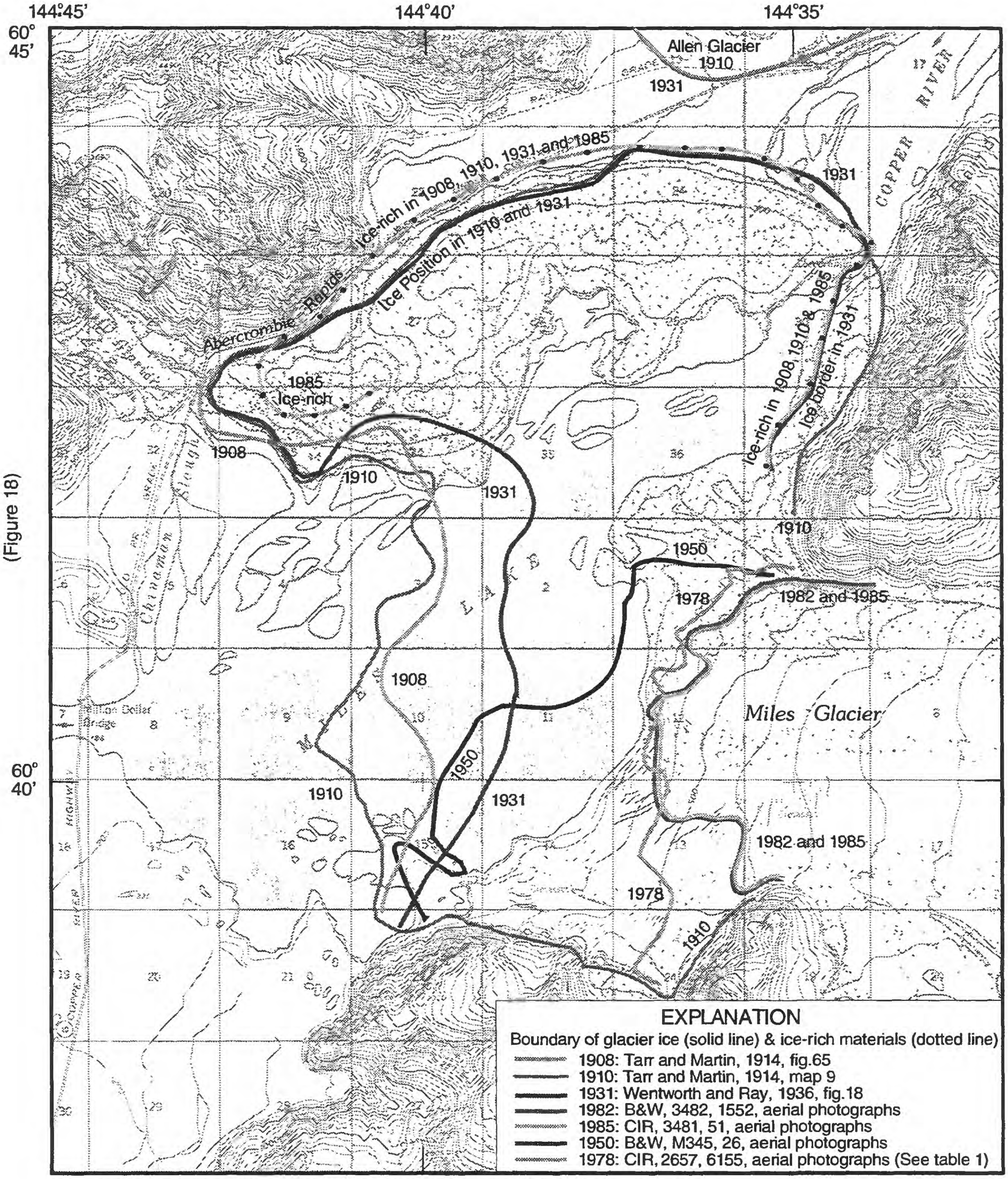
CONTOUR INTERVAL 100 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

Boundary of glacier ice (solid line) & ice-rich materials (dotted line)

- 1910: Tarr and Martin, 1914, map 9
- 1913: Wentworth and Ray, 1936, fig.15
- 1931: Wentworth and Ray, 1936, fig.15
- 1950: B&W, M372, 7, aerial photographs
- 1961-63: Post, 1967, p.D22
- 1965: Post, 1967, p.D22
- 1982: B&W, 3093, 1499, and CIR, 3092, 9310, aerial photographs
- 1985: CIR, 3481, 52 & 51, aerial photographs (See table 1)

Figure 16. Termini of Allen Glacier, 1910-85, southern part of Cordova D-2 quadrangle and small area of northern part of C-2. (See figure 6 for map location.)



Base from U.S.Geological Survey, Cordova (C-2), Alaska, 1:63,360, 1959.

0 1 2 MILES

0 1 2 KILOMETERS

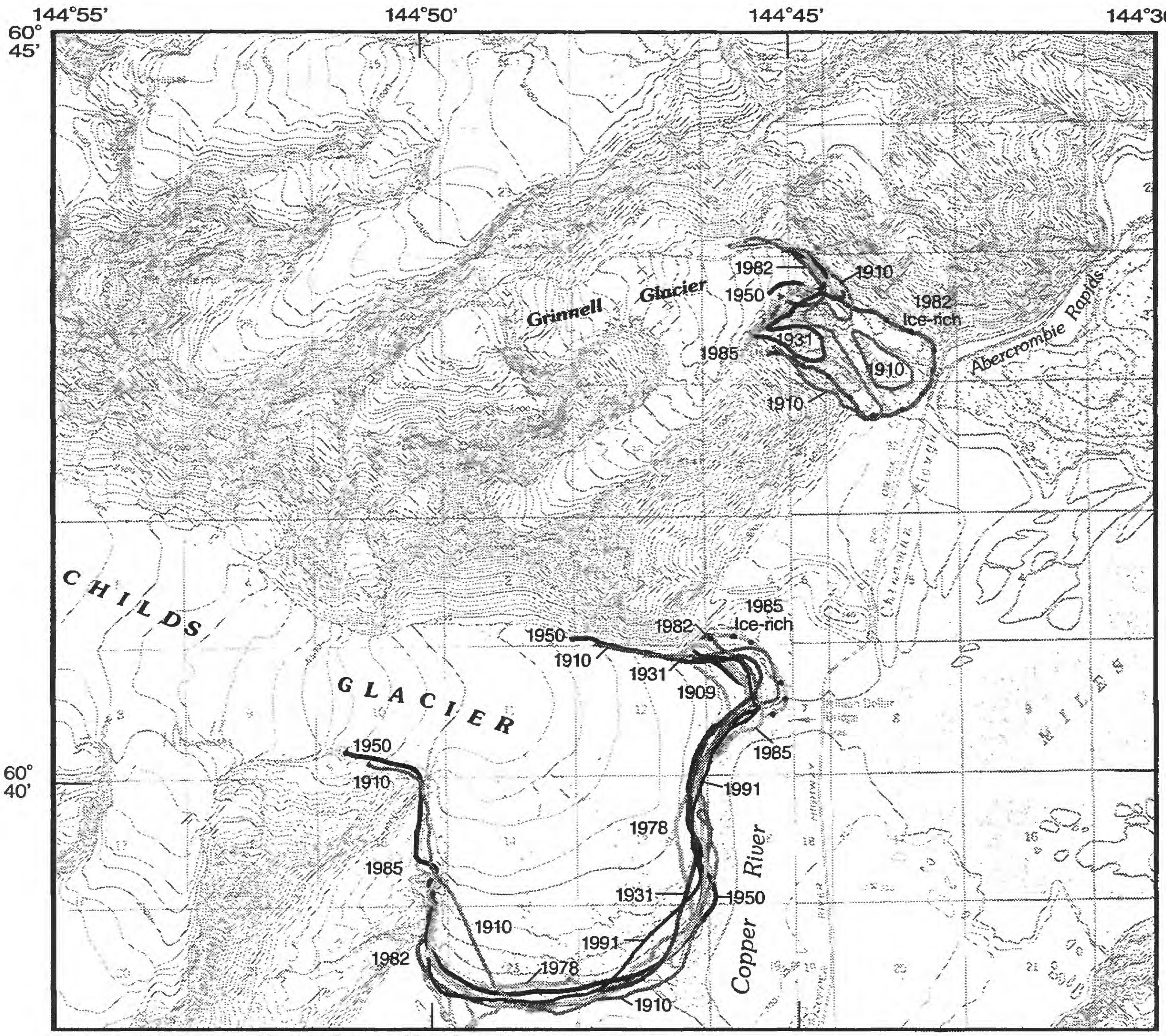
CONTOUR INTERVAL 100 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 17. Termini of Miles Glacier, 1910-85, northwestern part of Cordova C-2 quadrangle. (See figure 6 for map location.)

Grinnell Glacier was described by Tarr and Martin (1914, p. 434-438), Wentworth and Ray (1936, p. 918-921), and Field (1975, p. 338-340). The terminus of Grinnell Glacier during 1900-07 consisted of two ice tongues that extended almost into the Copper River (fig. 18). About 0.25 mi of the CR&NWR roadbed was built on a stagnant, ice-rich, forested terminal moraine adjacent to the Copper River. During 1910-11, the glacier advanced slightly, a distance less than 200 ft (Tarr and Martin, 1914, p. 437). By 1931, Wentworth and Ray (1936) show a thinning and shortening of the two cascading ice tongues and a widening of the exposed barren area between them (fig. 18). The positions of the terminus in photographs from 1978 and 1985 are similar and they indicate that the terminus has retreated about 5,000 ft since 1910. In 1985, the terminus was about 1 mi from the proposed highway route, but the glacial materials between the glacier and the highway routes may contain some ice.

Childs Glacier (fig. 18) was described by Tarr and Martin (1914, p. 395-413), Wentworth and Ray (1936, p. 924-926), Field (1975, v. 2, p. 340-343), and Lethcoe (1987, p. 141-144). This branched valley glacier actively calves into Copper River, commonly creating waves that propagate across the river tossing icebergs from Miles Glacier and large volumes of water onto the opposite bank. However, intermittently during the last 100 years, the glacier has retreated from the river. When Abercrombie ascended the Copper River in July 1884, Childs Glacier calved into the river, but during low-flow conditions in the Copper River in October 1898, he observed that the glacier no longer terminated in the river, but was separated from it by a beach about 1,500 to 1,800 ft wide (Tarr and Martin, 1914, p. 397). In early 1898, the glacier calved into the river, but during parts of 1905 and 1907 the glacier did not calve into the river (Tarr and Martin, 1914, p. 398-400). However, in 1909 to 1910, as the Million Dollar Bridge was being constructed, Childs Glacier was advancing. During the advance, the ice cliff at mid-glacier was 285 ft high and advancing about 30 to 40 ft/d (Tarr and Martin, 1914, p. 405-408). A northern lobe of the glacier advanced overland about 1,600 ft between 1909 and June 3, 1910, and advanced another 204 ft by October 5, 1910. During mid-August 1910, the northern lobe was advancing towards the bridge at rates as great as 8 ft/d (Tarr and Martin, 1914, p. 406) and it was feared that this lobe would advance and destroy the north end of the bridge. On October 5, 1910, the glacier was 1,571 ft from the bridge. On June 16 of the following year, the ice lobe had advanced to 1,474 ft from the bridge. Fortunately for the railroad, the advance came during high streamflow, which caused rapid calving from the glacier terminus, and the advance was nearly over by the beginning of the low-water stage in October.

During 1912, Childs Glacier began to recede. In 1931, a narrow bar separated the ice front and the Copper River in the central and northern parts of the terminus and ice fell on the bar and not into the river (Wentworth and Ray, 1936, p. 925). However, aerial photographs taken in August 1950, August 1978, August 1985, and August 1991 show that more than 1 mi of the glacier's face calved into the Copper River. The southern part of the terminus lies west of the river, is more than 2 mi wide, and has retreated about 1,000 ft from 1950 to 1985. The ice content of sediments south and southeast of Childs Glacier is unknown. In August 1991, the northern part of the terminus of Childs Glacier was about 0.5 mi from the Million Dollar Bridge on the Copper River Highway.



Base from U.S.Geological Survey, Cordova (C-3, C-2), Alaska, 1:63,360, 1951, 1959.

0 1 2 MILES

0 1 2 KILOMETERS

CONTOUR INTERVAL 100 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

Boundary of glacier ice (solid line) & ice-rich materials (dotted line)

- 1909: Tarr and Martin, 1914, fig.59
- 1910: Tarr and Martin, 1914, map 9
- 1931: Wentworth and Ray, 1936, fig.16
- 1950: B&W, M345, 24-26, aerial photographs
- 1978: CIR, 2657, 6155, aerial photographs
- 1982: B&W, 3482, 1552, aerial photographs
- 1985: CIR, 3481, 52 & 51, aerial photographs
- 1991: Color, 590, 17 aerial photographs (See table 1)

(Figure 17)

Figure 18. Termini of Childs Glacier, 1909-91 and Grinnell Glacier, 1910-85, northeastern part of Cordova C-3 quadrangle and northwestern part of C-2. (See figure 6 for map location.)

SUMMARY

- The Chugach Mountains in the lower Copper River basin annually receive heavy precipitation, as great as 200 in. water equivalent. Most of the precipitation falls as snow, which results in active glaciers. Hazards associated with glaciers and snow include overriding or destruction of roads and bridges by advancing ice, snowslides, rockslides, icebergs, floods, and debris flows.
- A major advance of a large glacier on any of the routes could block that route or alternatives through the valley.
- A retreating glacier exposes large quantities of loose sediments that are readily transported downslope during rainstorms, snowmelt, or floods.
- Landslides, snow avalanches, and drifting snow will periodically obstruct existing and proposed transportation routes. Earthquakes have triggered massive landslides in glacier-steepened regions. Landslide debris that covers part of a glacier may dramatically change the melting and flow rates of the glacier.
- Moraines and outwash deposits near retreating glaciers commonly contain ice and make poor roadbed foundations. As the ice melts, the land surface subsides.
- Floods from glaciers result from the failing of glacier-dammed lakes, failing of moraine-dammed lakes, and rapid releasing of liquid water stored within and beneath glaciers. These flood waters can pick up and carry large quantities of loose glacial and outwash materials and evolve into debris flows.
- About 60 glacier-dammed lakes are within the Copper River basin. Floods from the rapid release of these glacier-dammed lakes occur periodically and have destroyed several bridges within the basin.
- Most glaciers near proposed Copper River Highway routes are retreating slowly, but their recessions are interrupted by occasional advances. A tributary of Deserted Glacier shows evidence of a past surging, but this is not considered a hazard because the terminus of the main glacier does not show surging behavior.
- Four glaciers were within 1 mi of proposed routes for the extension of the Copper River Highway, on the basis of the most recent aerial photographs available (1978-91). Nine glaciers were within 3 mi of proposed routes.
- Allen Glacier had small advances from 1912-15 and 1961-65, about 0.5 and 0.4 mi, respectively. The terminus of Allen Glacier was as close as 1.3 mi from the three proposed inland routes in 1985. The glacial and outwash materials between Allen Glacier and Copper River contain ice and therefore the terrain will not make a stable road bed without major alteration.
- Miles Glacier currently calves into Miles Lake and its terminus is about 4 mi from Million Dollar Bridge, which spans the Copper River. However, between 1885 and 1888, the glacier was within 0.1 mi of the bridge site. Much of the glacial sediment exposed from this retreat may be ice rich.
- Childs Glacier calves into the Copper River about 0.5 mi downstream from Million Dollar Bridge. Between 1909 and 1911, a northern lobe of Childs Glacier advanced toward the bridge at rates as great as 8 ft/d. This advance caused much anxiety during the construction of the Million Dollar Bridge, which was about 1,500 ft from the glacier's terminus at that time. Large waves, produced by the calving of ice from the glacier into Copper River, commonly run up the opposite bank, creating dangerous conditions near the river's edge.

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