Glaciers of North America—

GLACIERS OF CANADA

GLACIERS OF THE COAST MOUNTAINS

By GARRY K.C. CLARKE *and* GERALD HOLDSWORTH

SATELLITE IMAGE ATLAS OF GLACIERS OF THE WORLD

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The Coast Mountains of Canada extend from southwestern British Columbia to southwestern Yukon Territory. Highland ice fields and associated outlet glaciers are present along the erosionally dissected mountain blocks. Mining is difficult in this area because of the glaciers, and prehistoric and historic jökulhlaups have resulted from glacier-dammed lakes

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By GARRY K.C. CLARKE[1] *and* GERALD HOLDSWORTH[2]

Abstract

The Coast Mountains follow the Pacific coast of Canada and extend from southwestern British Columbia to southwestern Yukon Territory. The predominantly granitic bedrock forms elevated blocks that have been deeply dissected by erosion, yielding a distinctive pattern of disjointed highland ice fields that are drained by radiating outlet glaciers. Popular interest in the glaciers of the Coast Mountains centers on the hazards and problems that they engender and on their attractions as a recreational resource. Scientific interest has largely focused on their status as climate indicators. We touch on these various themes by discussing the glacier-associated problems of the Granduc mining operation near Leduc Glacier in northwestern British Columbia, the outburst floods of glacier-dammed Flood Lake, and the recreational and scientific roles of small glaciers in Garibaldi Provincial Park near Vancouver, British Columbia.

Introduction

The Coast Mountains of Canada lie almost entirely within British Columbia and extend from near the Fraser River slightly north of the lat 49° N. boundary between Canada and the United States to just across the lat 60° N. boundary between British Columbia and Yukon Territory, a distance of some 1,500 km (fig.1). The section north of the Skeena River that follows the irregular border between the Alaskan “panhandle” and British Columbia is sometimes called the Boundary Ranges, and the section south of the Skeena River, the Pacific Ranges. Physiographically, the Coast Mountains resemble deeply dissected elevated blocks (Bostock, 1948). This gives the present-day glacierization a characteristic pattern: highland ice fields, drained by radiating outlet glaciers, are separated from one another by deep valleys. In late Wisconsinan time, when the region was covered by the Cordilleran ice sheet, these valleys were ice-filled, and the tops of the highest peaks protruded as nunataks; drainage to the Pacific Ocean was mainly by calving from tidewater glaciers. The end of this last glaciation left a spectacular fjord coastline and a network of U-shaped valleys that, in places, cut completely across the Coast Mountains. These valleys are now occupied by the major westward-flowing rivers of Canada. The pattern of highland ice fields broken by deep valleys is repeated over the entire length of the Coast Mountains. Some typical examples are the Frank Mackie highland glacier complex and

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***Figure* 1.**—*Coast Mountains, British Columbia, and surrounding area in Canada and the United States.*

Cambria Snowfield at the head of Portland Canal (fig. 2) and the highland ice fields of the Stikine River basin (fig. 3).

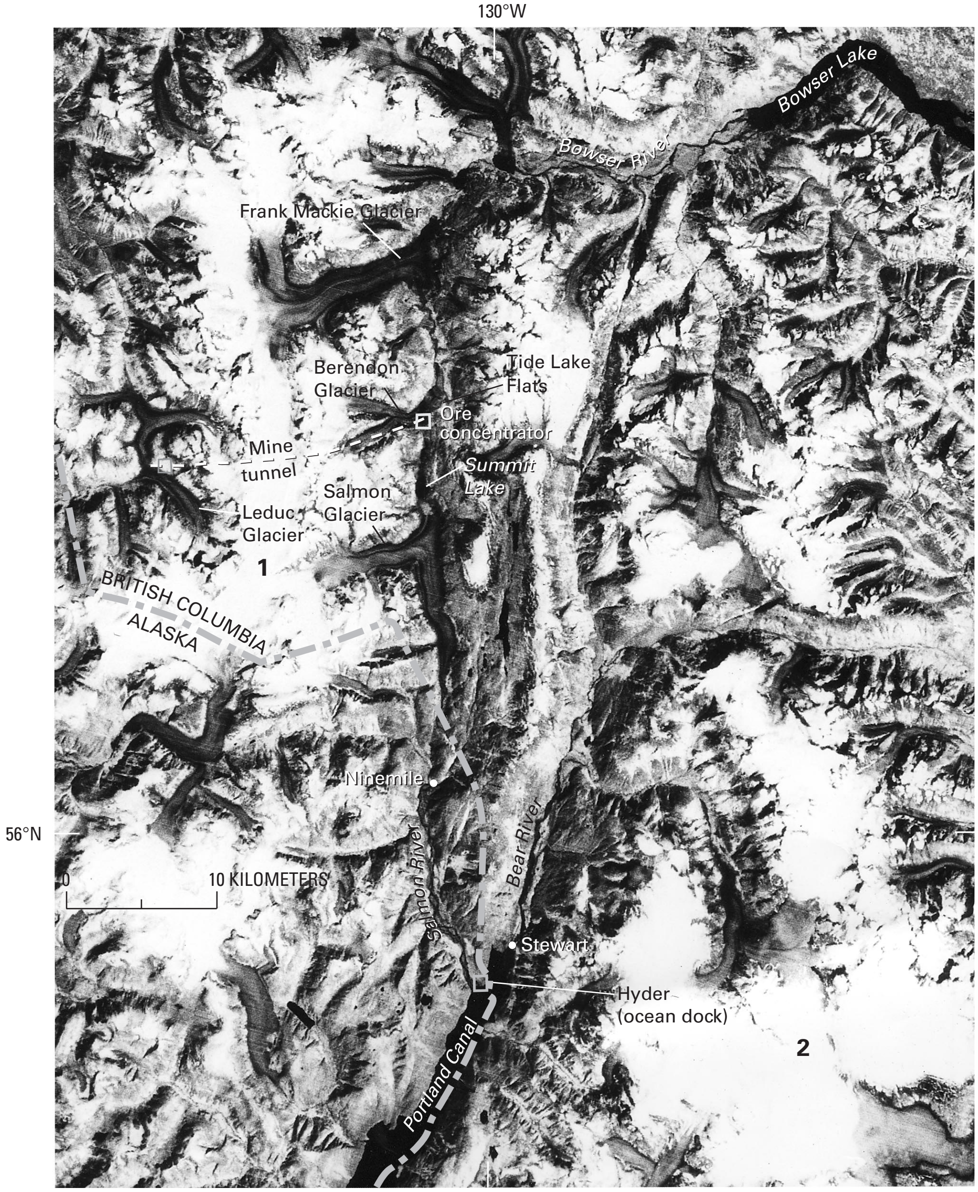
Although the scientific literature on the glaciers of the Coast Mountains is surprisingly sparse, no region in Canada has such close interaction between glaciers and humans as in this area. We shall take this interaction as our theme.

Hazards and Problems Created by Glaciers

Glaciers and Mining

Rich mineral deposits lie within the Coast Mountains, and the difficulty of exploring and mining these deposits has stimulated valuable glaciological work. The experience of the Granduc Operating Company in exploiting a copper deposit near Leduc Glacier illustrates these problems and is a fertile source of cautionary tales. Figure 2 shows the Coast Mountains at the head of Portland Canal, a remarkable fjord less than 5 km across, that extends

Figure 2.—Annotated Landsat MSS image of part of the Coast Mountains near Stewart, British Columbia, and the Granduc mining development. Copper ore is transported through an 18-km tunnel from a mine (shown by a small box) near Leduc Glacier east to a concentrator at the terminus of Berendon Glacier, then by truck to an ocean dock near Stewart. Annotations: 1, the Frank Mackie highland glacier complex; 2, Cambria Snowfield. Landsat image (21288–18435, band 7; 2 August 1978; Path 58, Row 21) is from the EROS Data Center, Sioux Falls, S. Dak. Map references: Leduc Glacier sheet 104B/1 and 104B/2, 1:50,000; Iskut River sheet 104B, 1:250,000.



105 km from near Stewart, British Columbia, southwest to Portland Inlet. Annotations on this figure show the Granduc mine and associated developments for transporting and concentrating the ore. The main practical problem is to transport ore through rough glacier-covered terrain to a dock near Stewart. This is done in two steps: an 18-km-long access tunnel passing beneath Berendon, Frank Mackie, and Leduc Glaciers allows unconcentrated ore to be moved from the mine to a mill at Tide Lake Camp near the terminus of Berendon Glacier. Tide Lake Camp is situated between glacier-dammed Summit Lake and Tide Lake Flats, the bed of a former proglacial lake dammed by Frank Mackie Glacier (Hanson, 1932; Haumann, 1960; Field, 1975). From Tide Lake Camp, the concentrated ore is transported by truck along an access road that follows the margin of Salmon Glacier, then crosses the international boundary and follows the Salmon River from Ninemile, Alaska, to a dock at Hyder, Alaska, near Stewart.

Initial supply of Tide Lake Camp and the mine site was by tractor-hauled sled along routes that passed over Salmon, Berendon, Frank Mackie, and Leduc Glaciers. Crevasses restricted use of these ice roads to the winter months when snow cover made safe crossings possible. In 1955, a fixed-wing landing strip was established on the surface of Leduc Glacier near the

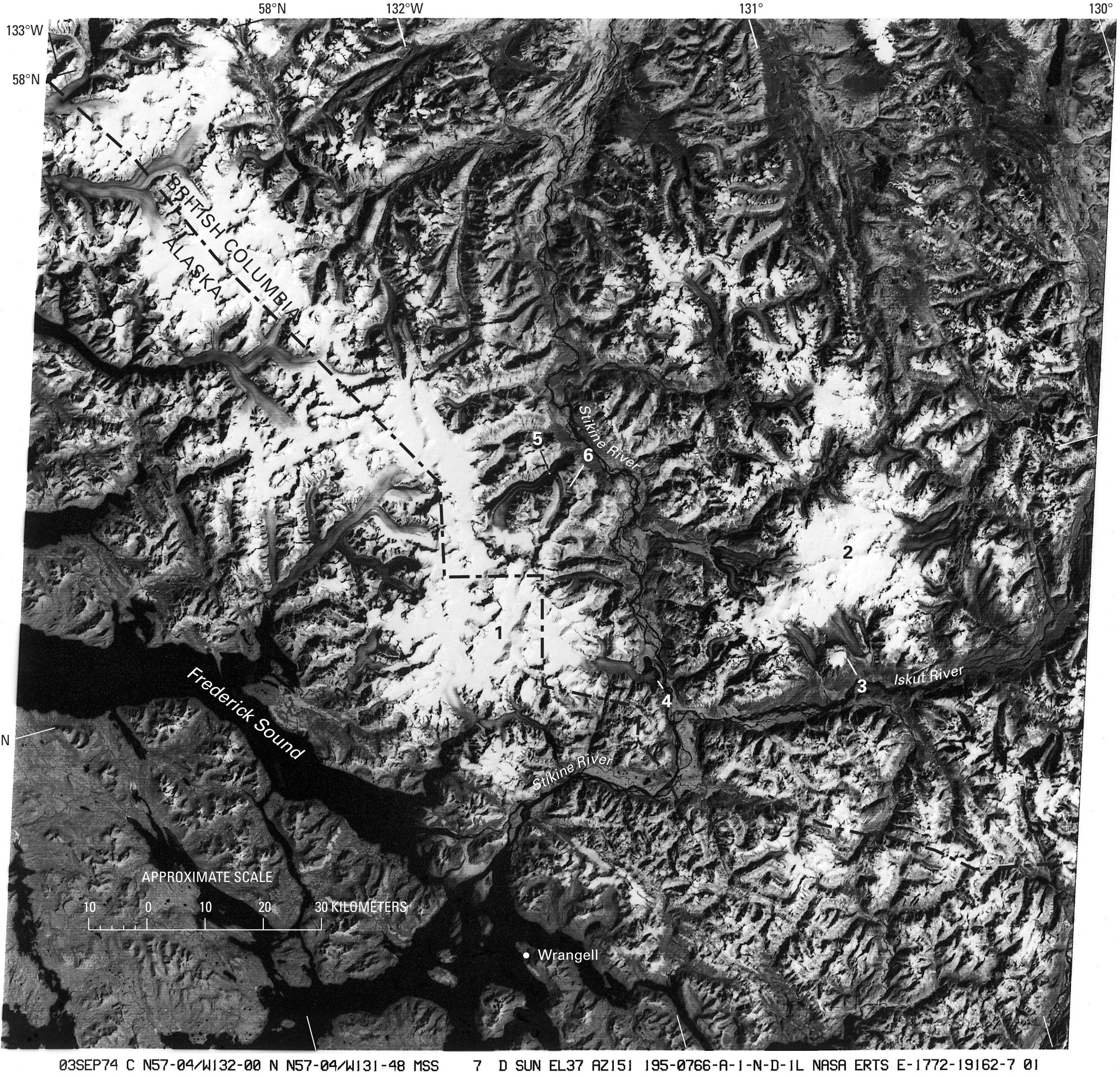


Figure 3.*—Annotated Landsat MSS image of part of the Boundary Ranges of the Coast Mountains near the confluence of the Stikine and Iskut Rivers, British Columbia and Alaska. Hydroelectric development plans for the Stikine-Iskut basin make it necessary to consider glacier hazards. Annotations: 1, 2, highland ice fields; 3, Hoodoo Mountain (a volcano); 4, Great Glacier (according to Native American oral tradition, this glacier once bridged the Stikine River); 5, Flood Glacier; 6, site of glacier-dammed Flood Lake (the 1979 outburst flood released* 200×10^6 m^3 *of water and gave a peak discharge of roughly 3,000* m^3 s^{-1}*). Landsat image (1772–19162, band 7; 3 September 1974; Path 60, Row 20) is from the EROS Data Center, Sioux Falls, S. Dak. Map references: Stikine River sheet 104 SE. and part of 104 SW., 1:506,880; Iskut River sheet 104B, 1:250,000.*

mine site. As ice roads and air transport are not practical for transporting ore from the mine to an ocean port, much of the early glaciological work was directed at selecting possible routes for a tunnel connecting the mine to a concentrator. One of these routes passed beneath Salmon Glacier, so deep drilling, gravity surveys, and seismic soundings were undertaken to ensure that the planned tunnel did not intersect glacier ice (Jacobs, 1958; Mathews, 1959; Russell and others, 1960; Doell, 1963); excellent mapping and glaciological studies were carried out by Haumann (1960). Four of five deep holes drilled through Salmon Glacier in 1956 were believed to have reached bedrock at depths ranging from 495 m to 756 m.

An exploratory cross-cut tunnel at the mine site was driven beneath Leduc Glacier in 1957, and holes were drilled upward from the tunnel into the base of the glacier. These holes eventually became connected to the subglacier drainage network, which caused the lower level of the mine to fill with water (Mathews, 1964). The inflow of water was sufficiently high in volume so that the tunnel could not be reclaimed by pumping; therefore, a complicated engineering operation involving holes that were drilled through Leduc Glacier and that intersected the tunnel had to be employed in an effort to stem the water flow (Walsh, 1963). The problem eventually solved itself when, in midsummer, water level dropped below the tunnel elevation.

Annual snowfall at Stewart is high, averaging 5.5 m a^{-1}, and at Tide Lake Camp, a record annual snow fall of 25 m has been recorded. Such high snowfall in an alpine area obviously creates a grave avalanche hazard. In February 1965, an avalanche destroyed the Granduc Mine Camp near Leduc Glacier and claimed more than 20 lives. Defensive measures were subsequently taken to control avalanches and protect the camp and access road.

Because the tunnel portal and ore concentrator were sufficiently close to the terminus of Berendon Glacier, they could have been destroyed by a glacier advance. Glaciologists contributed to the discussion of a possible advance by measuring mass balance and by predicting glacier variations from a kinematic wave model (Untersteiner and Nye, 1968; Fisher and Jones, 1971). They also suggested methods of prevention or mitigation that used albedo modification (Eyles, 1977; Eyles and Rogerson, 1977b) or that involved pumping 30°C waste water from the copper mill onto the glacier (Eyles and Rogerson, 1977a).

Tide Lake Camp originally drew its water from Summit Lake, but in December 1961, the lake drained unexpectedly through a 12-km melt tunnel beneath Salmon Glacier. The resulting jökulhlaup (glacier outburst flood) released 251×10^6 m^3 of water into the Salmon River drainage. Maximum discharge exceeded 3,000 m^3 s^{-1}, and the flood badly damaged the access road and a bridge at Ninemile. Until 1961, Summit Lake had drained stably to the north through Bowser River, but since 1900, Salmon Glacier has thinned considerably. The resulting reduction of ice pressure favors the formation of a drainage tunnel. The lake now fills and drains annually, but floods are less severe than the 1961 flood. Jökulhlaups from Summit Lake are among the best studied of any in the world (Mathews, 1965, 1973; Gilbert, 1971, 1972; Fisher, 1973; Clarke and Mathews, 1981).

In a fascinating account of the problems facing the mine developers, Mamen (1966) wrote: “When production is finally achieved.... It will mark man’s triumph over some of the severest obstacles Nature has ever placed in the path of mineral discovery and mine development.” This was hardly an overstatement. By 1970, when production began, practically every conceivable glacier-related problem had been faced.

Glaciers and Outburst Floods

Figure 3 shows an annotated Landsat image of the Stikine-Iskut River system in the Boundary Ranges of the Coast Mountains. These rivers join near the British Columbia-Alaska boundary and flow to the Pacific Ocean near Wrangell, Alaska. Two unnamed highland glacier systems are shown in figure 3: one (labeled 1 in figure) lies along the international boundary and is truncated to the south by the Stikine River valley, and the other (labeled 2) lies between the Stikine and Iskut Rivers. Hydroelectric and other development plans for the Stikine-Iskut basin make it necessary to consider glacier-related hazards to downstream structures. As an example, the 1979 jökulhlaup from Flood Lake (labeled 6) released 200×10^6 m^3 of water into the Stikine River, and peak flood discharge was roughly 3,000 m^3 s^{-1} (Mokievsky-Zubok, 1980; Clarke and Waldron, 1984). Similar floods have taken place for at least the past century and were well known to local inhabitants when John Muir visited in 1879 (Muir, 1915). Other large glacier-dammed lakes existed in the past. According to Native American oral tradition, Great Glacier once bridged the Stikine River (Kerr, 1936; Field, 1975). Perchanok (1980) reports that 78 active or potential glacier-dammed lake sites lie within the Stikine-Iskut basin and that jökulhlaups from 10 of these could have significant downstream effects. Apart from explorers' reports and geological reconnaissance work (for example, Kerr, 1948), scientific studies of the glaciers in this part of the Coast Mountains are practically nonexistent.

Recreational and Scientific Roles of Glaciers

Besides creating problems for mining and hydroelectric developments, glaciers give pleasure to hikers and skiers. Figure 4 shows the Coast Mountains in the region of Garibaldi Provincial Park, a popular alpine recreation area near the Whistler-Blackcomb ski resort and the city of Vancouver, British Columbia. Perennial snow patches make individual glaciers difficult to distinguish and give a misleading impression of the amount of ice cover. All the glaciers are small and tend to be associated with major peaks. Garibaldi Névé and its outlet glaciers are the largest glacier feature and lie on the slopes of Mount Garibaldi (2,678 m, labeled 8). Other examples are Cheakumus, Wedge, and Weart Glaciers associated, respectively, with Castle Towers Mountain (2,676 m, labeled 4), Mount Wedge (2,890 m, labeled 3), and Mount Weart (2,834 m, labeled 2). According to Mathews (1951), these peaks projected as nunataks above the Cordilleran ice sheet. Mount Garibaldi and several lesser features are volcanic, and Mathews' suggestion that "volcanism ceased about the time of disappearance of the last ice sheet" makes for interesting speculation. The climatic deterioration of the "Little Ice Age" led to a period of glacier growth that culminated around 1750–1850. At this climax, many of the glaciers were at their greatest extent since the Cordilleran ice sheet had disappeared. The climax has been followed by a period of rapid recession that has lasted to the present time.

Although the glaciers are small, they are relatively well studied owing to their accessibility from the Squamish-Pemberton road. Sentinel and Sphinx Glaciers (labeled 7 and 5), near Garibaldi Lake (labeled 6), have received intermittent scientific attention since 1945 and are well mapped. Their contribution to annual runoff is important; mass-balance variations have been measured, but ice-thickness and flow-velocity measurements are lacking (for example, Reid and Shastal, 1970; Mokievsky-Zubok, 1973; Mokievsky-Zubok and Stanley, 1976a). Wedge Glacier has been mapped, its retreat monitored, and ice-thickness measurements taken. Its maximum measured thickness was only 150 m, and this is likely to be typical for other glaciers in the region (Tupper and others, 1978). Place Glacier, north of Garibaldi Park, has also been mapped, and mass-balance measurements have been taken since 1964 (Mokievsky-Zubok and Stanley, 1976b). Place and Senti-

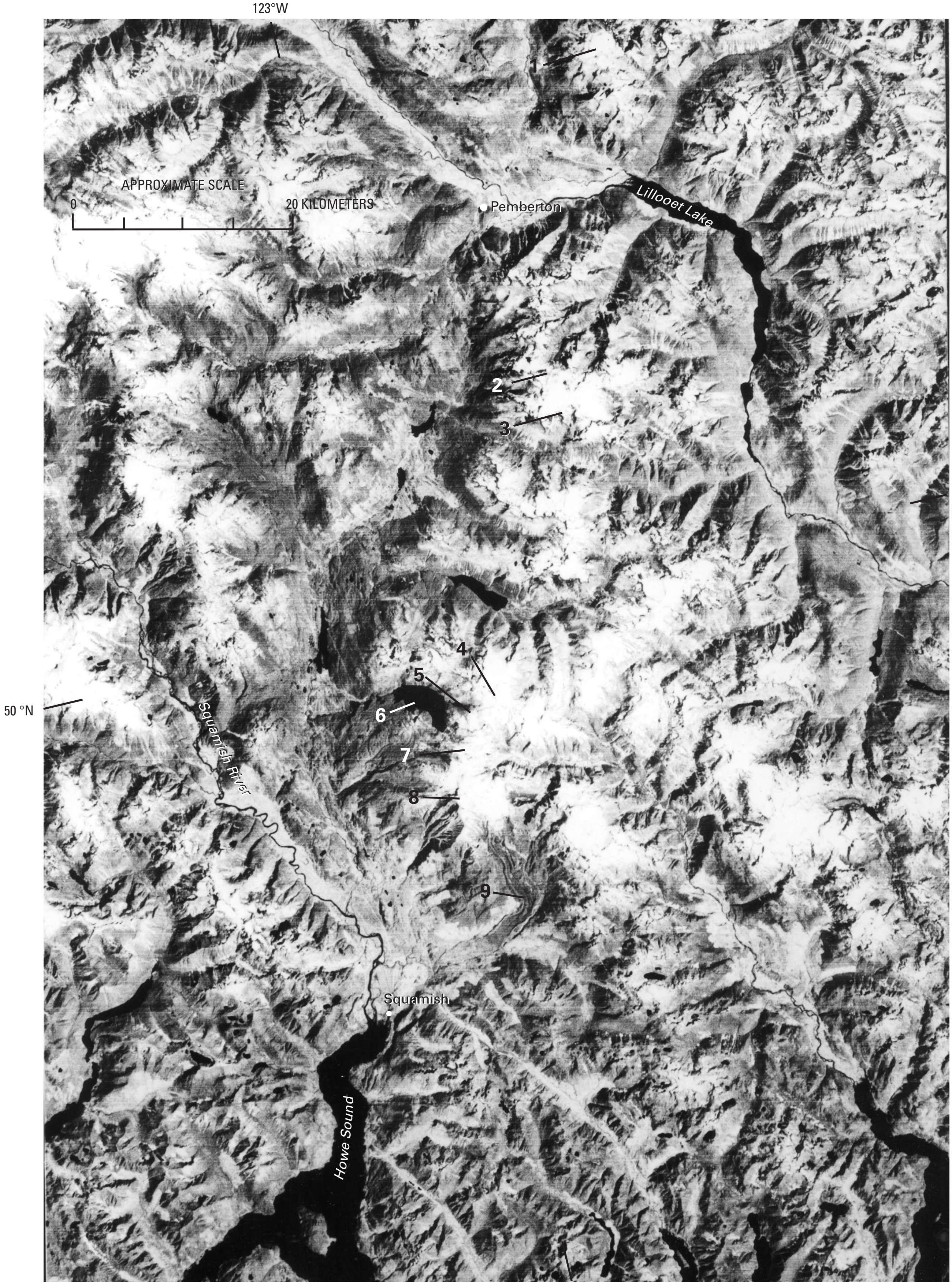


Figure 4.—*Annotated Landsat MSS image showing the region of Garibaldi Provincial Park, an alpine recreation area in the Coast Mountains to the north of Vancouver, British Columbia. Annotations: 1, Place Glacier; 2, Mount Weart; 3, Mount Wedge; 4, Castle Towers Mountain; 5, Sphinx Glacier; 6, Garibaldi Lake; 7, Sentinel Glacier; 8, Mount Garibaldi (elevation 2,678 m); 9, Ring Creek lava flow (note its similarity to a glacier). Landsat image (1385–18362, band 7; 12 August 1973; Path 51, Row 25) is from the EROS Data Center, Sioux Falls, S. Dak. Map references: Pemberton sheet 92J, 1:250,000; Vancouver sheet 92G, 1:250,000.*

nel Glaciers (labeled 1 and 7) are among the three glaciers of the Canadian Cordillera that have been the object of long-term mass-balance measurements, and their role as climate indicators has been examined by Letréguilly (1988) and Letréguilly and Reynaud (1989). A decline in field activity in the 1990's has been somewhat compensated by increasing use of satellite observations (Adam, Pietroniro, and Brugman, 1997; Adam, Toutin, and others, 1997).

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