# Glaciers of North America–

# GLACIERS OF CANADA

## GLACIERS OF THE CANADIAN ROCKIES

*By* C. SIMON L. OMMANNEY

## SATELLITE IMAGE ATLAS OF GLACIERS OF THE WORLD

*Edited by* RICHARD S. WILLIAMS, Jr., *and* JANE G. FERRIGNO

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*The Rocky Mountains of Canada include four distinct ranges from the U.S. border to northern British Columbia: Border, Continental, Hart, and Muskwa Ranges. They cover about 170,000 km$^2$, are about 150 km wide, and have an estimated glacierized area of 38,613 km$^2$. Mount Robson, at 3,954 m, is the highest peak. Glaciers range in size from ice fields, with major outlet glaciers, to glacierets. Small mountain-type glaciers in cirques, niches, and ice aprons are scattered throughout the ranges. Ice-cored moraines and rock glaciers are also common*

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## GLACIERS OF THE CANADIAN ROCKIES

*By* C. Simon L. Ommanney[1]


### Abstract

The Rocky Mountains of Canada include four distinct mountain ranges (Border, Continental, Hart, and Muskwa Ranges) extending from the U.S. border to northern British Columbia, a distance of 1,350 kilometers. The Rocky Mountains encompasses about 170,000 square kilometers, are about 150 kilometers wide, and have an estimated glacierized area of 38,613 square kilometers. Mount Robson, at 3,954 meters above sea level, is the highest peak. Within the Continental Ranges are the Front, *Park*, and Kootenay Ranges; these include some of the most spectacular and heavily glacierized mountains in North America. Major glaciers, such as the Waputik, Wapta, Freshfield, Mons, Lyell, and Columbia Icefields are located in these mountains. The Columbia Icefield (325 square kilometers) is the largest ice field in the Rocky Mountains; its three largest outlet glaciers are the Columbia, Athabasca, and Saskatchewan Glaciers. Glaciers range in size from ice fields, with major outlet glaciers, to glacierets. Small mountain-type glaciers in cirques, niches, and ice aprons are scattered throughout the ranges. Ice-cored moraines and rock glaciers are also common.


## Introduction

To the early explorers, the Rocky Mountains were a seemingly impenetrable barrier blocking access to the Pacific and inhibiting the coastal inhabitants in their movements to the east. The chain covers about 170,000 km$^2$ and stretches in a continuous series of parallel ranges 150-km wide, from the British Columbia/Alberta/United States border some 1,350 km to northern British Columbia, where the Liard River, in cutting through the chain, acts as a convenient boundary. The same mountain mass continues into the Yukon Territory, but the rocks of the mountains, named here the Mackenzie Mountains, are younger geologically. To the east, the limits of the Rocky Mountains are not sharp. From the heights of the Front Ranges, one passes through the Foothills and out into the Interior Plains. To the west, the boundary is marked by one of the world's greatest physiographic features, which can even be seen from the Moon—the Rocky Mountain Trench. The trench continues through the Yukon Territory and Alaska as the Tintina Trench. The highest elevation in the Rocky Mountains is Mount Robson, at 3,954 m above sea level (asl). The lowest elevation, 305 m, is in the north at the junction of the Liard and Toad Rivers.

Gadd (1986) gives an excellent account of the geology of the Rocky Mountains. The mountains were formed by strong compressive forces generated to the west of the Rocky Mountain Trench. During a 75-million-year period that began about 120 million years ago, a series of thrust faults forced the Precambrian, Paleozoic, and Mesozoic sedimentary rocks eastward along a fault

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plane over the soft Cretaceous shales of the Great Plains. The compressive forces produced a series of folds, which give the Rocky Mountains their characteristic parallel ranges. During the last 2 million years, intense glaciation in the region has eroded the mountains into big, rugged peaks separated by deep, wide valleys, creating a striking east-facing scarp.

There are four distinct ranges within the Rocky Mountains region, known as the Border, Continental, Hart, and Muskwa Ranges (figs. 1 and 2).[2] Included in the Continental Ranges are the Front, *Park*, and Kootenay Ranges. The distinctions between the ranges are based largely on geologic structure and physiography. The entire region is characterized by limestones, quartzites, and argillites, which form massively bold peaks, best expressed in the *Park Ranges* of the Continental Ranges. The *Park Ranges* contain some of the most spectacular and heavily glacierized mountains in North America (fig. 3). Flat to gently dipping beds of quartzite or limestone have produced castellated peaks, subsequently modified by glacial oversteepening; large talus cones have developed postglacially. Summit elevations decline northward and southward from the *Park Ranges*; in particular, the Hart Ranges are considerably lower than the other three ranges. Elevations increase farther north in the Muskwa Ranges, and the castellated limestone and quartzite peaks reappear around Churchill Peak (3,200 m) and Mount Lloyd George (3,000 m) (Slaymaker, 1972).

Glaciers in the Rocky Mountains (fig. 4, table 1) are typically of the small mountain type, lying in cirques, niches, or along some of the upturned strata as ice aprons. Scattered at intervals along the range are larger ice fields,[3] with major outlet and valley glaciers. Glacierets, ice-cored moraines, and rock glaciers occur at the limits of contemporary glacierization. In some situations, the avalanching of hanging glaciers has created regenerated glaciers lower on the mountain; part of the nourishment of the well-known Victoria Glacier is of this form (fig. 5).

Unfortunately, the precise area of permanent snow and ice in the Rockies is not known. Henoch (1967) made a determination for the major Canadian drainage areas, but because the Columbia Icefield drains to the Pacific Ocean, to Great Slave Lake, and into the Nelson River system that empties into Hudson Bay, it is hard to determine what proportion of the total area should be attributed to the Rocky Mountains alone (table 2).

The nature of the ice cover within part of the Rocky Mountains is indicated in table 3 (Ommanney, 1972a), which shows the distribution of various glacier types within the Nelson River drainage basin, stretching from Waterton Lakes National Park to the southern part of the Columbia Icefield. Major ice fields,[3] such as the Waputik, Wapta, Freshfield, Mons, Lyell, and Columbia Icefields,[3] are not adequately reflected in table 3. Because of the nature of their subglacial topography and ice cover, all of the constituent glaciers can be identified individually.

Hydrometric stations in the *Park Ranges* and Muskwa Ranges typically show two prominent stream-discharge peaks that correspond to snowmelt (June) and glacier melt (July–August), in addition to a minor peak in the fall. In the Hart Ranges, the glacier-melt peak is generally absent, whereas there is neither a fall-rain peak nor a glacier-melt peak (Slaymaker, 1972) in the Border Ranges farther south.

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[2] The names in this section conform to the usage authorized by the Secretariat of the Canadian Permanent Committee on Geographic Names (CPCGN); URL address: [http:// geonames.nrcan.gc.ca/english]. The Website is maintained by the Secretariat through Geomatics Canada, Natural Resources Canada, and combines the GPCGN server with the Canadian Geographical Names Data Base (CGNDB). Variant names and names not listed in the GPCGN/CGNDB are shown in italics. See also Canadian gazetteers for British Columbia (CPCGN, 1985) and for Alberta (CPCGN, 1988).

[3] Ice field is used in glaciological terminology to refer to “an extensive mass of land ice covering a mountain region consisting of many interconnected alpine and other types of glaciers, covering all but the highest peaks and ridges” (Jackson, 1997, p. 316). The UNESCO (1970) definition is slightly different. “Ice masses of sheet or blanket type of a thickness not sufficient to obscure the subsurface topography.” In Canada, icefield is used as a synonym for glacier in many glacier place-names and in the text to refer to such place-names, but is not necessarily used in the formal glaciological sense.

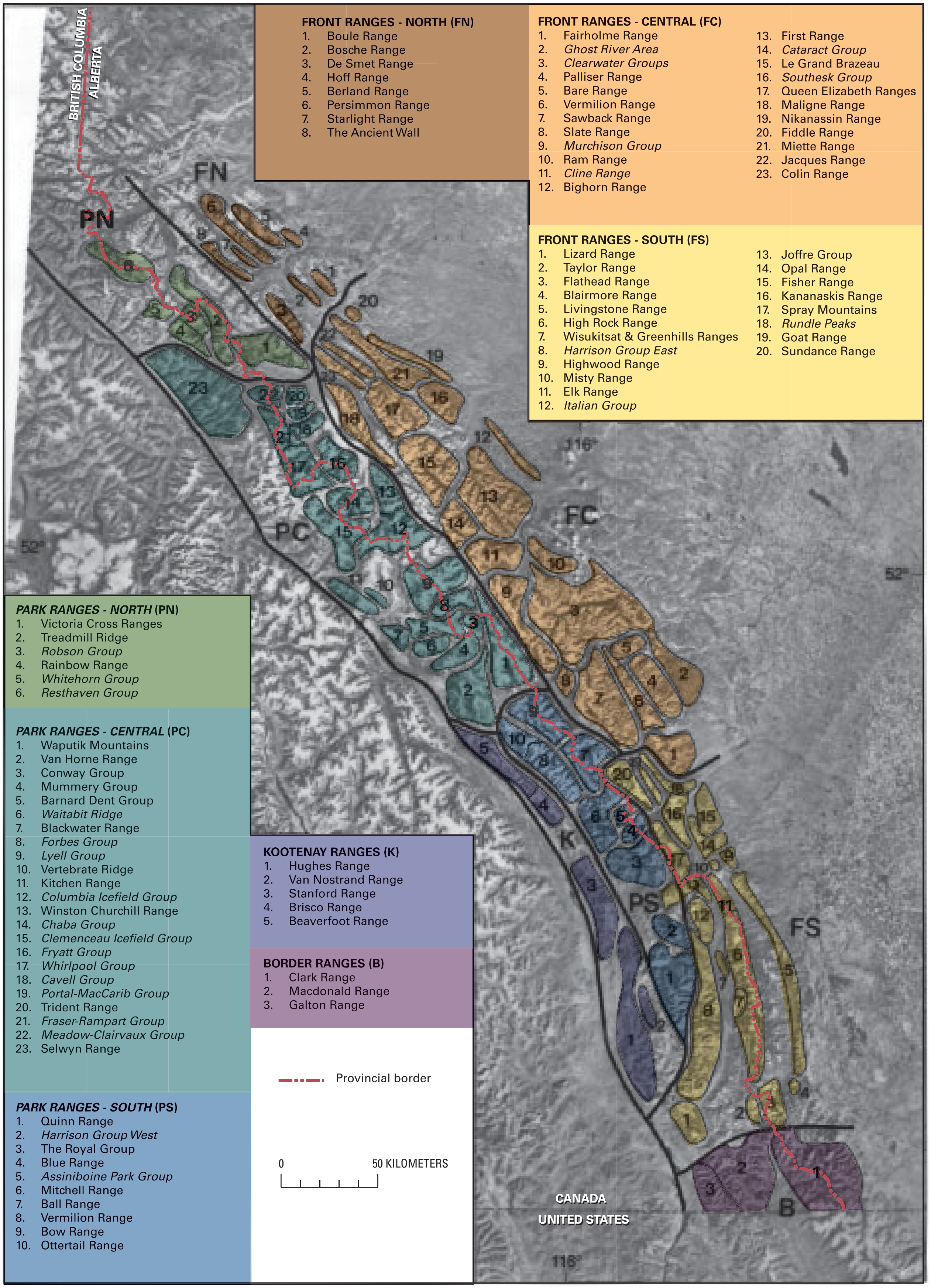



***Figure 1.***—*Mountain ranges of the southern Rocky Mountains. Landsat image mosaic used as map base.*

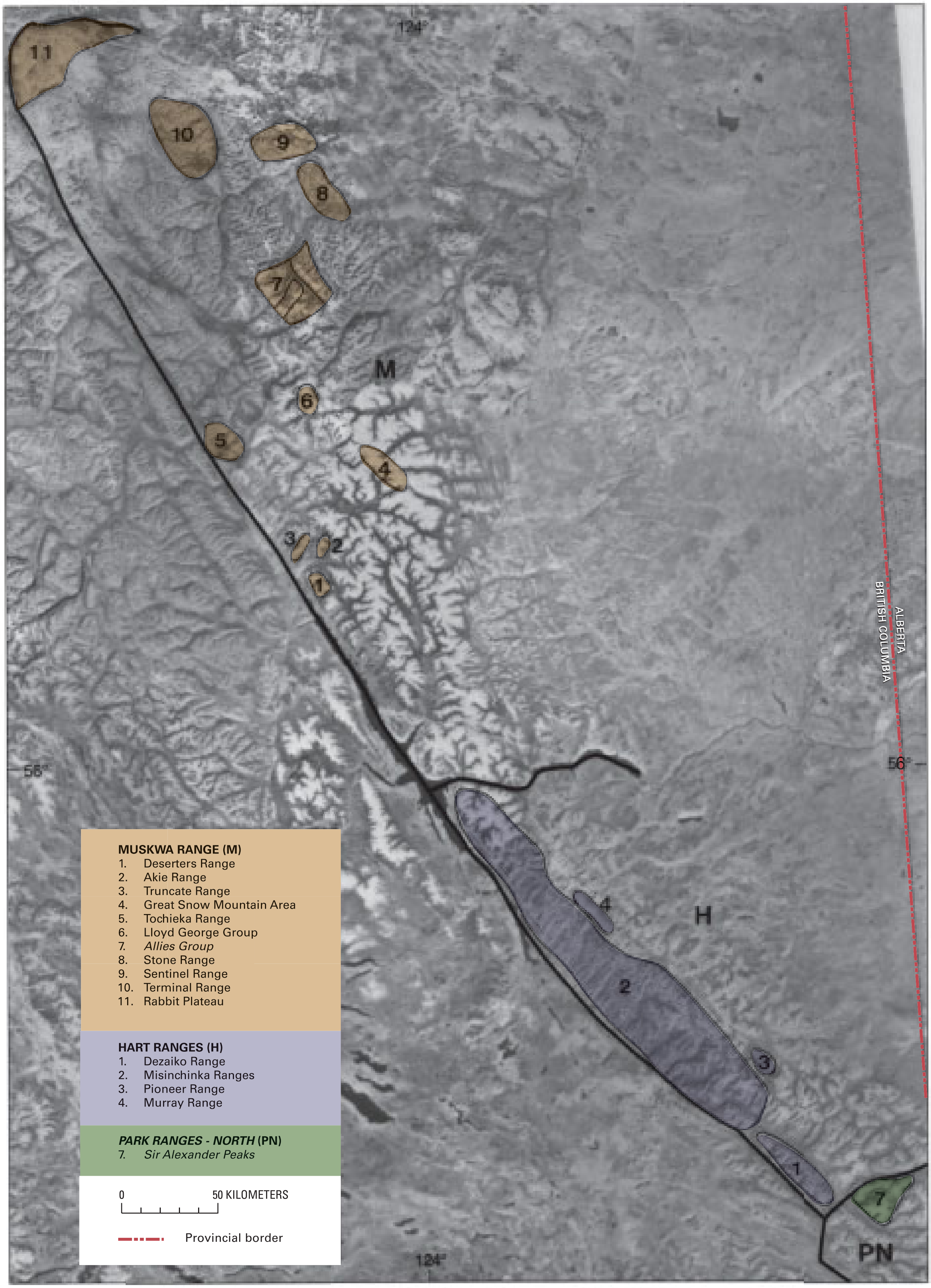



***Figure 2.***—*Mountain ranges of the northern Rocky Mountains. Landsat image mosaic used as map base.*

***Figure 3.**—High-angle oblique aerial photograph of Mount Assiniboine and environs, Banff National Park, Rocky Mountains, Canada, an area of spectacular relief and glacierized peaks. U.S. Geological Survey (USGS) photograph 69L2117, taken 8 September 1969 by Austin Post, is courtesy of Robert M. Krimmel, USGS.*

The glaciers and terrain of the major mountain ranges and their subsidiary mountain ranges, mountains, mountain groups, mountains peaks, and mountain ridges will be discussed here in turn, beginning with the Border Ranges at the southern end of the Rocky Mountains. All major ranges are identified by an alphanumeric code in figures 1 and 2.[4] The Continental Ranges, the largest mountain mass, are subdivided into a southern, central, and northern part because they cover such a large area. Within each subdivision, the mountains of the Front and Kootenay Ranges and *Park Ranges* are considered in turn. The terminology has been drawn from maps and alpine guides (Putnam and others, 1974; Boles and others, 1979); however, some of the names are not endorsed by the Canadian Permanent Committee on Geographical Names (CPCGN).[2] Those place-names not yet approved by the CPCGN are shown in italics.

[4] The major mountain ranges are coded with letters; subsidiary mountain ranges, mountains, mountain groups, mountain peaks, and mountain ridges are coded with numbers. It is noteworthy that many of the subsidiary mountain ranges have never been given formal names; in the subheadings in the text, they are simply referred to as "unnamed range." On figures 1 and 2 they are unnumbered. Glaciers and ice fields are described within the subsidiary mountain ranges, etc. The letters and numbers are keyed to figures 1 and 2, which delineate each major and subsidiary mountain ridge on a Landsat image mosaic base map.


***Figure 4.***—*Sketch map showing glaciers of the Canadian Rocky Mountains. Modified from the Canadian Geographic (Shilts and others, 1998). Used with permission.*

TABLE 1.—*Named glaciers of the Rocky Mountains cited in the chapter*

[The geographic coordinates for glaciers whose names have not been formally approved (shown in italics) may not be accurate. N.P. = National Park; BC = British Columbia; AB = Alberta; -- not shown in geonames database or glacier name is informal (italics); glacier name, map sheet, location of glacier, and province checked against the archives of the Geographical Names of Canada, Geomatics Canada, Natural Resources Canada [http://geonames.nrcan.gc.ca]]

| Glacier Name | Map sheet (1:250,000-scale) | Latitude North | Longitude West | Location | Province |
|---|---|---|---|---|---|
| Abruzzi Glacier | 082J06 | 50°25.0' | 115°07.0' | Kootenay | BC |
| Achaean Glacier | 094F08 | 57°22.0' | 124°04.0' | Peace River | BC |
| Albert Glacier | 082N04 | 51°02.5' | 117°50.5' | Kootenay | BC |
| Alexandra Glaciers | 082N14 | 51°59.0' | 117°09.0' | Banff N.P. | AB |
| Alexandra Icefield | 082N14 | 51°59.5' | 117°12.0' | Banff N.P./ Kootenay | AB/BC |
| Angel Glacier | 083D09 | 52°41.0' | 118°04.0' | Jasper N.P. | AB |
| Apex Glacier | 083C04 | 52°08.2' | 117°44.0' | Kootenay | BC |
| Athabasca Glacier | 083C03 | 52°11.0' | 117°15.7' | Jasper N.P. | AB |
| Ayesha Glacier | 082N10 | 51°38.8' | 116°35.6' | Kootenay | BC |
| Balfour Glacier | 082N09 | 51°34.0' | 116°26.0' | Banff N.P. | AB |
| Barbette Glacier | 082N10 | 51°44.0' | 116°36.0' | Banff N.P. | AB |
| Bath Glacier | 082N09 | 51°31.0' | 116°23.0' | Banff N.P. | AB |
| Beatty Glacier | 082J11 | 50°40.5' | 115°17.0' | -- | AB |
| Bennington Glacier | 083D09 | 52°40.5' | 118°19.0' | Cariboo | BC |
| Bennington Icefield | 083D09 | 52°39.3' | 118°17.9' | -- | AB |
| Berg Glacier | 083E03 | 53°07.0' | 119°08.0' | Cariboo | BC |
| Bonnet Glacier | 082O05 | 51°27.0' | 115°55.0' | Banff N.P. | AB |
| Boundary Glacier[1] | 083C03 | 52°11.5' | 117°11.4' | -- | AB |
| Bow Glacier | 082N10 | 51°38.9' | 116°30.4' | Banff N.P. | AB |
| Brazeau Icefield | 083C11 | 52°32.2' | 117°18.3' | -- | AB |
| Cairnes Glacier | 082N10 | 51°42.8' | 116°46.3' | Kootenay | BC |
| Campbell Glacier | 082N10 | 51°44.0' | 116°59.0' | Kootenay | BC |
| Campbell Icefield | 082N10 | 51°43.2' | 116°58.0' | Kootenay | BC |
| Castelnau Glacier | 082J11 | 50°31.5' | 115°09.4' | Kootenay | BC |
| Castle Glacier | 093H16 | 53°59.6' | 120°23.8' | -- | BC |
| *Castleguard Glacier I*[2] | 083C03 | 52°06.7' | 117°13.7' | Banff N.P. | AB |
| *Castleguard Glacier II*[2] | 083C03 | 52°06.2' | 117°14.5' | Banff N.P. | AB |
| *Castleguard Glacier III*[2] | 083C03 | 52°05.9' | 117°15.2' | Banff N.P. | AB |
| *Castleguard Glacier IV*[2] | 083C03 | 52°04.9' | 117°16.3' | Banff N.P. | AB |
| Cathedral Glacier[3] | 082N08 | 51°24.3' | 116°23.4' | -- | BC |
| Cavell Glacier | 083D09 | 52°40.9' | 118°03.0' | -- | AB |
| Center Glacier | 083C13 | 52°50.0' | 117°55.0' | -- | AB |
| Chaba Glacier | 083C04 | 52°14.0' | 117°41.0' | Jasper N.P. | AB |
| Chaba Icefield | 083C05 | 52°17.0' | 117°51.0' | Kootenay | BC |
| Chown Glacier | 083E06 | 53°23.0' | 119°23.0' | Jasper N.P. | AB |
| Clairvaux Glacier | 083D16 | 52°46.4' | 118°23.8' | Jasper N.P. | AB |
| Clemenceau Glacier | 083C04 | 52°14.0' | 117°54.0' | Kootenay | BC |
| Clemenceau Icefield | 083C04 | 52°11.0' | 117°48.0' | Kootenay | BC |
| Coleman Glacier | 083E03 | 53°10.0' | 119°02.7' | Jasper N.P. | AB |
| Columbia Glacier | 083C03 | 52°09.6' | 117°22.8' | Jasper N.P. | AB |
| Columbia Icefield[4] | 083C03 | 52°09.5' | 117°19.0' | Kootenay | BC |
| Columbia Icefield[4] | 083C03 | 52°09.5' | 117°18.0' | Jasper N.P. | AB |
| Conway Glacier | 082N15 | 51°46.1' | 116°49.1' | Banff N.P. | AB |
| *Cornucopia Glacier* | 083C11 | 52°33.5' | 117°14.8' | -- | AB |
| Coronet Glacier | 083C11 | 52°31.0' | 117°21.0' | Jasper N.P. | AB |
| Crowfoot Glacier | 082N09 | 51°38.3' | 116°25.2' | Banff N.P. | AB |
| Daly Glacier | 082N09 | 51°31.0' | 116°26.5' | Yoho N.P. | BC |

TABLE 1.—*Named glaciers of the Rocky Mountains cited in the chapter*—Continued

| Glacier Name | Map sheet (1:250,000-scale) | Latitude North | Longitude West | Location | Province |
|---|---|---|---|---|---|
| Delta Glacier[5] | 082N10 | 51°43.3' | 116°35.0' | Banff N.P. | AB |
| Diadem Icefield | 083C06 | 52°19.6' | 117°25.0' | -- | AB |
| Dome Glacier[6] | 083C03 | 52°12.1' | 117°18.1' | Jasper N.P. | AB |
| Drummond Glacier | 082N09 | 51°36.0' | 116°03.0' | Banff N.P. | AB |
| Duplicate Glacier | 083C04 | 52°12.8' | 117°54.8' | Kootenay | BC |
| East Glacier | 082N15 | 51°52.2' | 116°55.2' | Banff N.P. | AB |
| East Goodsir Glacier | 082N01 | 51°12.4' | 116°21.5 | Yoho N.P. | BC |
| East Lyell Glacier | 082N14 | 51°57.5' | 117°04.5' | Banff N.P. | AB |
| Elk Glacier | 082J11 | 50°31.0' | 115°09.0' | Kootenay | BC |
| Emerald Glacier | 082N07 | 51°30.0' | 116°32.0' | Yoho N.P. | BC |
| Eremite Glacier | 083D09 | 52°38.0' | 118°14.0' | Jasper N.P. | AB |
| *Foch Glacier* | 082J11 | 50°34.5' | 115°10.3' | -- | AB |
| Fraser Glacier | 083D09 | 52°38.2' | 118°16.7' | Jasper N.P. | AB |
| Freshfield Glacier | 082N15 | 51°47.0' | 116°53.0' | Banff N.P. | AB |
| Freshfield Icefield | 082N10 | 51°45.0' | 116°54.0' | Banff N.P. | AB |
| Fusilier Glacier | 094K07 | 58°22.0' | 124°52.0' | Peace River | BC |
| Ghost Glacier | 083C05 | 52°19.6' | 117°53.6' | Kootenay | BC |
| Glacier des Poilus | 082N10 | 51°34.0' | 116°35.0' | Yoho N.P. | BC |
| Gong Glacier | 083C06 | 52°22.0' | 117°28.8' | Jasper N.P. | AB |
| Goodsir Glacier | 082N01 | 51°12.2' | 116°22.6' | Yoho N.P. | BC |
| Great Snow Icefield | 094F08 | 57°27.0' | 124°06.0' | -- | BC |
| Haig Glacier[4] | 082J11 | 50°43.0' | 115°17.0' | -- | AB |
| Haig Glacier[4] | 082J11 | 50°43.0' | 115°19.0' | Kootenay | BC |
| Hanbury Glacier | 082N01 | 51°15.0' | 116°30.0' | Yoho N.P. | BC |
| Hector Glacier | 082N09 | 51°35.7' | 116°15.5' | Banff N.P. | AB |
| Hilda Glacier | 083C03 | 52°11.0' | 117°10.0' | -- | AB |
| Hooker Glacier | 083D08 | 52°23.4' | 118°05.0' | Kootenay | BC |
| Hooker Icefield[4] | 083D08 | 52°25.0' | 118°05.0' | Jasper N.P. | AB |
| Hooker Icefield[4] | 083D08 | 52°25.0' | 118°05.5 | Kootenay | BC |
| Horseshoe Glacier[7] | 082N08 | 51°20.5' | 116°16.0' | Banff N.P. | AB |
| Huntington Glacier | 083C02 | 52°09.8' | 116°57.6' | -- | AB |
| Ithaca Glacier | 094F08 | 57°23.0' | 124°08.0' | Peace River | BC |
| Kane Glacier[4] | 083D08 | 52°24.0' | 118°10.1' | Jasper N.P. | AB |
| Kane Glacier[4] | 083D08 | 52°24.6' | 118°09.5' | Kootenay | BC |
| King George Glacier | 082J11 | 50°35.8' | 115°23.6' | -- | BC |
| Kitchi Glacier | 093H16 | 53°54.3' | 120°24.5' | -- | BC |
| Kwadacha Glacier | 094F15 | 57°49.0' | 124°55.0' | Cassiar | BC |
| Lambe Glacier | 082N10 | 51°44.5' | 116°46.7' | Kootenay | BC |
| Lefroy Glacier | 082N08 | 51°22.5' | 116°16.1' | Banff N.P. | AB |
| Llanberis Glacier | 094F14 | 57°51.0' | 125°00.0' | Cassiar | BC |
| Lloyd George Glacier | 094F15 | 57°55.0' | 124°55.0' | Peace River | BC |
| Lloyd George Icefield | 094F15 | 57°52.0' | 124°58.0' | Peace River | BC |
| Lyautey Glacier | 082J11 | 50°37.0' | 115°13.0' | -- | AB |
| Lyell Icefield[4] | 082N14 | 51°55.8' | 117°04.7' | Kootenay | BC |
| Lyell Icefield[4] | 082N14 | 51°56.0' | 117°05.0' | Banff N.P. | AB |
| Mangin Glacier | 082J11 | 50°33.0' | 115°13.0' | -- | AB |
| Mary Vaux Glacier | 083C11 | 52°34.0' | 117°27.5' | -- | AB |
| Mastodon Glacier | 083D09 | 52°37.0' | 118°16.7' | Jasper N.P. | AB |
| McConnell Glacier | 094F14 | 57°57.8' | 125°14.0' | Cassiar | BC |

TABLE 1.—*Named glaciers of the Rocky Mountains cited in the chapter*—Continued

| Glacier Name | Map sheet (1:250,000-scale) | Latitude North | Longitude West | Location | Province |
|---|---|---|---|---|---|
| Meadow Glacier | 083D16 | 52°45.6' | 118°23.3' | Jasper N.P. | AB |
| Menagerie Glacier | 093H16 | 53°55.0' | 120°23.5' | -- | BC |
| Mist Glacier[8] | 083E03 | 53°07.7' | 119°10.0' | Cariboo | BC |
| Misty Glacier | 083C05 | 52°17.6' | 117°51.2' | Kootenay | BC |
| Molar Glacier | 082N09 | 51°37.1' | 116°16.0' | Banff N.P. | AB |
| Monkman Glacier | 093I11 | 54°34.0' | 121°22.0' | Peace River | BC |
| Mons Glacier | 082N15 | 51°52.5' | 116°59.3' | Banff N.P. | AB |
| Mons Icefield[4] | 082N14 | 51°51.5' | 117°00.7' | Banff N.P. | AB |
| Mons Icefield[4] | 082N14 | 51°52.0' | 117°00.0' | Kootenay | BC |
| Mount Brown Icefield | 083D08 | 52°22.1' | 118°136' | Cariboo; Kootenay | BC |
| Mount Brown Icefield | 083D08 | 52°22.0' | 118°13.0' | -- | AB |
| Mummery Glacier | 082N10 | 51°40.5' | 116°49.0' | Kootenay | BC |
| Mural Glacier | 083E03 | 53°12.0' | 119°11.0' | Jasper N.P. | AB |
| Murchison Icefield | 082N15 | 51°55.0' | 116°38.0' | Banff N.P. | AB |
| Nivelle Glacier | 082J11 | 50°31.0' | 115°11.0' | Kootenay | BC |
| Niverville Glacier | 082N15 | 51°47.2' | 116°57.5' | Banff N.P. | AB |
| North Alnus Glacier | 083D08 | 52°26.6' | 118°01.6' | Kootenay | BC |
| North Glacier | 082N15 | 51°52.3' | 116°57.3' | Banff N.P. | AB |
| Odyssey Icefield | 094F08 | 57°20.0' | 124°05.0' | -- | BC |
| Pangman Glacier | 082N15 | 51°46.0 | 116°57.0' | Banff N.P. | AB |
| Para Glacier | 083D09 | 52°39.7' | 118°16.8' | -- | AB |
| Paragon Glacier | 083D09 | 52°41.0' | 118°18.0' | -- | BC |
| Parapet Glacier[4,9] | 082N10 | 51°44.5' | 116°38.3' | -- | AB |
| Parapet Glacier[4] | 082N10 | 51°44.5' | 116°38.3' | Kootenay | BC |
| Parsnip Glacier | 093I11 | 54°32.0' | 121°27.0' | Peace River | BC |
| Peyto Glacier | 082N10 | 51°40.6' | 116°32.8' | Banff N.P. | AB |
| President Glacier | 082N07 | 51°30.2' | 116°34.3' | -- | BC |
| Prince Albert Glacier | 082J11 | 50°36.2' | 115°24.7' | -- | BC |
| Princess Mary Glacier | 082J11 | 50°35.0' | 115°24.2' | -- | BC |
| Pétain Glacier | 082J11 | 50°32.0' | 115°10.0' | Kootenay | BC |
| Quentin Glacier | 094F15 | 57°55.0' | 124°58.0' | Cassiar | BC |
| Rae Glacier | 082J10 | 50°37.4' | 114°59.1' | -- | AB |
| Ram River Glacier | 082N16 | 51°51.0' | 116°11.0' | -- | AB |
| Reef Glaciers | 083E03 | 53°07.0' | 119°00.5' | Cariboo | BC |
| Reef Icefield[4] | 083E02 | 53°08.5' | 119°00.6' | Jasper N.P. | AB |
| Reef Icefield[4] | 083E02 | 53°08.5' | 119°00.6' | Cariboo | BC |
| Resthaven Icefield | 083E06 | 53°26.0' | 119°28.0' | Jasper N.P. | AB |
| Rice Glaciers | 083C03 | 52°00.0' | 117°15.0' | -- | BC |
| Robson Glacier | 083E03 | 53°08.0' | 119°06.0' | Cariboo | BC |
| Saskatchewan Glacier | 083C03 | 52°08.3' | 117°12.1' | Banff N.P. | AB |
| Scarp Glacier | 083D09 | 52°38.9' | 118°21.4' | Cariboo | BC |
| Scott Glacier | 083D08 | 52°26.0' | 118°05.0' | Jasper N.P. | AB |
| Serenity Glacier | 083C05 | 52°23.0' | 117°59.0' | Kootenay | BC |
| Sharp Glacier | 082N01 | 51°12.2' | 116°20.1' | Kootenay N.P. | BC |
| Simon Glacier | 083D09 | 52°38.2' | 118°18.8' | Jasper N.P. | AB |
| Sir Alexander Icefield | 093H16 | 53°56.0' | 120°23.0' | Cariboo | BC |
| Sir James Glacier | 082N15 | 51°52.1' | 116°52.8' | Banff N.P. | AB |
| South Alnus Glacier | 083D08 | 52°24.7' | 118°00.4' | Kootenay | BC |
| Southeast Lyell Glacier | 082N14 | 51°54.5' | 117°01.6' | Banff N.P. | AB |

TABLE 1.—*Named glaciers of the Rocky Mountains cited in the chapter*—Continued

| Glacier Name | Map sheet (1:250,000-scale) | Latitude North | Longitude West | Location | Province |
|---|---|---|---|---|---|
| Southwest Lyell Glaciers....... | 082N14 | 51°54.7' | 117°05.4' | Kootenay | BC |
| Stagnant Glacier.................... | 094F14 | 57°52.0' | 125°03.0' | Cassiar | BC |
| Stanley Glacier ...................... | 083C04 | 52°08.1' | 117°56.6' | Kootenay | BC |
| Steppe Glacier[4]...................... | 083E03 | 53°09.5' | 119°00.6' | Cariboo | BC |
| Steppe Glacier[4]...................... | 083E03 | 53°09.0' | 119°01.0' | Jasper N.P. | AB |
| Stutfield Glacier..................... | 083C03 | 52°14.0' | 117°21.5' | Jasper N.P. | AB |
| Swiftcurrent Glacier ............. | 083E03 | 53°09.8' | 119°17.8' | Cariboo | AB |
| Swiftcurrent Icefield ............. | 083E03 | 53°11.0' | 119°15.0' | -- | AB/BC |
| Tipperary Glacier .................. | 082J11 | 50°41.0' | 115°24.0' | -- | BC |
| Tumbling Glacier[10]................ | 082N01 | 51°07.5' | 116°14.2' | Kootenay N.P. | BC |
| Tusk Glacier........................... | 083C04 | 52°14.0' | 117°56.0' | Kootenay | BC |
| Victoria Glacier...................... | 082N08 | 51°23.0' | 116°16.0' | Banff N.P. | AB |
| Vista Glacier........................... | 083D16 | 52°46.3' | 118°26.5' | Cariboo | BC |
| Vreeland Glacier.................... | 093I11 | 54°34.0' | 121°27.0' | Peace River | BC |
| Vulture Glacier[4]..................... | 082N09 | 51°35.9' | 116°27.5' | Banff N.P. | AB |
| Vulture Glacier[4]..................... | 082N09 | 51°35.9' | 116°27.5' | Kootenay | BC |
| Waitabit Glacier..................... | 082N10 | 51°42.0' | 116°54.7' | Kootenay | BC |
| Wales Glacier[4] ....................... | 083C04 | 52°10.0' | 117°37.5 | Jasper N.P. | AB |
| Wales Glacier[4] ....................... | 083C04 | 52°09.2' | 117°39.6' | Kootenay | BC |
| Wapta Icefield[4]....................... | 082N09 | 51°38.0' | 116°30.0' | Banff N.P. | AB |
| Wapta Icefield[4]....................... | 082N09 | 51°38.0' | 116°30.0' | Kootenay | BC |
| Waputik Glacier..................... | 082N09 | 51°32.3' | 116°22.8' | Banff N.P. | AB |
| Waputik Icefield[4]................... | 082N09 | 51°34.5' | 116°27.2' | Banff N.P. | AB |
| Waputik Icefield[4]................... | 082N09 | 51°34.0' | 116°27.0' | Yoho N.P. | BC |
| Washmawapta Icefield.......... | 082N01 | 51°10.0' | 116°18.0' | Kootenay | BC |
| Wenkchemna Glacier............ | 082N08 | 51°18.7' | 116°14.2' | Banff N.P. | AB |
| West Alexandra Glacier......... | 082N14 | 51°59.0' | 117°13.0' | Kootenay | BC |
| West Chaba Glacier............... | 083C04 | 52°15.0' | 117°46.1' | -- | AB |
| West Glacier........................... | 082N15 | 51°51.6' | 116°59.3' | Banff N.P. | AB |
| West Washmawapta Glacier.. | 082N01 | 51°11.0' | 116°19.0' | Kootenay | BC |
| Wilson Icefield ....................... | 083C02 | 52°01.1' | 116°48.0' | Banff N.P. | AB |
| Wishaw Glacier...................... | 093H16 | 53°57.0' | 120°12.0' | Peace River | BC |
| Wokkpash Glacier ................. | 094K07 | 58°16.0' | 124°43.0' | Peace River | BC |
| Yoho Glacier........................... | 082N10 | 51°36.0' | 116°33.0' | Yoho N.P. | BC |

[1] Two other Boundary Glaciers, in Cassiar, BC, are listed in the geonames database.

[2] Castleguard Glacier, without roman numeral subdivisions, in Banff N.P., AB, is listed in the geonames database.

[3] Two other Cathedral Glaciers, in Cassiar, BC, and in Yukon Territory, are listed in the geonames database.

[4] Some glaciers and icefields straddle the border between the Provinces of Alberta (AB) and British Columbia; hence, they are listed twice although the ice is contiguous.

[5] There is another Delta Glacier, in Cassiar, BC, listed in the geonames database.

[6] Another Dome Glacier, in Nunavut, is listed in the geonames database.

[7] Another Horseshoe Glacier, in Kootenay, BC, is listed in the geonames database.

[8] Another Mist Glacier, in Kootenay, BC, is listed in the geonames database.

[9] In addition to the Parapet Glacier in the Rocky Mountains, there is a Parapet Glacier in Nunavut listed in the geonames database.

[10] Another Tumbling Glacier, in Nunavut, is listed in the geonames database.

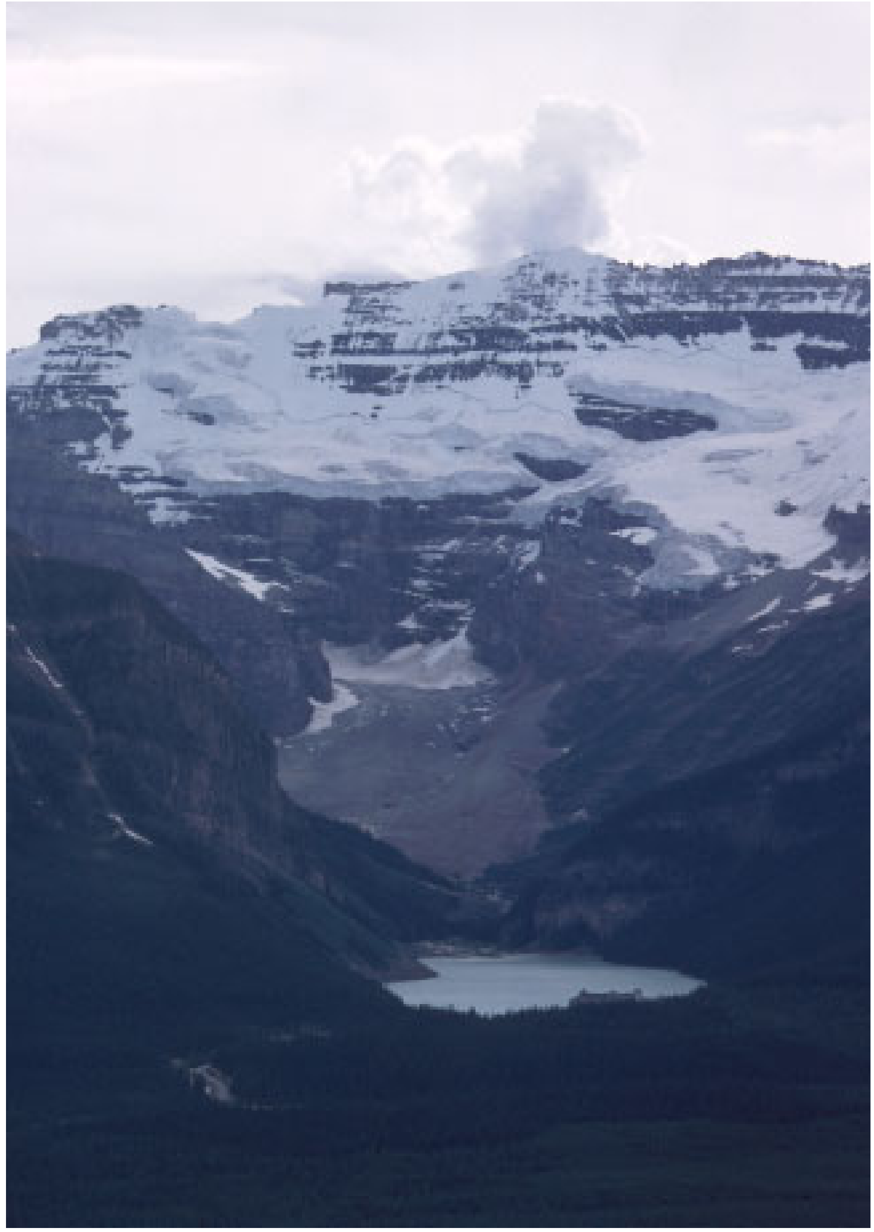
*

***Figure 5**.—Photograph of the Victoria Glacier, Rocky Mountains, Alberta, Canada, in August 1973, showing its morainic-debris-covered terminus and glacierets on the steep valley wall. Photograph by C. Simon L. Ommanney, National Hydrology Research Institute [NTS Map: 082N08]. Glacier 4*5BAA–37, Glacier Atlas of Canada, Plate 7.3, Red Deer River, Glacier Inventory, Area 4*5, Inland Waters Branch, Department of Energy, Mines and Resources, 1970, scale 1:500,000.*

TABLE 2.—*Estimate of glacierized area of the Rocky Mountains of Canada (from Henoch, 1967)*

| Drainage Areas | Area (square kilometers) |
|---|---|
| Pacific Ocean | 37,659 |
| Nelson River | 328 |
| Great Slave Lake | 626 |
| Total | 38,613 |

TABLE 3.—*Number and types of glaciers within the Nelson River basin (from Ommanney, 1972a)*

| Drainage Area | Ice Field | Outlet Glacier | Valley Glacier | Mountain Glacier | Glacieret | Rock Glacier, Ice-Cored Moraine | Total |
|---|---|---|---|---|---|---|---|
| Oldman River | | | | 2 | 33 | 18 | 53 |
| Waterton River | | | | | 4 | | 4 |
| Bow River to Lake Louise | 2 | 1 | | 92 | | 8 | 103 |
| Pipestone River | | 2 | | 34 | 1 | 12 | 49 |
| Baker Creek | | | | 12 | | 6 | 18 |
| Bow River and Brewster Creek | | | | 36 | | 12 | 48 |
| Spray River | 1 | | | 75 | 2 | 13 | 91 |
| Lake Minnewanka | 1 | | | 23 | | 8 | 32 |
| Kananaskis Lake | | | | 69 | 3 | 7 | 79 |
| Ghost River | | | | 3 | | 3 | 6 |
| Elbow River | | | | 5 | | 4 | 9 |
| Highwood River | | | | 15 | 1 | 20 | 36 |
| Red Deer River | | | | 58 | 1 | 8 | 67 |
| Siffleur River | | | | 97 | 6 | 16 | 119 |
| Mistaya River | | | | 66 | 6 | 6 | 78 |
| Howse River | 1 | | 1 | 79 | 3 | 7 | 91 |
| Arctomys Creek | | | | 23 | 1 | 4 | 28 |
| Alexander River | | | | 57 | 1 | 9 | 67 |
| North Saskatchewan River | | 1 | | 59 | 4 | 12 | 76 |
| Cline River | | | 1 | 87 | 5 | 15 | 108 |
| Clearwater River | | 1 | | 49 | 1 | 13 | 64 |
| North Saskatchewan (middle) | | | | 29 | | 6 | 35 |
| Blackstone River | | | | 3 | | 4 | 7 |
| Opabin Creek | | | | 4 | | | 4 |
| Job Creek | | | | 27 | 3 | 9 | 39 |
| Brazeau River | 3 | | | 33 | 2 | 6 | 44 |
| Brazeau Lake | 2 | | | 47 | 1 | 15 | 65 |
| Isaac Creek | | | | 20 | | 5 | 25 |
| Southesk River | | | | 51 | 1 | 17 | 69 |
| Thistle Creek | | | | 3 | | 2 | 5 |
| Cardinal River | | | | 5 | | 1 | 6 |
| Total | 9 | 5 | 2 | 1,163 | 79 | 266 | 1,524 |

## Border Ranges (B)[4]

The Border Ranges (fig. 1, B) mark the southern limit of the Rocky Mountains in Canada. They include the Galton, Macdonald, Clark, Wilson, and *Lewis Range*s. No substantial ice bodies exist here. The glacierets that are located in the Border Ranges are of little significance for water supply but may be important for some plant and animal life. Abandoned cirques, tarns, horns, and other remnants of mountain glaciation testify to the previous presence and areal extent of extensive glaciers.

### Clark Range (Wilson and *Lewis Range*s) (B1)[4]

The Clark Range (fig. 1, B1) lies along the Continental Divide that forms the border between the provinces of British Columbia and Alberta in the southern Rocky Mountains. The range rises to an elevation of almost 3,000 m asl in Mount Blakiston (2,919 m) and has a mean peak elevation of about 2,500 m asl. The Wilson and *Lewis Range*s are outliers within Waterton Lakes National Park.

Although no glaciers are shown on the National Topographic System (NTS) maps for this area nor are any observable on the satellite images, interpretation of aerial photographs for the Canadian Glacier Inventory has revealed some permanent snow and ice, or glacierets, in sheltered areas of the park and farther north in the range around Mount Haig (2,611 m).

### Macdonald Range (B2)

The Macdonald Range (fig. 1, B2), lies west of the Clark Range and is separated from it by the *Flathead Basin*; it also has no glaciers, according to current maps. No inventory has been completed for this area, so it is not known whether glacierets exist. Any accumulation of perennial ice is unlikely, because the mean elevation of the range is lower than that of the Clark Range and, at this latitude in the Rocky Mountains, permanent snow and ice tend to remain only on the sheltered eastern and northern slopes rather than on the more exposed western flanks.

### Galton Range (B3)

At an even lower mean elevation, the Galton Range (fig. 1, B3) forms the western flank of the Border Ranges. The range abuts the Rocky Mountain Trench, which in this area includes the Kootenay River and Lake Koocanusa. Because the maximum height is 2,230 m asl and the mean height is just over 2,000 m, it is reasonably certain that not even permanent snow patches exist here.

## Continental Ranges (South—Border Ranges to Kicking Horse Pass)

Because the Continental Ranges extend more than 725 km and contain thousands of glaciers, several of which have been studied and are quite well known, they have been divided into three sections—south, central, and north.

The northern boundary of the southern area is marked by the Trans-Canada Highway and the main line of the Canadian Pacific Railroad (CPR), both of which follow the Bow River from the Foothills, through Banff to the Kicking Horse Pass and its famous spiral tunnel, and then along the Yoho River to the west. This coincides with the northern limit of the Kootenay Ranges. The southern limit has been taken as the beginning of the Border Ranges, which were discussed previously. The slightly warmer climate south of Kicking Horse Pass means that generally this group of mountain ranges contains fewer and smaller ice fields and glaciers than those to the north, but there is ample evidence of previous glacierization.

The series of parallel ranges running from east to west have been grouped and are discussed according to the area within which they fall—the Front, *Park,* and Kootenay Ranges.

### Front Ranges (South) (FS)

The Front Ranges (fig. 1, FS) constitute a series of parallel mountain ranges rising from the Foothills up to and beyond the Continental Divide that marks the provincial boundary. The outer, or eastern, group of ranges consists of the Blairmore, Livingstone, Highwood, Misty, Opal, and Fisher Ranges and ends in the north at the *Rundle Peaks*. The next parallel group of ranges is made up of the Flathead, Taylor, High Rock, Wisukitsat, Greenhills, Elk, and Kananaskis Ranges. The final section of the Front Ranges is made up of the Lizard Range, the *Harrison*, *Italian* and Joffre Groups, Spray Mountains, and the Sundance Range. It is this inner and higher set of ranges in which several glaciers are found, particularly in the Spray Mountains and in the *Italian* and Joffre Groups. The divide follows the central range as far as the Elk Range then swings over and passes out into the *Park Ranges*.

### Lizard Range (FS1)

The Lizard Range (fig. 1, FS1) is the southernmost element of the Front Ranges and is situated on the western flank of the Rocky Mountains, south of the Kootenay Ranges. Elevations here are <2,300 m, and there are no glaciers.

### Taylor Range (FS2)

Just to the west of the Continental Divide, the mountains in the Taylor Range (fig. 1, FS2) are somewhat higher in elevation, up to 2,445 m, but the orographic-precipitation regime is insufficient to sustain any permanent ice masses.

### Flathead Range (FS3)

The elevation of the mountains increases within the Flathead Range (fig. 1, FS3), averaging about 2,500 m asl, but with higher peaks such as Mount Ptolemy (2,815 m) and Mount Darrah (2,745 m). Mount Ptolemy has a few rock glaciers in its vicinity (for example, Canadian glacier inventory glacier No.*4*5AA16 and 17), and there are some glacierets farther south in the headwaters of the Carbondale River. None, however, is shown on the published topographic maps.

### Blairmore Range (FS4)

Moving toward the prairies and almost in the Foothills, elevations drop to close to 2,000 m in the Blairmore Range (fig. 1, FS4), and no glaciers of any size exist.

### Livingstone Range (FS5)

Just to the north of the Blairmore Range, the Livingstone Range (fig. 1, FS5), a long, sinuous, limestone range, almost 100-km long, is the first of five major ranges that constitute the next group in the Continental Ranges. Some peaks, such as Centre Peak and Mount Burke, rise to about 2,500 m. Although no glaciers are visible on the Landsat images or any NTS maps, a group of four rock glaciers has been identified at the southern end of the range near the Blairmore Range.

### High Rock Range (*Tornado Group*) (FS6)

Situated parallel to the Livingstone Range and to its west, the High Rock Range (fig. 1, FS6), also known as the *Tornado Group*, rises from 2,550 m in Crowsnest Mountain in the southern part of the range and extends past Tornado Mountain (3,100 m) to several 3,000-m peaks in the northern part. A small ice apron and rock glacier (*4*5BL5 and 6; Ommanney, 1989) occur at the foot of Mount Cornwell; they are remnants of the glaciers observed there during the 1916 survey (Interprovincial Boundary Commission, 1924). Small glaciers, glacierets, ice-cored moraines, and rock glaciers are mostly found at the foot of the higher peaks on the north- and east-facing slopes, though none are shown on NTS maps. This may explain Denton's (1975) conclusion that there was no glacier on Tornado Mountain.

### Wisukitsat and Greenhills Ranges (FS7)

Two small ice-free ranges, the Wisukitsat and Greenhills Ranges (fig. 1, FS7), lie between the High Rock Range and the next major parallel feature of the Continental Ranges, to the west, the *Harrison Group East*. Both are fairly low, with peaks less than 2,700 m and 2,400 m in elevation, respectively, and are not known to be glacierized.

### *Harrison Group East* (FS8)

The last major mountain block in this discussion of the Front Ranges (South) is the *Harrison Group East* (fig. 1, FS8), which is almost 100 km long and about 15 km wide. It is bounded to the east by Elk River and to the west by Bull River. Summit elevations are lowest in the southern part (<2,500 m) and rise to just over 3,000 m northward. No detailed studies have been made of the ice cover in this range, so it is not known whether glacierets and rock glaciers can be found here. It would seem likely, as well-developed glaciers are found just to the north around Mount Abruzzi in the *Italian Group*.

### Highwood Range (FS9)

Moving farther north again, the next major eastern outlier of the Rockies is the Highwood Range (fig. 1, FS9). It has elevations varying from 2,782 m (Mount Head) to more than 2,800 m in the northern part of the range. Small glaciers are found at the headwaters of tributaries of Sheep River.

### Misty Range (FS10)

Lying at the headwaters of Sheep River and cut off to the west by Highwood River, the Misty Range (fig. 1, FS10) rises to more than 3,000 m asl in Mist Mountain (3,138 m) and Mount Rae (3,219 m). The latter is the location of *Rae Glacier* [*4*5BJ–4] (fig. 6) (Gardner, 1983), which was studied briefly by a group from the University of Saskatchewan (Lawby and others, 1994). There are three other glaciers near *Rae Glacier*, as well as many other small ones at the head of Mist Creek. Gardner (1983) refers to several small cirque and niche glaciers above 2,900 m in elevation on shaded and leeward slopes.

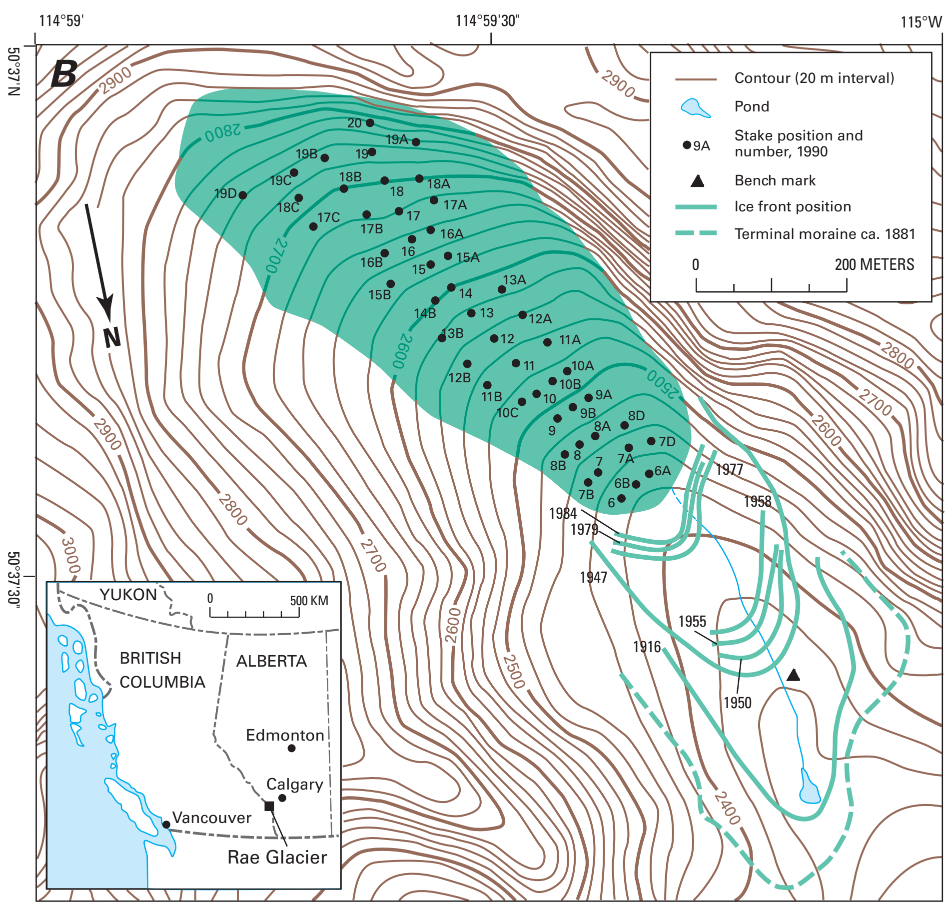
### Elk Range (FS 11)

The Elk Range (fig. 1, FS11) is a northerly extension of the High Rock Range. Mean maximum elevations vary from 2,600 to more than 2,800 m. Again, small glaciers are scattered along the base of the range in sheltered north- and east-facing basins.

### *Italian Group* (FS12)

The *Italian Group* (fig. 1, FS12) is really a continuation of the *Harrison Group*. It is centered on Mount Abruzzi, a major peak rising to 3,265 m asl, with other peaks exceeding 3,000 m in its vicinity. Many small glaciers are located here in sheltered north- and east-facing cirques. Most are about 1 km long, with snouts terminating around 2,450 m. Abruzzi Glacier (4 $km^2$), which is the largest, is some 2 km wide, 2.5 km long, and descends to 2,500 m. This is the southernmost group of glaciers in the Canadian Rocky Mountains, if one relies solely on the existing topographic maps. However, glacier inventory studies have revealed small permanent ice


***Figure 6.***—*Rae Glacier, Misty Range, Rocky Mountains,* **A**, *Photograph taken August 1985. Glacier 4*5BJ–4, Glacier Atlas of Canada, Plate 7.2, Bow River Glacier Inventory, Area 4*5B, Inland Waters Branch, Department of Energy, Mines and Resources, 1970, scale 1:500,000.* **B**, *Modification of sketch map showing historical terminus survey and stake positions for 1990 as determined by a group from the University of Saskatachewan (Lawby and others, 1994).*



masses all the way south to the U.S./Canada border. Just over the border in Glacier National Park, Montana, 37 named, small mountain glaciers have been documented within the park, and two outside. [See section "Glacier Retreat in Glacier National Park, Montana," in the Glaciers of the Western United States (J–2) part of this volume.] Glacier National Park, not to be confused with the Canadian Glacier National Park in the Selkirk Mountains of central British Columbia, near Revelstoke, is one of two contiguous national parks, north and south of the border; the other is Waterton Lakes National Park, Alberta.

### Joffre Group (French Military Group) (FS13)

Bounded to the east by Elk River and to the west by the Palliser River, the Joffre, or *French Military Group* (fig. 1, FS13), is a northwesterly extension of the *Italian Group* and has peaks rising to a maximum in Mount Joffre (3,449 m) and more and larger glaciers than in the previously discussed mountain ranges. The Mangin and Pétain Glaciers are about 5 $km^2$ in area and 4.5 and 3.5 km in length, respectively. The *Foch Glacier*, Elk, Castelnau, Lyautey and Nivelle Glaciers are 1.5 to 2 km in length, and there are several other unnamed glaciers nearby of comparable size. Only the Nivelle Glacier is located on the western side of the main range. The average lowest elevation of the ice varies from 2,400–2,600 m. The equilibrium line altitude (ELA) likely lies between 2,600 and 2,700 m.

### Opal Range (FS14)

The toe of an L-shaped range, the Opal Range (fig. 1, FS14), provides part of the initial buttress of the Rocky Mountains, which face the Foothills to the east, and has the upper part of the "L" tucked in behind the more northerly Fisher Range. Along with the following two ranges, it forms part of what has been called the *Kananaskis Range*. The western limits are marked by the broad valley of the Kananaskis River. There is a slight east-to-west gradient in maximum peak elevations from 2,900 m to slightly more than 3,000 m. The peaks to the west resemble the Sawback Range. The sharp and jagged peaks were created by erosion of the nearly vertical, steeply dipping beds of the Rundle Limestone. No glaciers are shown on the published maps, but the glacier inventory identified some small ice aprons, glacierets, and rock glaciers in parts of the range.

### Fisher Range (FS15)

Fisher Range (fig. 1, FS15) marks the northern limit of the easternmost ranges of the Rocky Mountains considered in this part of the Continental Ranges. Elevations are similar to those in the Opal Range, rising to a maximum of just over 3,000 m asl at Mount Fisher, where the glacier inventory identified two small cirque glaciers, the only permanent ice here.

### Kananaskis Range (FS16)

Although there are no glaciers large enough for skiing, this is the area of Mount Allan in the Kananaskis Range (fig. 1, FS16), which includes the area chosen for Canada's winter Olympic downhill skiing events in 1988. The range lies across the Kananaskis River valley and is bounded on the west by Smith-Dorrien Creek with mountains rising slightly to just over 3,100 m asl. Numerous small ice aprons and cirque glaciers have been identified here, as well as several small rock glaciers.

### Spray Mountains (British Military Group) (FS17)

Otherwise known as the British Military Group, after the association of peak and glacier names, the Spray Mountains (fig. 1, FS17) contain several glaciers along the divide—a continuation of those found farther south in the Joffre Group. The largest, about 4 $km^2$, 3 km long, and descending to 2,225 m, is the Haig Glacier. *Beatty Glacier*, just to the south of the Haig Glacier, is only about 1.5 km long and terminates a little higher at 2,380 m. Other glaciers vary in length from 0.5 to 3 km and have average snout elevations of about 2,500 m asl. The ELA in this range is estimated to be about 2,650 m on the east side and 2,670 m on the west side.

### ***Rundle Peaks*** **(FS18)**

Paralleling the Trans-Canada Highway on its southern margin, as the highway enters the Rocky Mountains and curves northward toward Banff and Banff National Park, are the *Rundle Peaks* (fig. 1, FS18). Peak elevations are less than 3,000 m and include the Three Sisters above the town of Canmore, Alberta, and Mount Rundle, all of which afford the scenic backdrop to the Banff townsite from Mount Norquay. There are no glaciers in this range.

### **Goat Range (FS19)**

West of the *Rundle Peaks* is the small Goat Range (fig. 1, FS19), stretching from the Spray Lakes Reservoir, which can be seen clearly on Landsat images, to the southern end of Sulphur Mountain in Banff. The lower part of the range has elevations comparable to those of the *Rundle Peaks*, approximately 2,900 m, but, unlike the latter, it does have several small cirque glaciers and ice aprons around Mount Nestor (2,960 m).

### **Sundance Range (FS20)**

As viewed from space, the Sundance Range (fig. 1, FS20) looks like a giant tuning fork; it extends south-southeast from the Banff area before splitting into the two tines that reach to the head of the Spray Lakes Reservoir. Mean peak elevations vary from 2,800–2,950 m asl. Although not shown on NTS maps, the southern part, from Cone Mountain to Fatigue Mountain (2,959 m), contains numerous small glaciers (*4*5BC61–78, 84–91; Ommanney, 1989) that lie along benches and terraces eroded in the tilted strata. Some climbers include this range with the *Assiniboine Park Group* [and the Blue and Mitchell Ranges, as part of the *Assiniboine Park Group*] in the *Park Ranges*. Such trans-range mountain groups make the delineation of meaningful groups of mountain ranges extremely difficult, because differentiation may be based on physiographic, geologic, or other considerations.

## ***Park Ranges*** **(South) (PS)**

The *Park Ranges* (fig. 1, PS) lie between the Kootenay and Front Ranges. They are generally higher and more heavily glacierized than the Front Ranges (South). The northern limit of this area is composed of the Ball, Vermilion, Bow, and Ottertail Ranges; the latter includes the Washmawapta Icefield. In the vicinity of Mount Assiniboine—the “Matterhorn” of the Rocky Mountains—are found the *Assiniboine Park Group* and Royal Group, as well as the Blue and Mitchell Ranges. In the southern part, the ranges narrow into the western part of the *Harrison Group* and terminate in the Quinn Range. Glaciers are concentrated in the northern part of the *Park Ranges* (South) and also around Mount Assiniboine.

### **Quinn Range (PS1)**

The Quinn Range (fig. 1, PS1) is about 50 km long; it is nestled between the *Harrison Group East* of the Front Ranges and the Van Nostrand

Range of the Kootenay Ranges. The range rises to a maximum height of 3,300 m asl at Mount Mike, and maximum elevations are generally close to 3,000 m, yet no glaciers are shown on the maps.

### ***Harrison Group West*** **(PS2)**

The Bull and White Rivers separate the western and eastern sections of the *Harrison Group*, the *Harrison Group East* (fig. 1, FS8), and the *Harrison Group West* (fig. 1, PS2). The western part of the *Harrison Group West* is somewhat higher than the eastern part, having several peaks >3,000 m asl; Mount Harrison rises to 3,359 m. Despite the fact that Mount Harrison is higher than Mount Abruzzi and about 40 km farther north, there are apparently no glaciers in the vicinity.

### **The Royal Group (PS3)**

The centerpiece of the Royal Group (fig. 1, PS3) is Mount King George (3,422 m), an impressive landform of towers and massive walls, but there are several other peaks that also rise above 3,000 m. The *Princess Mary*, *King George*, and *Prince Albert Glaciers* are located on the flanks of Mount King George. They vary in area from 0.5 to 1.5 $km^2$ and have termini at about 2,450 m asl. More than 2 km long, the *Tipperary Glacier* is located on Mount Cradock; another small glacier (Albert Glacier) fills a cirque north of Mounts Queen Elizabeth and King Albert. Part of The Royal Group, with elevations ranging up to 2,950 m asl, lies to the west, separated from the rest of the group by the Albert and Cross Rivers.

### **Blue Range (PS4)**

The small mountain block of the Blue Range (fig. 1, PS4) straddles the Continental Divide south of Mount Assiniboine, from which it is separated by Aurora and Owl Creeks. Elevations do not reach 2,900 m even along the border, and no glaciers are shown on current maps, even though glacier inventory work on the eastern end of the range revealed numerous cirques having small ice bodies and large moraines.

### ***Assiniboine Park Group*** **(PS5)**

The dominant peak in the southern Rockies and the highest in the southern Continental Ranges, Mount Assiniboine (3,618 m) (fig. 3) rises as a majestic horn above its surrounding glaciers, which lie on shelves around the main mountain core, the *Assiniboine Park Group* (fig. 1, PS5). The Indian name means "stone-boiler," after the practice of using hot stones for cooking. Of the dozen glaciers on Mount Assiniboine, the largest is about 2.5 $km^2$ in area. The average elevation of the glacier tongues ranges from 2,450 to 2,550 m. On the east side of the group, the equilibrium line probably lies at about 2,650 m. Rock-glacier forms in the area have been studied by Yarnal (1979). Although a popular stop for tourists and climbers, no scientific studies have been done on the glaciers in this area. The *Assinboine Park Group* is well-defined on all sides, limited by the Mitchell River and the Aurora, Bryant, and Owl Creeks.

### **Mitchell Range (PS6)**

The main part of the Mitchell Range (fig. 1, PS6) lies along the east side of the Kootenay River south of the Simpson River. This part has peaks rising to >2,900 m. The western slopes of the Mitchell Range are deeply incised with well-developed cirque basins that probably show evidence of recent glaciation, if not some permanent ice. The range spreads out eastward in a series of four connected blocks ending at Simpson Ridge, where a small glacier (0.5 $km^2$) is located beneath Nestor Peak; its snout is at 2,485 m.

### Ball Range (PS7)

As one drives from Banff northward to the Kicking Horse Pass, the Ball Range (fig. 1, PS7) can be seen where it forms part of the eastern section of the *Park Ranges*. Limited on three sides by the broad valleys of the Vermilion and Bow Rivers, the Ball Range has peaks varying from 2,800 to 3,100 m that reach a maximum elevation at Mount Ball (3,312 m). The six glaciers plotted on the NTS maps are all located on this mountain. They are less than 1 km long and have lower elevations differing by as much as 1,000 m (2,057–3,050 m). The largest has an area of about 0.75 $km^2$. Stanley Glacier (0.6 $km^2$ in area) is the only one lying on the western side of the range.

### Vermilion Range (PS8)

Not to be confused with the Vermilion Range of the Front Ranges, 45 km to the northeast, this Vermilion Range (fig. 1, PS8) forms a major ridge to the west of the Continental Divide between the Vermilion and Beaverfoot Rivers, rising to maximum elevations of >3,000 m. Although maps include the Washmawapta Icefield in the Ottertail Range, the Vermilion Range should probably be considered as ending at Wolverine Pass. Six glaciers lie in cirques along the eastern slope of the range, the largest being Tumbling Glacier about 1 $km^2$ in area. Average snout elevations are at about 2,100 m asl and lengths vary from 0.2 to 1.5 km.

### Bow Range (PS9)

The Bow Range (fig. 1, PS9) is the focal point of the visit of most tourists to Banff National Park. The range marks the northern limit of the area considered as the southern Continental Ranges. It is some 21 km long, 19 km wide, and has peaks that are amongst the highest of the mountain ranges discussed so far—Mounts Allen (3,301 m), Lefroy (3,423 m) and Victoria (3,646 m), and Deltaform (3,424 m) and Hungabee Mountains (3,492 m). Glaciers occur on both sides of the main range and include several debris-covered and rock-glacier forms. Many glaciers exceed 1 km in length. On the western side, the lowest elevation of glaciers is about 2,600 m asl, but several termini end at lower elevations; on the east, the glaciers tend to be at even lower elevations. The popular Lake Louise is dammed by an early Holocene moraine formed by the Victoria Glacier; it probably formed during the Eisenhower Junction glaciation, some 10,000 years before present (B.P.) (Kucera, 1976). Ironically, Moraine Lake is dammed by a rock slide from the Tower of Babel (Kucera, 1976) rather than by a moraine. Kucera (1976) and Gardner (1978b) provide popular accounts of the glaciers and landforms in this area. Several glaciers that have been the subject of specific studies and comments are discussed below.

#### Horseshoe Glacier

Horseshoe Glacier, with an area of 4.3 $km^2$, is about the same size as Victoria Glacier (3.5 $km^2$ in area) but has not been studied in detail. It is fed by snow avalanches from Ringrose Peak, Mount Lefroy, Hungabee Mountain, and The Mitre at the head of Paradise Valley. It extends some 1.3 km from 2,800 m to 2,220 m asl, through a heavily debris-covered ablation zone that makes up over half its area and retards its rate of retreat. The glacier was described by the Vauxes and Sherzer in the early part of the century (Sherzer, 1907, 1908; G. and W.S. Vaux, 1907b). The snout, which is an ice cliff, calves directly into a proglacial lake dammed by deposits left by the retreating glacier. The lake is fed by glacier meltwater from a terminus that has receded 945 m from its “Little Ice Age” maximum (Gardner, 1978b).

### Wenkchemna Glacier

Wenkchemna Glacier, located in the Valley of the Ten Peaks at the head of Moraine Lake, is 3.7 km$^2$ in surface area, of which two-thirds is covered in moraine. Wenkchemna Glacier extends more than 4 km, from a number of independent ice streams that flow from the mountain wall below the Wenkchemna Peaks at about 2,700 m to a tongue at 1,900 m asl. These streams turn down valley to create the 1-km-wide ice-and-debris tongue that is estimated to be from 30 to 100 m thick. The glacier surface is irregular and hummocky, and thaw pits have formed where surface lakes have penetrated the underlying ice and drained. The comparative inactivity of the glacier, and the effectiveness of the debris as a sediment trap, means that the meltwater stream is clear, and a delta is not forming at the head of Moraine Lake. Around the margin and terminus are arcuate ridges up to 3 m high that are characteristic of rock glaciers. The early observations made here by Sherzer (1907, 1908), by the Vaux family (G. and W.S. Vaux, 1907b; by G. Vaux, 1910; M.M. and G. Vaux, 1911), by Field and Heusser (1954), along with more recent observations by Gardner (1977, 1978a), all show very little change in the glacier limits since 1903. Gardner reported the glacier had thinned by up to 50 m. Although several people have observed the debris-covered ice terminus encroaching on the surrounding forest, Kucera (1976) is of the opinion that Wenkchemna Glacier is shrinking.

### Victoria Glacier

Victoria Glacier (fig. 5), lying at the head of Lake Louise, is probably one of the most frequently photographed glaciers in the Rocky Mountains, although some visitors may not recognize the debris-covered tongue for what it is. The glacier is visible and easily accessible from Chateau Lake Louise by a good trail that passes beside the lake.

The continuous ice stream flows northward from Abbot Pass (2,923 m) for about 2 km before turning sharply to the northeast, where it degenerates into an indistinct debris-covered ice tongue after another 2 km. The Abbot Pass basin contains less than 20 percent of the accumulation area. The rest, some 1.8 km$^2$ in area, lies in a broad apron that stretches from Popes Peak past Mount Victoria toward Abbot Pass and avalanches 300 m or more to form a reconstituted ice mass where the Abbot Pass ice stream changes direction. It is mainly an interrupted valley glacier; of its 3.5 km$^2$ area, 24 percent is debris-covered. Lefroy Glacier (1.3 km$^2$) flows from the basin between Mount Lefroy and The Mitre and is separated from Victoria Glacier by a band of moraine.

The earliest known record is a 1897 photo by William Hittel Sherzer (Collie, 1899). The following year, long-term studies were initiated by the Vaux family of Philadelphia—George Jr., William, and Mary—who carried out observations in 1898, 1899, 1900, 1903, 1907, 1909, 1910, and 1912 (G. and W.S. Vaux, 1901, 1907a, b, 1908; G. Vaux, 1910; M.M. and G. Vaux, 1911; M.M. Vaux, 1911, 1913; Cavell, 1983). These observations were interspersed with those of Sherzer, who returned to the area in 1904 and 1905 on behalf of the Smithsonian Institution (Sherzer, 1905, 1907, 1908). Studies in the inter-war years were sparse, apparently limited to surveys in 1931 and 1933 by the Alpine Club of Canada (Wheeler, 1932, 1934). The reasonably good historical record led to the selection of this glacier by the Calgary office of the Dominion Water and Power Bureau (DWPB) in 1945 for its network of glaciers being assessed for their contribution to runoff. The position of the terminus and changes in its areal extent were measured, and a set of plaques were placed on the ice surface to measure velocity (McFarlane, 1945, 1946a, 1947; McFarlane and May, 1948; Meek, 1948a, b; McFarlane and others, 1949, 1950; May and others, 1950; Carter, 1954). The surveys continued every year until 1950, then biennially until 1954, when the snout was so covered in debris that it was almost impossible to identify the toe

(Ommanney, 1971). Recession from various surveys is shown in figure 9; the average value is about 13.5 m $a^{-1}$. Average velocities, measured upstream of the junction with the Lefroy Glacier, are given in table 4.

Osborn (1975) reported on the penetration of the "Little Ice Age" moraines by advancing rock glaciers. Luckman and others (1984) extended their studies of the Holocene to this area, and some investigations have been initiated on sedimentation in Lake Louise (Hamper and Smith, 1983).

TABLE 4.—*Average annual surface movement of Victoria Glacier (m $a^{-1}$)*

| | | | |
|---|---|---|---|
| 1899–1900 | 44.8 | 1947–1948 | 23.8 |
| 1899–1905 | 34.4 | 1948–1949 | 32.0 |
| 1906–1918 | 31.7 | 1949–1950 | 25.6 |
| 1945–1946 | 20.7 | 1950–1952 | 25.3 |
| 1946–1947 | 39.6 | 1952–1954 | 31.4 |

*Cathedral Glacier*

The *Cathedral Glacier* (0.84 $km^2$ in area) is poised like a Sword of Damocles above one of Canada's main transportation routes through the Rocky Mountains. Situated on Cathedral Mountain on the south side of *Kicking Horse Valley*, between approximately 2,410 m and almost 3,000 m elevation, *Cathedral Glacier* has, at least five times in 1925, 1946, 1962, 1978, and 1982, generated mudflows that blocked the Canadian Pacific Railroad (CPR) line and even buried the Trans-Canada Highway. Both Jackson (1979a, b, 1980) and Holdsworth (1984) speculated on the possible cause of these jökulhlaups. It is thought that the surface topography of the glacier, particularly a giant snowdrift ridge, permits development of a surface lake at 2,960 m asl, which is recharged by normal snowmelt and rain. A pulse discharge through the glacier and down a narrow ravine picks up speed and unconsolidated till to create a mudflow that heads towards the CPR tracks in the spiral tunnel section and the Trans-Canada Highway. The regional firn line at 2,890 m asl is situated below the lake level. This is one of two major glacier hazards identified in the Rockies, the other being associated with Hector Glacier and Peyto Glacier.

### Ottertail Range (PS10)

The Ottertail Range is a northwesterly extension of the Vermilion Range and is similar to it in many respects. The highest peak is Mount Goodsir at 3,562 m. Glaciers in the northern part of the range, including the Hanbury Glacier, Goodsir Glacier, *East Goodsir Glacier*, and Sharp Glacier, also lie in east- and north-facing basins, except for the West Washmawapta Glacier and Washmawapta Icefield, which fills a large basin below Limestone Peak. The Washmawapta Icefield is only about 4 $km^2$ in area and hardly warrants its name. Glaciers terminate at about 2,500 m asl on this side of the range but are generally lower (some 2,300 m) on the eastern side. Hanbury Glacier is about the same size as the Washmawapta Icefield.

## Kootenay Ranges (K)

South of Kicking Horse Pass, the Kootenay Ranges (fig. 1) form the western limit of the Rocky Mountains. The physiographic transition farther westward is very sharp, because the mountains drop down steeply into the Rocky Mountain Trench and the Kootenay and Columbia River systems. The range is narrow in the north, where it consists of the Beaverfoot (fig. 1, K5), Brisco (fig. 1, K4), and Stanford Ranges (fig. 1, K3), having peak heights varying from 2,500–2,700 m. Farther south it broadens into the 90-km-long Hughes Range (fig. 1, K1), which joins Lizard Range to form the southwestern limit of the Continental Ranges. The mountains here are slightly higher, up to 2,800 m, and are higher still in the eastern, parallel Van Nostrand Range (2,905 m) (fig. 1, K2). However, none of the topographic maps show any evidence of perennial ice features in the Kootenay Ranges.

## Continental Ranges (Central—Kicking Horse Pass to Yellowhead Pass)

This central region, extending 300 km between Lake Louise and Mount Robson, is the most heavily glacierized part of the Continental Ranges. The mountains in this region trend northwest to southeast and are divided into the Front Ranges and the *Park* (or *Main*) *Ranges* (fig. 1). The former consist of Devonian and younger limestones, dolomites, and shales, all of which dip steeply to the west, whereas the latter are made up of nearly horizontal beds of Cambrian and older quartzitic sandstones, limestones, dolomites, and shales (Gardner, 1972). At the northern end is Mount Robson (3,954 m), the highest mountain in the Rockies. Most peaks in the Front Ranges have elevations between 2,800 m and 3,280 m asl, whereas those in the *Park Ranges* vary in elevation between 3,125 m and 3,600 m. Local relief is generally on the order of 1,400 m to 1,900 m.

The ranges become progressively drier from west to east toward the prairies. Hence the eastern ranges do not contain many glaciers or ice fields. Westward, the first large glacier is the Bonnet Glacier, on the east side of Castle Mountain and hidden from the view of the average tourist by the 18-km-long bulk of that impressive mountain. The glaciers take a variety of forms, including ice fields such as the Columbia Icefield, outlet glaciers such as the Athabasca and Saskatchewan Glaciers, valley glaciers such as Robson Glacier, and mountain glaciers of the cirque, niche, and ice-apron type such as the Angel Glacier. Located north of Kicking Horse Pass, the Waputik Icefield is the first of a long series of ice fields that straddle the Continental Divide (figs. 7, 8). The second is the Wapta Icefield, source of the Yoho and Peyto Glaciers, followed by the Campbell and Freshfield Icefields, which send a magnificent valley glacier to feed the Howse River. Next come the Mons and Lyell Icefields, southeast of the largest ice field in the Rocky Mountains, the Columbia Icefield (fig. 4). This last ice field culminates in the Snow Dome, which is the hydrographic apex of the continent and drains into three oceans. Located immediately northwest of the Columbia Icefield, the Continental Divide is capped by the Clemenceau, Chaba, and Hooker Icefields (fig. 4). The only ice fields off the main divide are the Wilson Icefield and *Brazeau Icefield*, which lie just east of the valleys of the North Saskatchewan and Athabasca Rivers.

The glaciation level is lowest in the western parts of the *Park Ranges* and through the Yellowhead Pass (about 2,600 m asl) but rises in the vicinity of Mount Robson to more than 2,900 m and climbs eastward toward the Front Ranges to more than 3,100 m (Østrem, 1973b).

In this part of the Continental Ranges, moraines of the “Little Ice Age” are evidence of the most significant regional Holocene glacial event in the Rocky Mountains. The best developed moraines are those from the early 1700’s, when about one-third of the glaciers showed maximum advance, and from the mid- to late-nineteenth century, when major readvances built moraines close to or beyond that earlier extent (Luckman, 1986).

Rock glaciers are distributed throughout the area. Luckman and Crockett (1978) reported on those in the southern half of Jasper National Park. The 119 rock glaciers identified range in area from 0.035 $km^2$ to 1.57 $km^2$ and lie between 1,710 and 2,670 m asl; that is 400 to 600 m below the glaciation level. Their distribution seems to be controlled strongly by lithology, and they are predominantly oriented to the north. In Banff National Park, Papertzian (1973) found no evidence for lithological control of the 80 rock glaciers there. They range in area from 0.011 $km^2$ to 1.26 $km^2$ and lie between 1,737 and 2,743 m asl. Østrem and Arnold (1970) mapped both rock glaciers and ice-cored moraines in southern British Columbia and

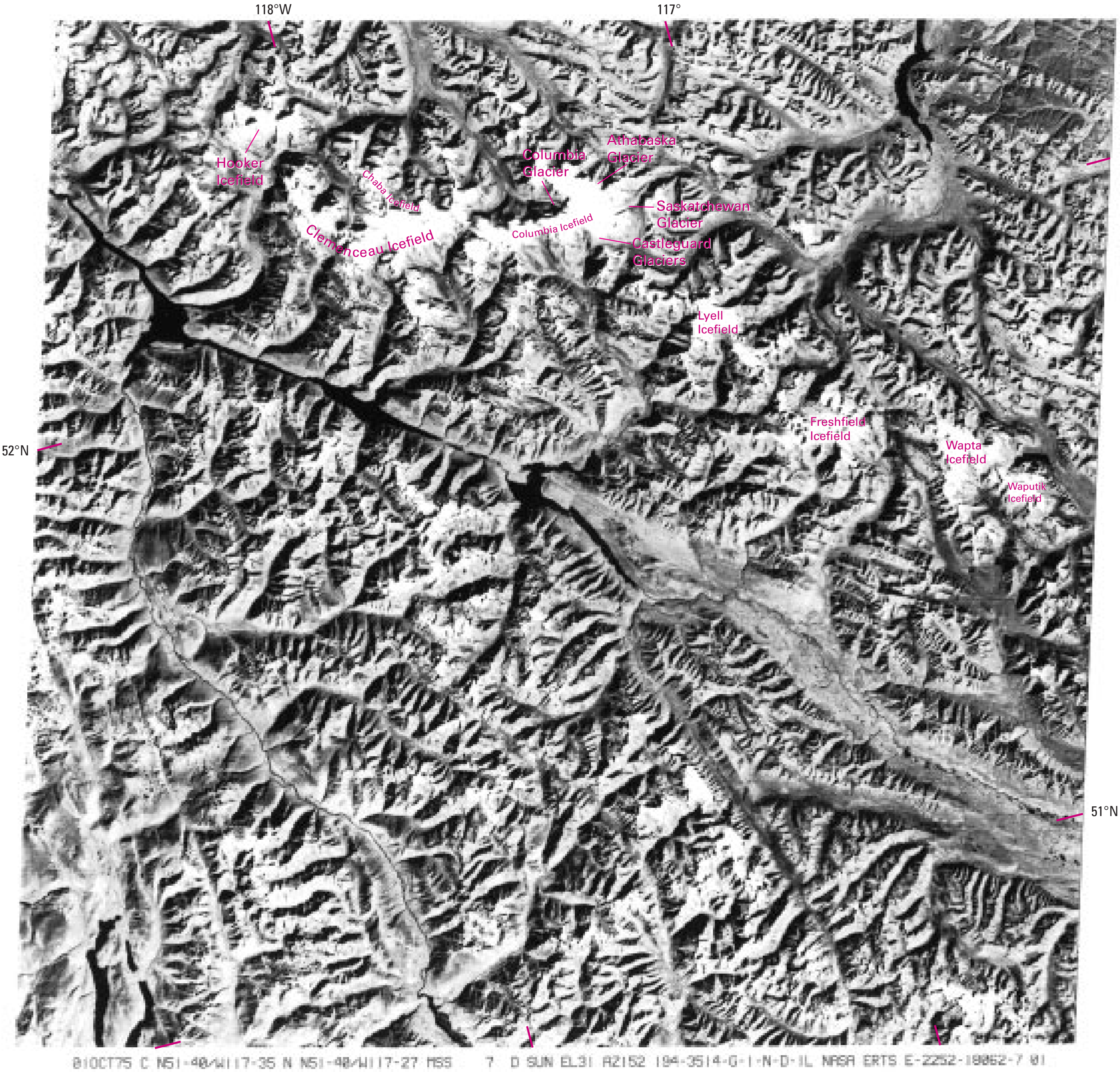



*__Figure 7.__—Landsat 2 MSS image of several ice fields and outlet glaciers in the Rocky Mountains, including the Columbia, Wapta and Waputik Icefields. Landsat image (2252- 18062, band 7; 1 October 1975; Path 48, Row 24) from the EROS Data Center, Sioux Falls, S. Dak.*

Alberta without distinguishing between them. An intermediate form that is quite common is the debris-covered glacier, such as Dome Glacier.

Descriptions of Rocky Mountain glaciers date from the time when Athabasca Pass was a major fur-trade thoroughfare, and they became more common once the Canadian Pacific Railroad line was completed. Despite the fairly long history of formal and informal glacier study, data for the whole range are sporadic. This is especially true for glaciers of the Front Ranges and for ice masses away from the main transportation routes such as the Clemenceau Icefield. However, virtually all of the detailed information on glaciers in the Rockies comes from the central Continental Ranges, primarily through investigations at the Peyto, Saskatchewan, and Athabasca Glaciers.

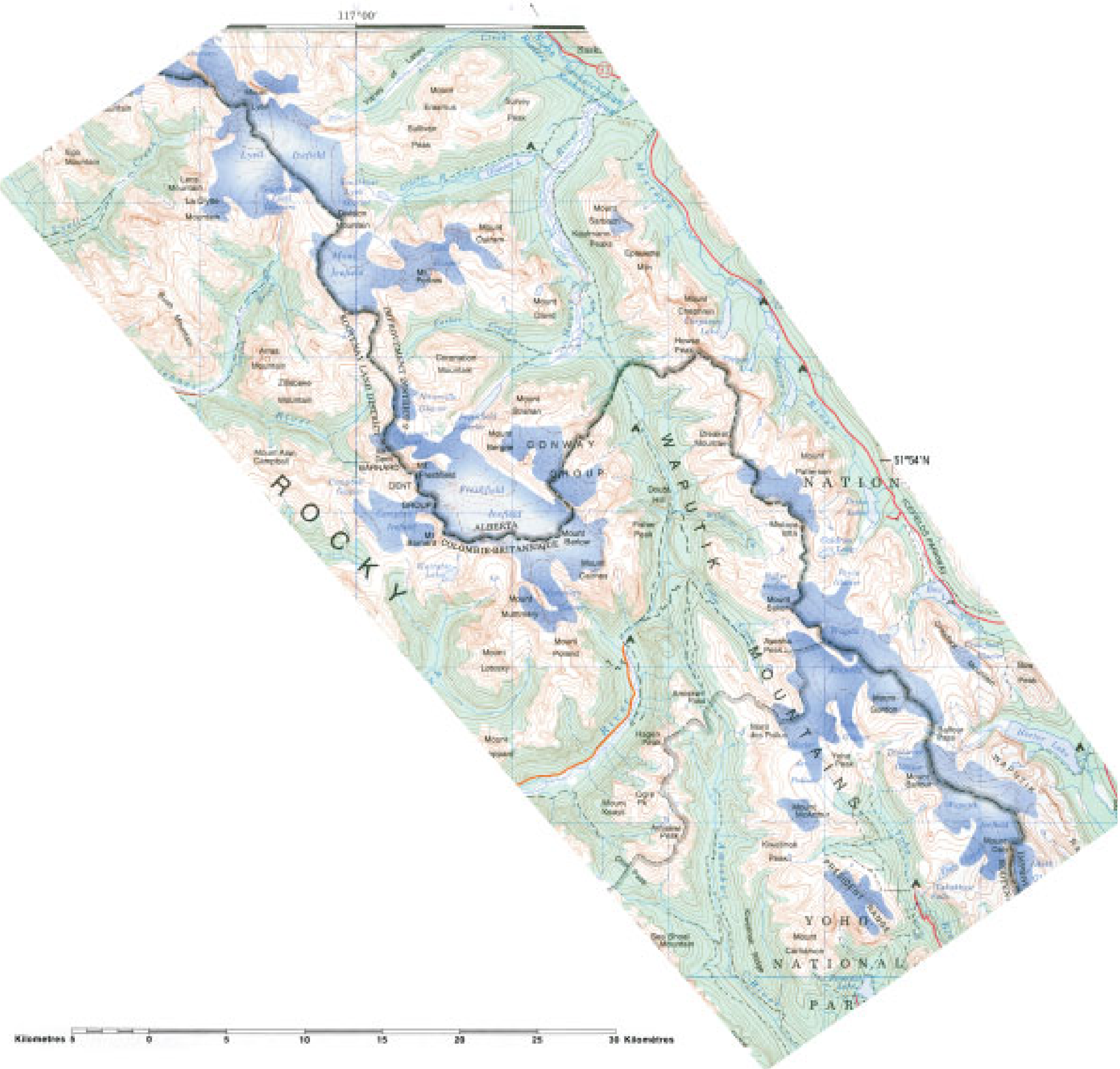



*__Figure 8.__—Slightly reduced segment of the 1:250,000-scale topographic map of the Golden quadrangle (82N) showing the major ice fields along the crest of the Rocky Mountains from Waputik Icefield in the south to Lyell Icefield in the north. ©1997. Produced under licence from Her Majesty the Queen in Right of Canada, with permission of Natural Resources Canada.*

## Front Ranges (Central) (FC)

The Front Ranges (Central) (fig. 1, FC) are a continuation of the series of parallel ridges described from the region to the south, although the parallelism may be less pronounced. Mountain outliers are found to the east in the Bighorn (fig. 1, FC12), Nikanassin (fig. 1, FC19), and Fiddle Ranges (fig. 1, FC20). The southern section, starting with the Fairholme Range (fig. 1, FC1) just north of the Bow River, continues northwest of Lake Minnewanka, with the Ghost River area bordering the Foothills, and extends westward through the Palliser (fig, 1, FC4), Bare (fig. 1, FC5), Vermilion (fig. 1, FC6), Sawback (fig. 1, FC7), and Slate Ranges (fig. 1, FC8). Between the Red Deer River and the North Saskatchewan River, the Front Ranges are more blocky in outline, with only two large groups, *Clearwater* (fig. 1, FC3) and *Murchison Groups* (fig. 1, FC9), and the Ram Range (fig. 1, FC10) as a northeasterly outlier. Between the Ram Range and the Athabasca River are a series of mountain blocks and groups whose boundaries are not very distinct. From south to north these are *Cline Range* (fig. 1, FC11), First Range (fig. 1, FC13), the *Cataract Group* (fig. 1, FC14), Le Grand Brazeau (fig.1, FC15), the *Southesk Group* (fig. 1, FC16), Queen Elizabeth Ranges (fig. 1, FC17), and Maligne Range (fig. 1, FC18), with the parallel Colin (fig. 1, FC23), Jacques (fig. 1, FC22), and Miette Ranges (fig. 1, FC21) rounding out this section in the north. The characteristics of the ranges and their glaciers will be discussed in turn.

***Figure 9.****—(opposite page) Variations of glaciers in the Rocky Mountains, compiled by C.S.L. Ommanney; based on the published work of many glaciologists.*

### Fairholme Range (FC1)

The Fairholme Range (fig. 1, FC1) is a large S-shaped feature that is clearly visible in satellite images. It extends some 25 km from where the Trans-Canada Highway passes through the towns of Exshaw and Canmore to Lake Minnewanka. Several peaks lie between 2,800 and 3,000 m asl, but the range is essentially free of ice.

### *Ghost River Area* (FC2)

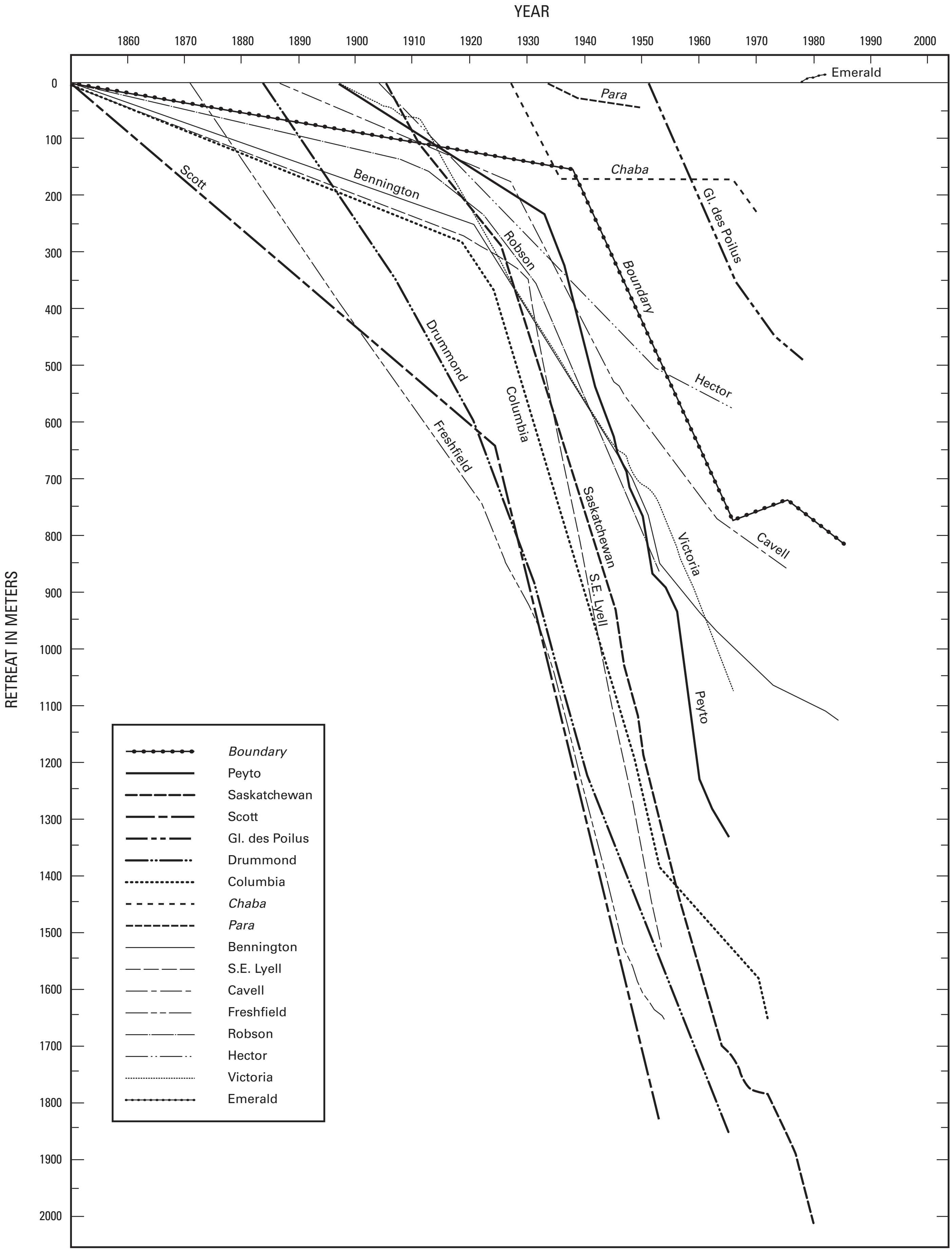
The Ghost River area (fig. 1, FC2), including the irregular mountain mass lying north of Lake Minnewanka and east of the Ghost River, has a few tiny cirque glaciers around Mount Oliver. These are the easternmost glaciers in the central Front Ranges. Elevations range to a maximum of slightly more than 2,900 m.

### *Clearwater Groups* (FC3)

Probably the largest mountain block in this section of the Continental Ranges is the *Clearwater Groups* (fig. 1, FC3). They adjoin the northern part of the *Ghost River Area* and extend northwestward, encompassing the headwaters of the Clearwater River to end where the North Saskatchewan River cuts through the Front Range. The *Clearwater Groups* are bounded to the west by the Pipestone and Siffleur Rivers, and most of the glaciers are concentrated in the part of the group just to the east of these two river valleys. In the southwestern sector is found Drummond Glacier. There are about a dozen glaciers in the headwaters of the Clearwater River, which range in area from 0.5 $km^2$ to 3 $km^2$ and which generally terminate at elevations between 2,450 and 2,550 m. The equilibrium line altitude (ELA) probably lies between 2,600 and 2,650 m asl. Average peak elevations rise to well over 3,000 m, with a maximum at 3,373 m. To the north, the glaciers flow into the Escarpment and Ram Rivers, the latter having as its source the glacier of the same name.

#### Drummond Glacier

About 8.5 $km^2$ in area and 3.5 km in length, Drummond Glacier flows from just over 3,000 m to 2,375 m; it is the largest glacier in the *Clearwater Groups*. It is part of a small ice field about 13 $km^2$ in area just west of Mount Drummond at the headwaters of the Red Deer River. Historical photographs taken in 1884, 1906, 1917–20, 1930, and 1939 and 1963, were used by Brunger and others (Brunger, 1966; Nelson and others, 1966; Brunger and others, 1967) to reconstruct its recession (fig. 9). The University of Calgary group also made measurements of ablation and surface movement from 1962 to 1965.



YEAR
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
RETREAT IN METERS
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Emerald
Para
Chaba
Gl. des Poilus
Scott
Bennington
Robson
Boundary
Drummond
Columbia
Hector
Freshfield
Saskatchewan
Victoria
Cavell
S.E. Lyell
Peyto
Boundary
Peyto
Saskatchewan
Scott
Gl. des Poilus
Drummond
Columbia
Chaba
Para
Bennington
S.E. Lyell
Cavell
Freshfield
Robson
Hector
Victoria
Emerald

### Ram River Glacier

The Ram River Glacier (fig. 10) was the most easterly, and hence most continental, of the five selected by the Canadian Government as representative glacier basins for the International Hydrological Decade (IHD) in an east-west transect of the cordillera. It was the smoothest, the smallest (1.89 $km^2$), the most compact, and, because of a mean elevation of 2,750 m, at the highest elevation of those studied. Possibly because of this, it is also the least dynamic. It lies in a cirque dominated by high, steep cliffs. A standard mass-balance measurement program was carried out here from 1965 to 1975, and the results (fig. 11) have been published (Young and Stanley, 1976a). A base map at a scale of 1:10,000 was published in 1967. The mean specific winter balance for the decade was 0.88 m water equivalent (w.e.), the annual balance was –0.43 m, and the mean equilibrium line was 2,838 m asl.

## Palliser Range (FC4)

Surrounded by Lake Minnewanka and Cascade and Ghost Rivers, and south of Red Deer River, Palliser Range (fig. 1, FC4) is a westerly extension of the *Ghost River Area*. The maximum elevation in the range is 3,162 m at Mount Aylmer, with other peaks ranging from 2,900 to 3,100 m, which is

***Figure 10.***—*Photograph of the Ram River Glacier, Rocky Mountains, Alberta, Canada, in August 1973. Glacier 4*5DC–2, Glacier Atlas of Canada, Plate 7.4, North Saskatchewan River Glacier Inventory, Area 4*5D, Inland Waters Branch, Department of Energy, Mines and Resources, 1970, scale 1:500,000. Photograph by A.D. Stanley, National Hydrology Research Institute [NTS Map: 082N16].*

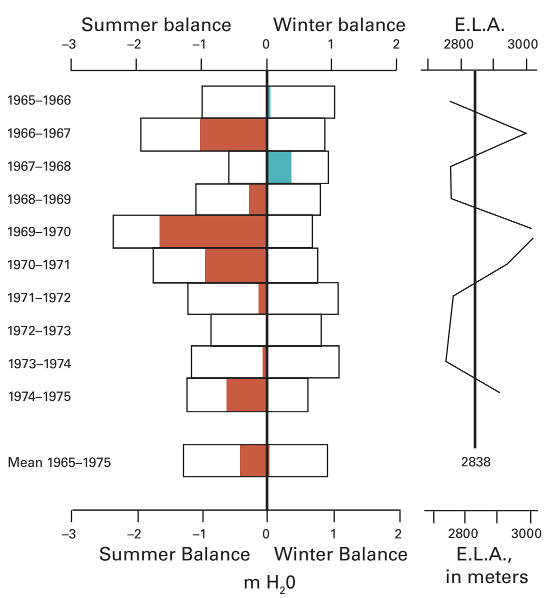



***Figure 11.***—*Mass-balance measurements of the Ram River Glacier, Rocky Mountains, Alberta, from 1965 to 1975 (from Young and Stanley, 1976a).*

roughly the elevation of the glaciation level. Three small glaciers have been identified in the central part of the range.

### Bare Range (FC5)

Slightly lower in height, 2,750–2,950 m, the Bare Range (fig. 1, FC5) is a 20-km extension of the Palliser Range through which flows the Panther River. Because it is below the regional glaciation level, no glaciers have been observed here.

### Vermilion Range (FC6)

The Vermilion Range (fig. 1, FC6) lies west of Cascade River; it is bounded to the south by Banff and to the north by the Red Deer River. Elevations through its 60-km extent are on the order of 2,850–2,950 m. Just south of Prow Mountain is a cluster of small glaciers along the headwaters of a tributary of Red Deer River.

### Sawback Range (FC7)

Farther westward, the last major mountain block in this transect before reaching the *Park* or *Main Ranges*, is the Sawback Range (fig. 1, FC7). It adjoins the Vermilion Range on the east and has a sharp boundary on the west created by the Bow River valley, through which runs the Trans-Canada Highway. To the north it is limited by the Red Deer River valley. Elevations increase here above the regional glaciation level to more than 3,200 m in Mounts Douglas and St. Bride and in Bonnet Peak. Ice cover lies predominantly along the east side of the range in a series of almost continuous masses north of Bonnet Peak. The largest of these is Bonnet Glacier, 3.3 km long and about 6 $km^2$ in area with a snout at 2,560 m asl. Other glaciers from 0.5 to 1.2 km in length also terminate below 2,600 m asl.

### Slate Range (FC8)

Bounded by Pipestone River and Baker Creek, the Slate Range (fig. 1, FC8) lies at the northwest corner of the Sawback Range. Peaks rise to slightly more than 3,000 m in elevation. The ice cover is concentrated in a small ice field around Mount Richardson. Glaciers range from 0.5 to 1.0 km in length, and their lower limits are from 2,410 to 2,570 m asl.

### *Murchison Group* (FC9)

The *Murchison Group* (fig. 1, FC9) is more than 50 km long and generally 10 km wide, although becoming broader northward. It is bounded on the west by the broad valley of the Mistaya and Bow Rivers, on the east by the Siffleur and Pipestone Rivers, and in the north by the North Saskatchewan River trench. Many peaks rise to more than 3,000 m asl, and the range tends to climb northward to a maximum of 3,210 m in Mount Loudon, well above the regional glaciation level. About 20 glaciers are found here. They average just over 1 km in length, with termini at 2,500 m asl. The largest are the Hector and Molar Glaciers, 3.0 km and 2.0 km long, respectively. The ELA probably lies at about 2,750 m asl. This range includes the smallest named ice field in the Rocky Mountains, the *Murchison Icefield*, which is about 0.3 $km^2$ in area.

#### Hector Glacier

Hector Glacier lies in the southern part of the *Murchison Group*. It flows from Mount Hector, at about 3,350 m, northward for 3 km to 2,430 m asl. In the 1960's, this glacier was heavily crevassed and split into several tongues. Brunger (1966) and Brunger and others (1967) used historical photographs to reconstruct the recession of the western snout (fig. 9). In the late summer of 1938, a large ice mass separated from the glacier and fell into the Molar

Creek valley, uprooting trees and destroying everything in its path. The glacier traveled more than 3 km and spread a broad carpet of ice over the valley up to 60-m-deep. Old-timers in the district reported no similar occurrence during the previous 40 years (B.C. Mountaineer, 1939). This represents the second major known glacier hazard in the Rocky Mountains, in addition to the repeated mudflows from the *Cathedral Glacier*, previously discussed.

### Ram Range (FC10)

Guarding the southern side of the pass through the Front Ranges created by the valley of the North Saskatchewan River, Ram Range (fig. 1, FC10) is a small, L-shaped block on the northern end of the Clearwater Group. Elevations average about 2,500 m with a maximum of 2,844 m. A few tiny ice masses are found in sheltered north-facing valleys.

### ***Cline Range*** (FC11)

Bounded by the North Saskatchewan River to the south and the Cline River to the north, *Cline Range* (fig. 1, FC11) contains numerous small cirque glaciers, generally less than 1 $km^2$ in area and terminating on average at about 2,400 m asl. The Wilson Icefield, 12 $km^2$ in area, which rises to 3,261 m on Mount Wilson, lies above the regional glaciation level at 3,000 to 3,100 m in elevation. It is located in the southwestern corner of the range and contains about a dozen outlet glaciers, which range in length from 2 to 4 km and have termini that flow down to 2,000 m. The highest peak is Mount Cline (3,361 m), with small glaciers on its north and south slopes. One of these was, for a short time, subject to some commercial exploitation as the Ice Age Company mined it for "pure" freshwater and "gourmet" ice for sale in Alberta (Brugman, 1989; Rains, 1990). An application to expand the operation led to an environmental impact assessment (Ice Age Co., 1989) and non-renewal of the mining licence. Although there are several other peaks with elevations of more than 3,000 m, average peak elevations are about 2,800 m.

### Bighorn Range (FC12)

The Bighorn Range (fig. 1, FC12) is about 5 km broad at its widest part and 44 km long. It lies well outside the main body of the Rockies and could be considered part of the transition to the Rocky Mountain Foothills. It has no glaciers, and its peaks average less than 2,500 m in elevation.

### First Range (FC13)

The next major mountain block in the Front Ranges is the First Range (fig. 1, FC13). The Brazeau River marks its northern boundary and the Cline River its southern one. The 40x25 km block is cut by Job and Coral Creeks, with the section to the west being known as the *Job Creek Peaks*. Peak elevations average between 2,750 and 2,900 m asl, rising to a maximum of 3,150 m. Detailed aerial photographic analysis in this area revealed more than 40 small glaciers in the western section, with a particularly heavy concentration at the head of Job Creek. About the same number have been plotted in the main First Range. Most lie in the headwaters of the Bighorn River and Littlehorn Creek and in the eastern basin of Job Creek. The glaciers are too small to see on Landsat images and are not shown on current topographic maps.

### ***Cataract Group*** (FC14)

Nestled in behind *Job Creek Peaks*, and divided from the *Park Ranges* by the valley of the North Saskatchewan River, is the *Cataract Group* (fig. 1, FC14). Peak elevations here average more than 3,000 m and have a maximum in Mount Stewart (3,312 m). Increased elevation and proximity to the source of moisture mean that the area covered by glaciers is now a little denser. Almost 70 small glaciers can be found in this group, of which the Huntington (1.5 km$^2$) and Coleman Glaciers (2 km$^2$) are amongst the largest. The regional equilibrium line altitude is thought to lie at about 2,550 m asl. Large proglacial moraine areas and rock glaciers are common.

### Le Grand Brazeau (FC15)

Stretching some 50 km from the Rocky Mountain Foothills to the *Park Ranges* is the mountain block referred to as Le Grand Brazeau (fig. 1, FC15), not be to be confused with the Brazeau Range, which is a small feature 75 km to the east in the Foothills. Officially the name is applied only to that part of the mountain block centered on Poboktan Mountain (3,323 m), but climbers have used the wider application. Peaks rise to more than 3,000 m asl with several reaching about 3,200 m. The regional glaciation level is at about 2,900 m. As in the mountain group to the south, glacier density increases westward, and there is a predominance of rock glaciers, debris-covered glaciers, and large expanses of proglacial moraine. West of Poboktan Mountain, the glaciers drain to the Arctic Ocean, and to the east they contribute to the Nelson River system that flows into Hudson Bay. Most of the 25 larger ice bodies terminate between 2,350 and 2,500 m asl. Their lengths range from 1 to 2.5 km, but some extend to 3.5 km, and one is 4.2 km long. *Cornucopia Glacier* is probably typical of those in the area; it is 2.5 km long and has a snout at 2,550 m asl. It forms part of *Brazeau Icefield*, which lies at the junction with the Queen Elizabeth Ranges and is the largest ice field in the Front Ranges, having an area of 40 km$^2$.

### ***Southesk Group*** (FC16)

North of Southesk River and south of Rocky River lies the 25- by 30-km-wide *Southesk Group* (fig. 1, FC16). There are a few tiny glaciers in the headwaters of Ruby and Thistle Creeks and the Cairn River. To the west, glaciers become larger, and three are more than 1 km in length, terminating at about 2,400 m asl. Peak elevations tend to lie below 3,000 m, although Mount Balinhard rises to 3,130 m and is the site of North Glacier.

### Queen Elizabeth Ranges (FC17)

Extending northwestward from *Brazeau Icefield* for more than 50 km are the Queen Elizabeth Ranges (fig. 1, FC17). Whereas the largest ice-covered area is that around Mount Brazeau (3,470 m), others are found around Maligne Mountain (3,193 m) and Mount Unwin (3,268 m). Coleman (1903) visited the area in 1902 and described the ice field as rising into two white mounds to the south and sinking away to dirty surfaces of ice in the valleys to the east. All glacier tongues show signs of recession. Kearney (1981) dated the moraines here and in the vicinity of *Mary Vaux* and *Center Glaciers*. Peak elevations decline northward from more than 3,200 m to about 2,500 m. As a result, most of the glaciers are found around the upper part of Maligne Lake. Almost 20 glaciers average 1 to 2.54 km in length and have lower snout elevations of about 2,300 m asl. Coronet Glacier (3.5 km long), an outlier of *Brazeau Icefield*, is one of the largest, exceeded only by the 5-km-long glacier flowing north from Mount Brazeau.

### Maligne Range (FC18)

Somewhat lower and lying between the Maligne and Athabasca Rivers, the Maligne Range (fig. 1, FC18) extends for more than 60 km in a northwestward orientation and marks the western limit of this section of the Front Ranges. Average peak elevations are about 2,600 m. About two dozen small cirque glaciers and ice aprons are located in sheltered north- and east-facing basins, the largest being those on the slopes of Mount Kerkeslin (2,956 m).

**Nikanassin Range (FC19)**

The ranges in the northern section of the central Front Ranges (FC) begin to decline in height and break up into a series of more isolated, parallel ridges in the region of the Nikanassin Range. Elevations in the Nikanassin Range (fig. 1, FC19) are less than 2,500 m and there are no glaciers.

**Fiddle Range (FC20)**

An extension northward of the Nikanassin Range, Fiddle Range (fig. 1, FC20) has an even lower elevation and likewise no glaciers.

**Miette Range (FC21)**

West of and parallel to the Fiddle and Nikanassin Ranges lies the Miette Range (fig. 1, FC21). It is slightly higher than these two ranges, rising to a maximum of 2,795 m asl. Some tiny permanent ice masses may exist in north-facing cirques, but all would be too small to be visible from space or to be shown on topographic maps.

**Jacques Range (FC22)**

To the west of the Miette Range lies the Jacques Range (fig. 1, FC22), which has an unnamed extension of the range to the southeast. Mountain elevations in the Jacques Range are comparable to those in Miette Range; it is unlikely that there are any glaciers here.

**Colin Range (FC23)**

The northwesternmost parallel range in this transect of the Front Ranges is the Colin Range (fig. 1, FC23). Mountain elevations here rise to 2,600 m asl. No glaciers are plotted on any of the topographic maps, and because the highest peaks lie below the regional glaciation level, it is not expected that any glaciers will be found here.

## *Park Ranges* (Central) (PC)

The central section of the *Park*, or *Main, Ranges* (fig. 1, PC) consists of three more-or- less parallel sets of mountains between the valley of the Athabasca River on the east and the Rocky Mountain Trench on the west. The southern part of the central section (PC) is separated from the southern section (PS) by Kicking Horse Pass with the Canadian Pacific Railroad (CPR) and the Trans-Canada Highway. The northern limit of the central section is marked by Yellowhead Pass, which is the route of the Canadian National Railroad (CNR) from Edmonton to the west. This part of the *Park Ranges* contains the greatest concentration of glaciers in the Rocky Mountains, including all of the main ice fields (figs. 7, 8). Moving northward through the inner chain, one passes the Waputik Mountains, with the Wapta and Waputik Icefields; the Conway, Barnard Dent, and *Forbes Group*s, with the Freshfield Icefield, Campbell Icefield, and Lyell Icefield; the Columbia Icefield and the Winston Churchill Range, and thence through the *Fryatt*, *Cavell*, and *Portal-MacCarib Group*s to the Trident Range. The central chain includes the Van Horne Range, the *Chaba* and *Clemenceau Icefield Group*s with their extensive ice covers, and the *Whirlpool*, *Fraser-Rampart*, and *Meadow-Clairvaux Groups*. The westernmost chain is largely unnamed, apart from the large block of the Selwyn Range at the northern end. All are discussed below, with particular emphasis being given to the areal coverage of glacier ice and those glaciers that have been studied in the most detail.

## Waputik Mountains (PC1)

Extending northward from Kicking Horse Pass is a triangular, elevated area of peaks and ridges bounded on the east by the Bow and Mistaya Rivers and the mass of the Front Ranges, and on the west by the valleys of the Amiskwi and Blaeberry Rivers. The Waputik Mountains (fig. 1, PC 1) contain the subsidiary President and Waputik Ranges as well as the two southernmost major ice fields of the Rockies, the Waputik and Wapta Icefields (figs. 7, 8). An inventory of the glaciers in this region was completed by Stanley (1970) as a pilot study for the world inventory of perennial snow and ice masses. He found more than 100 glaciers that covered an area of 146 km$^2$. They ranged in elevation from 2,100 to 3,200 m and had an average snowline in the vicinity of 2,400 m. The Waputik Range lies east of the Waputik Icefield (fig. 8) between Bow River and Bath Creek. It rises to about 2,750 m and contains one major ice mass from which drains the Waputik Glacier (3 km$^2$). Just west of the Yoho River is the President Range. Peaks here are on the order of 3,000 m asl, and a number of small glaciers are nestled around them, including the Emerald Glacier and the *President Glacier*. The Emerald Glacier is a small ice apron whose northern section is almost detached; it covers an area of only 0.6 km$^2$. Part of the tongue has a continuous supraglacier debris cover and part is relatively debris free. Batterson (1980), Rogerson and Batterson (1982), and Rogerson (1985) determined rates of advance for the push moraine of Emerald Glacier (fig. 9).

*President Glacier* flows from the north slope of The President toward Little Yoho River. Its present snout is at 2,353 m asl, but it formerly extended downslope an additional 2 km. The *President Glacier* had one advance about 1714 and a second about 1832 (Bray, 1964). In 1937, McCoubrey (1938) noted a marked shrinkage of ice (32–36 m) on the left side of the glacier as compared to the earlier survey by Roger Neave in 1933 (Wheeler, 1934). Later, Bray (1965) discussed the relationship between solar activity and glacier variation here.

### Waputik Icefield

The main feature in the southern section of these mountains is the Waputik Icefield (figs. 7, 8, and 12). It is some 53 km$^2$ in area, straddles the Continental Divide between Mount Bosworth and Balfour Pass, and is the source of a number of quite large glaciers. The Waputik Icefield can easily be identified on Landsat images (fig. 7). Bath Glacier (4.3 km$^2$) has a large ice apron that extends 7 km southward from the slopes of Mount Daly and can be seen from the Trans-Canada Highway. Most of the ice field drains westward through Daly Glacier (13.7 km$^2$ in area) with much of the remainder flowing northward in Balfour Glacier (5.9 km$^2$ in area). Glaciers terminate at about 2,100 m, and the equilibrium line altitude lies close to 2,450 m asl.

#### Balfour Glacier

At the time of the initial photographs by Wilcox (1900), Balfour Glacier (fig. 13) was a compound valley glacier draining about 14 km$^2$ of the northeast sector of the Waputik Icefield (figs. 7, 8). The glacier is now about half that size (8.8 km$^2$). Its main stream is a northwesterly flowing mass that no longer coalesces with the glaciers draining the ice aprons north and east of Mount Balfour. McFarlane (1945) did not include this glacier in the Dominion Water and Power Bureau (DWPB) network because of the high cost of visiting it.

Studies of proglacial Hector Lake established a chronology of proglacial-lake sedimentation back to 1700 (Smith, 1978; Leonard, 1981, 1985; Smith and others, 1982). Most sediment in the lake is provided by nival and glacial meltwater from Balfour Creek. Sediment input varies with inflow discharge and is controlled mainly by melting rates (Smith, 1978).

Leonard (1986a, b) documented the changing glacial outwash sedimentation and glacial activity over a period of about 1,000 years. He concluded that the very regular rhythmic laminations were indeed true varves and could be correlated with the climate record from Lake Louise. Multiple cores were used to assess lake-wide sedimentation characteristics likely related to changes in total sediment input. The maximum ice stand occurred about 1847. Recession rates averaged about 10 m $a^{-1}$ from the late 1840's to 1900 and then increased fourfold from 1900 to 1948. Since 1948, recession has been almost negligible. The major moraine-building episodes of 1700–1720 and 1840–1860 were periods of persistent high sedimentation

***Figure 12.***—*High-angle oblique aerial photograph of the 53 km$^2$ Waputik Icefield looking northwest. The ice field straddles the Continental Divide and is the source of a number of large outlet glaciers. University of Washington photograph F2116, taken 7 August 1961 by Austin Post, U.S. Geological Survey, is courtesy of Robert M. Krimmel, USGS.*

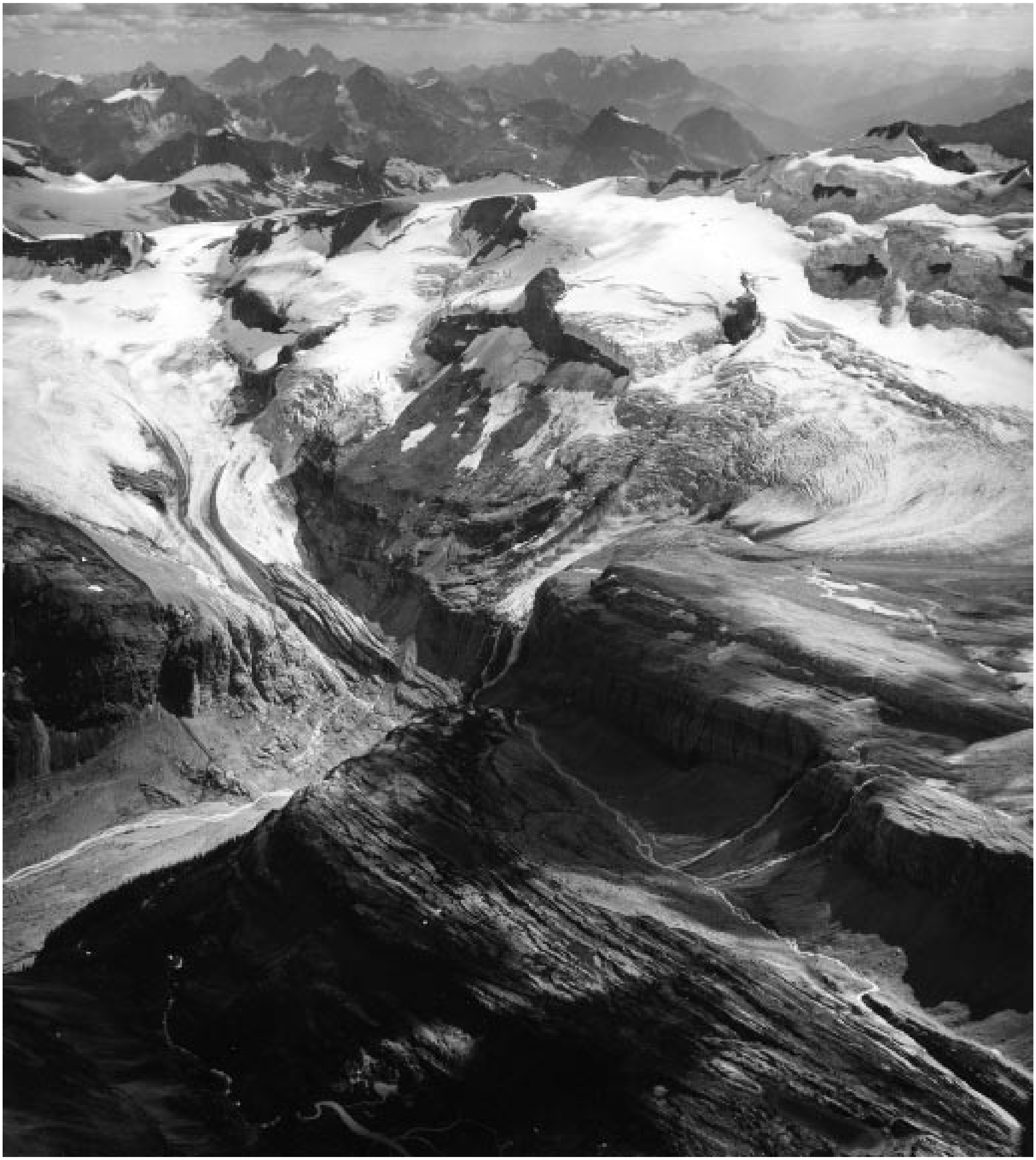


***Figure 13.****—High-angle oblique aerial photograph of the Balfour Glacier, a major northward flowing outlet glacier on the Alberta side of the Waputik Icefield. The glacier drains east into Hector Lake and the Bow River to the left of the photograph. Glacier *4*5BAA–63, 64, 65, Glacier Atlas of Canada, Plate 7.3, Red Deer River, Inland Waters Branch, Department of Energy, Mines and Resources, 1970, scale 1:500,000. University of Washington photograph F2113, taken 7 August 1961 by Austin Post, U.S. Geological Survey, is courtesy of Robert M. Krimmel, USGS.*

rates as was that of the very rapid ice recession period, 1910–1945. The two earlier periods were probably because of high glacial erosion rates and the later period almost certainly due to high sediment availability.

### Wapta Icefield

Wapta Icefield (fig.8) lies northwest of the Waputik Icefield; it is about 80 $km^2$ in area and has been one of the focal points of glaciological research in the Rocky Mountains. It is drained on the Alberta side by the Vulture (4.9 $km^2$ in area), Bow (5.1 $km^2$ in area) and Peyto (12.6 $km^2$ in area) Glaciers and, on the British Columbia side, by the Yoho (20.9 $km^2$ in area) and Ayesha (3.2 $km^2$ in area) Glaciers, as well as by the Glacier des Poilus (12.8 $km^2$ in area). The Glacier des Poilus is the southwestern extension of the Wapta Icefield and occupies two large basins. It flows from almost 3,000 m down to 2,240 m and has an equilibrium line altitude at about 2,450 m asl. Bigras (1978) reported on the sediment transport, discharge, volumetric change, and geomorphology of this glacier. He concluded that it had lost $4.5x10^6$ $m^3$ of ice during the last century. Average recession since 1951 is shown in figure 9.

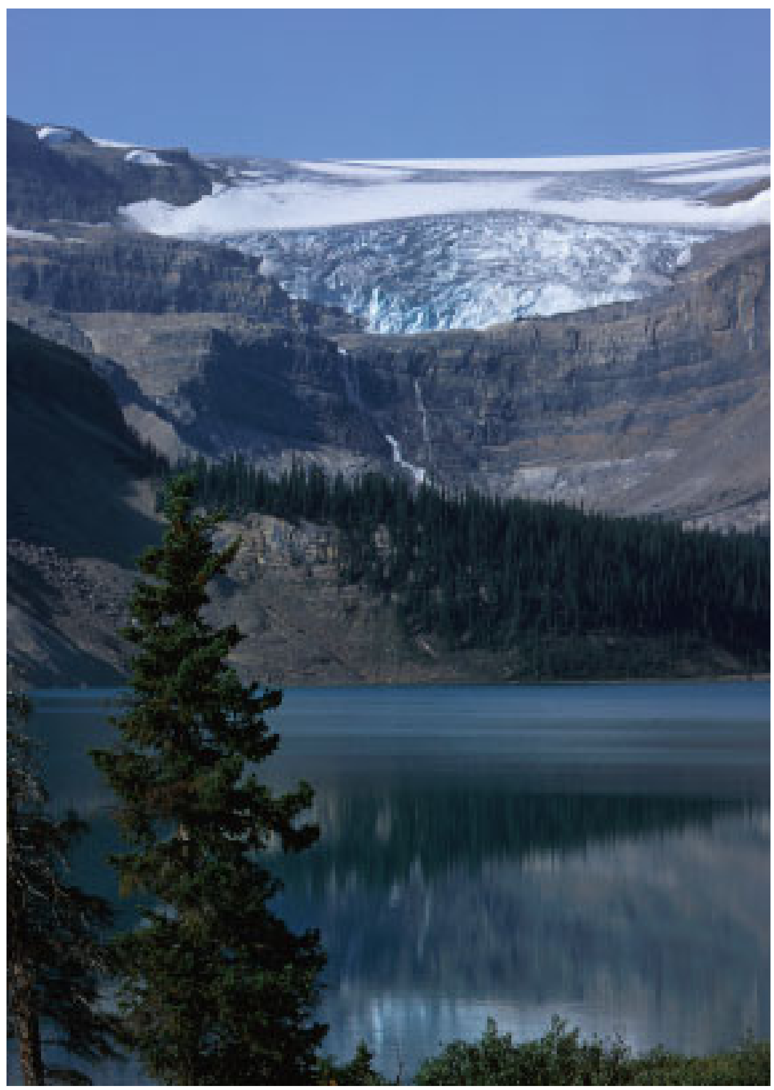
Crowfoot Glacier (1.5 $km^2$ in area), part of a separate outlier glacier (5 $km^2$ in area) which lies east of the Wapta Icefield (figs. 7, 8), is frequently photographed by motorists traveling on what Parks Canada now refers to as the Icefields Parkway. Leonard (1981) investigated lichen growth curves here and found them to be 35 percent lower than those reported by Luckman (1977), thus casting doubt on some regional growth curves. Elevations of mountain peaks rise to more than 3,100 m, and the regional ELA lies at about 2,440 m. Northward, the range narrows. There are significant ice accumulations around Mistaya Mountain, namely, the Delta (2.2 $km^2$ in area), Barbette (4.5 $km^2$ in area) and Parapet (1.1 $km^2$ in area) Glaciers, and also around Mount Sarbach (1.5 $km^2$ in area). Howse Peak (3,289 m), the highest in these mountains, is located in this part of the *Park Ranges* (Central).

#### Bow Glacier

Bow Glacier (fig. 14) flows northeast for 3 km from the Wapta Icefield (figs. 7, 8) and begins to descend steeply from about 2,600 m asl. Its terminus rests at just over 2,300 m asl, about 200 m above the recent maximum position. The lower part of the glacier is quite heavily crevassed where the ice flows out of the ice field over a series of ridges. The popular Num-Ti-Jah Lodge, just off the Icefields Parkway, affords an excellent view of the glacier across Bow Lake.

The glacier was first visited in 1897 (Stutfield and Collie, 1903) when the ice extended below the base of the main cliff. The terminus remained there until 1922 before retreating above the base of the cliff by 1933 (Wheeler, 1934). Further retreat from the 1933 position appears to have been comparatively minor. The glacier was photographed in 1945 by the DWPB but not investigated further, as it was then hanging over the cliff (McFarlane, 1945). Heusser (1956) concluded that the glacier retreated 1,100 m from 1850 to 1953. Aerial photographs taken in 1952 show a narrow lake developing between the glacier and cliff edge. By 1966, only a quarter of the

***Figure 14.***—*Photograph of the terminus of the Bow Glacier, Rocky Mountains, Alberta, Canada, in September 1973, showing its snowline. Photograph by C. Simon L. Ommanney, National Hydrology Research Institute [NTS Map: 082N10]. (Glacier 4*5BAA–78, Glacier Atlas of Canada, Plate 7.3, Red Deer River, Glacier Inventory, Area 4*5, Inland Waters Branch, Department of Energy, Mines and Resources, 1970, scale 1:500,000).*



present-day lake was visible, and by the 1980's, the entire lake could be seen and the glacier tongue was a few meters above it (Smith, 1981).

A number of studies have been carried out on sedimentation in Bow Lake and the reduction in sediment input caused by the development of the proglacial pond (Kennedy, 1975; Leonard, 1981, 1985; Smith, 1981; Smith and Syvitski, 1982; Smith and others, 1982). Leonard (1981, 1985) was able to explain up to 70 percent of the sedimentation rate variance when he compared the Bow Lake varve record to the ablation-season temperature record from Lake Louise. The sediment load carried by the stream flowing from the glacier was substantial enough to create a large delta at the western end of Bow Lake. Church and Gilbert (1975) have looked at the long profile and mean clast size of the outwash fan. In 1997 a group from the University of Alberta installed an automatic weather station at Bow Glacier and commenced a continuing study of sedimentation and runoff chemistry (M.J. Sharp, oral commun., 2000).

#### Peyto Glacier

The first records of Peyto Glacier (fig. 15) were photographs taken by Wilcox in 1896 and by Thorington in 1923. Recession since 1923 was recorded by Thorington, Kingman, Dickson, and Vanderburg in 1933 (Wheeler, 1934) and again by Kingman in 1936 (McCoubrey, 1938). In 1945, it was selected as a representative glacier by the DWPB, and for the next 17 years the position of the snout, changes in the areal extent of Peyto Glacier, and ice velocities were measured (fig. 9). The glacier gradually retreated into a narrow gorge, which made it less representative. After 1962, the survey was terminated. Detailed reports, prepared by the DWPB as internal documents, were summarized by Ommanney (1972b), and some results have been published (McFarlane, 1946a; Meek, 1948b; McFarlane and others, 1950; Collier, 1958).

Heusser (1954, 1956) used photographic and botanical techniques to reconstruct the recent history of Peyto Glacier. The recessional moraine was dated to 1863 and four other moraines were identified. Retreat from 1865 to 1953 was determined to be about 1,009 m. Brunger and others (1967) concluded that an ecesis interval (colonization of flora and fauna in deglacierized terrain) of 25 years was more appropriate than the 12-year interval used by Heusser. They found glacier response lagged climate by about 15 years, close to the 20-year lag estimated by Collier (1958).

In 1965, Peyto Glacier was selected as one of the representative International Hydrological Decade (IHD) glacier basins in the Rocky Mountains by

***Figure 15**.—Photograph of the Peyto Glacier, Rocky Mountains, Alberta, Canada, in July 1967. A prominent, sharp-crested lateral moraine can be seen on the right valley wall grading into a less prominent terminal moraine, evidence of significant thinning and retreat of the Peyto Glacier. Photograph by C. Simon L. Ommanney, National Hydrology Research Institute [NTS Map: 082N10]. (Glacier 4*5DB–32, Glacier Atlas of Canada, Plate 7.4, North Saskatchewan River. Glacier Inventory, Area 4*5D, Inland Waters Branch, Department of Energy, Mines and Resources, 1970, scale 1:500,000.)*

the Canadian Government. The 13.4 $km^2$ glacier originates at an elevation of 3,185 m asl; its tongue is at about 2,100 m asl, and the mean elevation is 2,635 m. The measurement program was described by Østrem and Stanley (1969). Young (1976) modified this methodology and proposed a grid square technique to produce accumulation, ablation, and mass-balance maps using associations between snow depth and terrain geometry (for example, surface slope, azimuth, and local relief). The technique could be used to assess the recurrence patterns of accumulation, bias in sampling networks, effects of different sized sampling networks, progress of melt throughout an ablation season, as well as being able to extrapolate to unvisited parts of the glacier (Young, 1974a). The assumption of a linear function for snow accumulation produced results that seemed realistic but were substantially different from those derived from the normal stake network (Young, 1974b).

A report on the glaciological, hydrological, and meteorological data collected for the IHD program (1965 to 1974) has been published (Young and Stanley, 1976b). A plot of the mass balance, including more recent data (Mokievsky-Zubok and others, 1985; IAHS/UNEP/UNESCO, 1988, 1993, 1999; IAHS/UNESCO, 1998) is given in figure 16. Young (1977a, 1981) found that the same annual balance was produced by different combinations of winter accumulation and summer ablation; the patterns did not necessarily repeat themselves. Fluctuations in meltwater discharge over a few days closely parallel the air-temperature curve, that from Lake Louise being a better predictor than the Peyto Glacier station. The elevation of the transient snowline was a good indicator of the health of the glacier. Letréguilly (1988) found mass balance to be almost entirely related to summer temperature. The correlation was best with data from the meteorological station in Jasper, some 200 km away, rather than with the closest station at Lake Louise. This is in line with Tangborn's conclusion (1980) that mass balance here was likely most dependent on summer ablation. Letréguilly also found that the correlation coefficients of meteorological data with the ELA were as good or better than with the mass balance. Yarnal (1984) demonstrated that the mass balance of Peyto Glacier is also related to the 500-mbar patterns. Synoptic atmospheric pressure patterns having cyclonic circulation favor glacier accumulation, whereas anticyclonic types inhibit the buildup of the regional snowpack. Ablation is suppressed by synoptic patterns associated with cloudy days and (or) low temperatures and is enhanced by patterns associated with warm sunny days. Peyto Glacier accumulation appears to be associated with the large-scale patterns. According to Xie and Zhang (1986), the glacier has a reasonably stable regime with a coefficient of glacial stability of 0.33. Others, in analyzing global mass-balance data, which include those from Peyto Glacier, have concluded that representative mass-balance values might be obtained from observations at the ELA (Ohmura and others, 1986), at the weighted mean altitude (Valdeyev, 1986), or another single point (Konovalov, 1987). Attempts to develop appropriate indices for these and other glacier characteristics, using data from Peyto Glacier, are continuing (Bahr and Dyurgerov, 1999; Dyurgerov and Bahr, 1999).

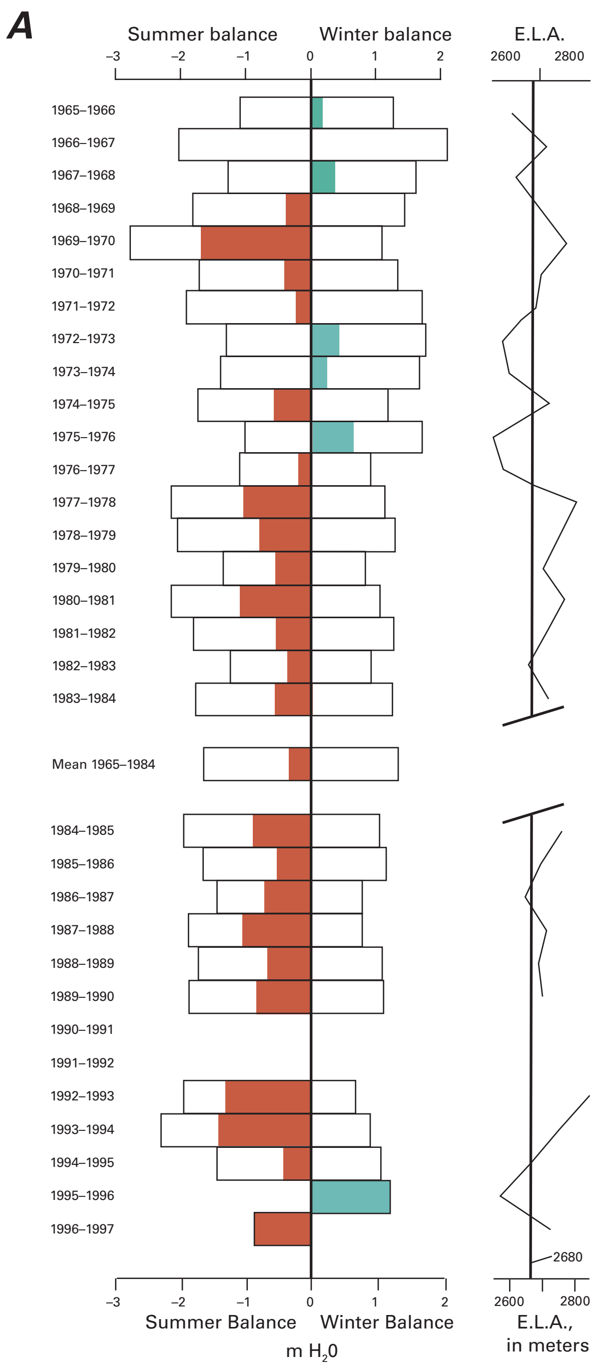
The glacier's accessibility, only a 2- to 3-hour walk from Peyto Lookout off the Trans-Canada Highway, and the availability of semipermanent facilities soon led to the development of many other complementary studies, often in collaboration with Canadian and other universities.

A map of the glacier, at a scale of 1:10,000 with 10-m contours, was prepared as a base for glaciological research. A nine-color edition using a French bedrock-portrayal technique was published in 1970 (Sedgwick and Henoch, 1975), followed in 1975 by a Swiss-style eight-color map; bedrock portrayal and shaded relief added a three-dimensional effect (Henoch and Croizet, 1976).

A subsequent experiment produced an orthophotograph, stereomate, digital-terrain model, and contour map of part of the glacier (Young and Arnold, 1977). There was good agreement in the ablation area with elevations of the existing map (<1 m) but large discrepancies in the freshly snow-covered accumulation area. The accumulation area had thinned by about 20 m since 1966–76.

Holdsworth and others (1983) and Goodman (1970), using a radio-echo-sounder, measured depths of 40–192 m in the ablation area and 120–150 m in the accumulation area, indicating that the 1967 seismic survey by Hobson and Jobin (1975) was seriously in error, and the volume of $532 \times 10^6$ m$^3$ of water equivalent was wrong by at least a factor of 2–3.

Power and Young (1979a, b), using a modified University of British Columbia (UBC) model, compared simulated discharge for 1967–74 to that



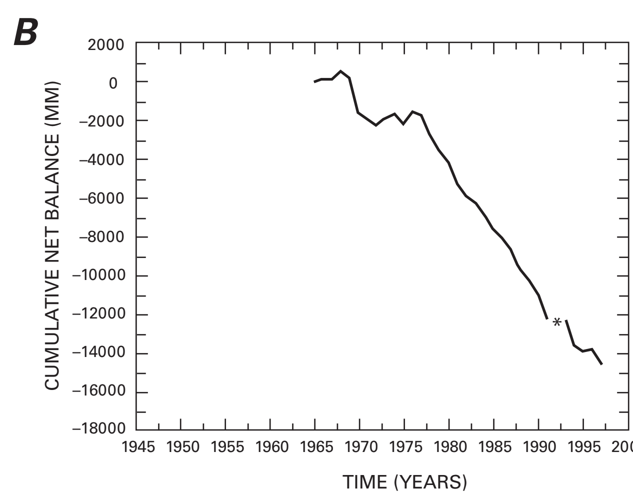




***Figure 16.*—A**, *Mass-balance measurements of the Peyto Glacier, Rocky Mountains, Alberta from 1965 to 1997 (from Mokievsky-Zubok and others, 1985; IAHS/UNEP/UNESCO, 1988, 1993, 1999; IAHS/UNESCO, 1998, and Demuth (written commun., 2001);* **B**, *Cumulative specific net balance of Peyto Glacier from 1965 to 1997 (IASH/UNEP/UNESCO, 1999). Asterisk indicates absence of measurements in mass-balance series.*

predicted using algorithms derived from mean daily temperature and then extended the results using a lapse rate of 0.65°$C^{-100m}$ with an arbitrary reduction of 15 percent melt applied to the accumulation area (Young, 1980). The model simulates snowmelt and icemelt processes reasonably well. The results confirm that the Peyto Glacier tends to compensate for changes in snowmelt runoff; for example, lower winter snowpacks produce high glacier-melt runoff. The response time of the basin and its various flow components is closely linked to the progression of the snowline upglacier, although summer hydrographs can vary markedly over the seasons. The difference between the calculated and measured discharge over an 8-year period averaged $5x10^6$ $m^3$, which could be accounted for by an average evaporation over the basin of 200 mm $a^{-1}$ (Young, 1982). Gottlieb (1980) obtained reasonably good overall agreement using a degree-day approach and simplified water routing procedures, but his model did not seem to be able to predict peak flows.

Derikx (1973) considered a glacier analogous to a ground-water system and developed a black-box model to predict meltwater runoff in response to meteorological data. Although a linearized equation with simple boundary conditions is a very crude approximation of reality, the results showed a fair correspondence between the calculated and measured meltwater discharge. Derikx and Loijens (1971) refined the model by adding inputs distributed by different elevation bands and by separating the four hydrological components (exposed ice, snow-covered ice, firn, and rock). Daily discharge calculated by the model was 21 percent higher or lower than the measured value. In the warm, dry period of 2–27 August 1967, when the snowcover had been removed, Peyto Glacier contributed 40 percent of the Mistaya River streamflow. Applied to the other glaciers in the basin, this means glacier-melt contribution in August can reach 80 percent. Loijens (1974) observed that 46 percent of the annual flow in the river in 1967 occurred in a 7-week period and that 70 percent of this was supplied by glacier runoff and 31 percent by glacier icemelt. Average ice ablation contributed 15 percent to annual streamflow. Young (1977b) reported that 4 years of negative balance contributed some $37x10^6$ $m^3$ of water from storage, or 20 percent of total streamflow, and 4 positive years retained $13.8x10^6$ $m^3$. Hence he proposed a revision in the contribution to annual flow in the North Saskatchewan River at Saskatchewan River Crossing caused by the 1948–66 reduction in glacier volume. He suggested 8–10 percent compared to Henoch's (1971) original estimate of 4 percent.

Prantl and Loijens (1977) and Collins and Young (1979, 1981) used hydrochemical characteristics to separate the various flow components and to study their temporal variation. Conductivity falls rapidly as dilute meltwater arrives at the gauge and rises steadily as chemically enriched meltwater routed more slowly through basal tunnels, cavities, and subglacier moraines reaches the portal.

Johnson and Power (1985, 1986) reported on a high-magnitude catastrophic event that substantially modified the proglacial area of Peyto Glacier. A major storm led to the overtopping of a drainage tunnel and the collapse of a large section of ice-cored moraine. The downstream area was subjected to alternate damming, flooding, and draining. Flood waves up to 26 $m^3$ $s^{-1}$ deposited an estimated 6,000 $m^3$ of gravel in the valley, destroying the gauging facility. Other major flooding episodes occurred in 1984, again in association with extreme rainfall events.

Goodison (1972a) derived a snowmelt-rainfall recession curve and found that any particular day's rainfall takes about 5 days to pass through a completely snow-covered basin. The response time shortens as the season progresses. Regression models developed using 1968 data accounted for 82.4 percent of the discharge variation in the 1969 hydrograph and provided a particulary good fit to the June–July runoff. Another study found no statistically meaningful relationship between global radiation and ablation (Goodison, 1972b). Østrem (1973a) came to a similar conclusion in the course of developing an operational model based on temperature, wind, and precipitation. Daily computed runoff values were within about 21 percent of the observed values. The negative correlation between glacier discharge and radiation has been observed for other glaciers where liquid precipitation, usually associated with low incoming short-wave radiation, is a dominating influence on glacier runoff. However, Munro (1975) found that short-term variations in the meltwater hydrograph were closely controlled by the net radiative flux; the sensible heat flux was also an important energy source. Munro and Young (1982) concluded that net shortwave radiation was the prime determinant of meltwater discharge. Estimates were a fair approximation of energy equivalents of ablation derived from stake measurements. An unexpectedly thin boundary layer, about 1 m deep, was attributed to katabatic control of flow (Munro and Davies, 1976). Such a finding has implications for the long-term effectiveness of the turbulent-transfer approach (Munro and Davies, 1977). Another factor in the long-term suitability of turbulent transfer theory for glacier-melt prediction is the finding by Stenning and others (1981) that katabatic layer development and characteristics are also subject to synoptic-scale influences.

Föhn (1973) found fair agreement between energy- and mass-balance results. About 20 percent of daily snowmelt takes place internally as a result of the penetration of solar radiation. At the base of the snowpack, the water table fluctuated 10–50 mm throughout the first 9 days under conditions of continuous snowcover. At some times, lateral inflow of water made up for actual mass loss at the upper end of the snowpack.

By studying the weathering surface in a 5,320-m$^2$ ablation-area site, Derikx (1975) concluded that the hydrological response time was extremely short and closely followed melt calculated from the hourly energy balance. Any delay seemed to be mainly the result of the channel network. Dye-tracer tests by Collins (1982) gave average flow-through velocities of 0.13–0.35 m s$^{-1}$, with delays of up to 5 h at low flows and under 2 h during times of peak surface ablation, thus showing a strong dependence on discharge.

The glacier has fairly extensive ice-cored moraines. A simple model suggested that their ablation could be estimated from meteorological variables, if the surface temperature of the debris layer were available (Nakawo and Young, 1982).

Krouse (1974) demonstrated that the isotopic record retains characteristics of the winter precipitation record, but he and West (1972) have both attributed some of the large isotope fluctuations to wind drainage on the glacier and to the topographic shape of the ice surface (Krouse and others, 1977). This conclusion was supported by Foessel (1974), who found “cool-air pooling” in the ablation area in response to dish-shaped terrain, and who developed an equation that proved very reliable in predicting daily mean temperatures at any elevation in the basin. He also found that seasonal temperature trends behaved in a cyclic manner in response to migration of synoptic weather systems over western Canada (in line with the findings of Yarnal (1984) in relation to mass balance).

The suspended sediment regime is very irregular seasonally and diurnally; pulses of sediment occur independently of discharge variations. Sediment concentrations averaged about 660 mg l$^{-1}$ and ranged from 19 to 3,379 mg l$^{-1}$, with one extreme event at 14,000 mg l$^{-1}$. The total suspended sediment output in 1981 was in excess of 68,000 tonnes. Subglacier reorganization of outflow streams that change sediment availability seemed to be the main factor influencing sediment output (Binda and others, 1985). Downstream in the drainage basin of the Peyto Glacier, Smith and others (1982) estimated that over a 75-day measurement period in 1976 some

$40 \times 10^3$ tonnes of material was transported to and deposited in Peyto Lake. In 1996, a special session of the annual Canadian Geophysical Union scientific meeting in Banff, Alberta, was devoted to past and present work on Peyto Glacier. Papers from this session will be published by the National Water Research Institute in its science report series (M.N. Demuth, oral commun., 2000).

Yoho Glacier

Yoho Glacier is the largest southern outflow from the Wapta Icefield (figs. 7, 8). It flows 7 km from the center of the ice field at 3,125 m asl to a terminus at 2,150 m asl. The ELA on the glacier surface lies at about 2,450 m. The first description of Yoho Glacier was published by Habel (1898) when the ice was close to its maximum (Bray and Struik, 1963). At that time the Yoho Glacier had a magnificent ice fall that attracted visitors for many years. Subsequently, studies were conducted by W.H. Sherzer of the Smithsonian Institution (Sherzer, 1907, 1908), and the Yoho Glacier was included in a set of observations undertaken by the Vaux family (Vaux, G., Jr., and Vaux, W.S., 1907a, b, 1908; Vaux, G., 1910; Vaux, M.M. and Vaux, G., Jr., 1911; Vaux, M.M., 1911, 1913). These studies were extended by A.O. Wheeler and members of the Alpine Club of Canada (ACC), which held a number of field camps in that valley (Wheeler, 1907, 1908, 1909, 1910, 1911, 1913, 1915a, 1917, 1920a, b, 1932, 1934). The Yoho Glacier was inspected in 1945 by the DWPB, but by then had retreated up the valley and was a hanging glacier unsuitable for recording purposes (McFarlane, 1945, Meek, 1948a, b). Heusser (1956) concluded that a series of recessional moraines had formed in about 1865, 1880, and 1884. Parks Canada became interested in the hydrology of Yoho National Park, and an attempt was made to extend the record of glacier recession (Kodybka, 1982). For a short time, the National Hydrology Research Institute extended their Peyto Glacier program to include observations on the glaciers and streams around the Yoho Glacier. No report of that work has been published.

### Van Horne Range (PC2)

Between the Amiskwi River and the Rocky Mountain Trench and south of Blaeberry River lies the Van Horne Range (fig. 1, PC2). Maximum elevations here are less than 2,900 m asl, which is the height of the regional glaciation level. Some of the deep, north- and east-facing cirques may contain small glaciers, but none is shown on the topographic maps. The range consists of a number of northwest- and southeast-trending ridges.

### Conway Group (PC3)

The Conway, Mummery, and Barnard Dent Groups all form part of the same range that lies west of the Blaeberry River and is centered on the Freshfield Icefield (figs. 7, 8). The Conway Group (fig. 1, PC3) is the easternmost of the three groups. Many peaks rise above 3,000 m, reaching a maximum elevation of 3,260 m asl at Solitaire Mountain. The ice-covered area of more than 20 $km^2$ contains several glaciers, of which the most notable are the Cairnes, Lambe, and Conway Glaciers, which range in length from 4 to 5 km with ELA's at about 2,400 m.

### Mummery Group (PC4)

Southwest of the Conway Group, running parallel to and north of the Blaeberry River, is the Mummery Group (fig. 1, PC4). Elevations trend southwesterly from above 3,000 m at the apex of the Freshfield Icefield (fig. 8) downward to the 2,500-m range near the Rocky Mountain Trench. The main glaciological feature is Mummery Glacier, a southward-flowing extension of Freshfield Icefield. This 7-km-long glacier is joined near its tongue by a large glacier flowing eastward from Mount Mummery (3,320 m). Its ELA is about 2,450 m asl.

### Barnard Dent Group (PC5)

The Barnard Dent Group (fig. 1, PC5) contains three major ice masses, including the bulk of the 78-$km^2$ Freshfield Icefield (fig. 8). This ice field is situated in a northeasterly basin that flows into Howse River through a magnificent valley glacier. The Campbell Icefield (13 $km^2$) lies to the west of the Continental Divide. A significant ice accumulation is also on Mount Alan Campbell. Summit elevations generally exceed 3,000 m, with the highest being that of Mount Freshfield (3,325 m). Apart from the Freshfield (11 km), Campbell (5.5 km), Pangman (4.2 km), and Niverville (2.5 km) Glaciers, most are 1 to 2 km long and terminate between 2,200 and 2,400 m. Waitabit Glacier, just to the south of the Freshfield Icefield, has been reduced to three small, disconnected ice masses that total slightly more than 1 $km^2$.

#### Freshfield Glacier

Field (1979) provided a comprehensive and illustrated report on Freshfield Glacier (figs. 7, 8, and 17) following the American Geographical Society (AGS) expedition there in 1953, and Ommanney (1984) has compiled a list of publications about work on Freshfield Glacier. The Freshfield Glacier was determined to be slightly over 14 km long when mapped by the Interprovincial Boundary Survey in 1917 (Interprovincial Boundary Commission, 1924). According to Heusser (1956), the glacier began to retreat in 1871. Short readvances took place in 1881 and 1905 (Heusser, 1956); in

***Figure 17.****—High-angle oblique aerial photograph of Freshfield Glacier, a major northeastward flowing outlet glacier of the 78 $km^2$ Freshfield Icefield. According to Heusser (1956), the glacier began to retreat in 1871. It was more than 14 km long in 1917 when mapped by the Interprovincial Boundary Survey. Most recently it has been mapped as 11 km long. A series of ogives can be seen on the tongue of the glacier that has been created as the slope of the glacier increases down glacier. Glacier 4*5DAC–22, Glacier Atlas of Canada, Plate 7.4, North Saskatchewan Glacier Inventory, Area 4*5D, Inland Waters Branch, Department of Energy, Mines and Resources, 1970, scale 1:500,000. Photograph F642–89, taken 21 August 1964 by Austin Post, U.S. Geological Survey, is courtesy of Robert M. Krimmel, USGS.*

1897, Collie (1899) reported on a small push moraine formed in that year. For most of the 20th century, retreat has been continuous and rapid, with a total recession of 1,640 m (fig. 9). The Freshfield Glacier was discovered by Hector (1861) in 1859, a time when the snout was within 100 m of the ancient terminal moraine. The Freshfield Glacier had a row of angular blocks running down the center of the ice stream. One of the largest boulders was used by all the early observers as a common reference point, thus minimizing errors (McFarlane, 1947). The glacier was observed by Stutfield and Collie (1903) in 1897 and 1902, by Hickson (1915) in 1913, by Palmer (1924a, b) in 1922, and by Thorington (1927, 1932, 1938, 1945) in 1926, 1930, 1934, 1937 and 1944.

The long historical record was one reason why the DWPB selected Freshfield Glacier for their studies of the water resources of mountainous rivers in 1945. The position of the snout and changes in its areal extent were measured, and a set of plaques was placed on the ice surface to measure velocity. The survey was abandoned after 1954 due to the expense, including logistics of accessing the glacier. Detailed reports were prepared by the DWPB as internal documents, but some results were published (McFarlane, 1947; McFarlane and May, 1948; Meek, 1948a, b; McFarlane and others, 1949, 1950; May and others, 1950; Carter, 1954). The AGS expedition used photographic and botanical techniques (Field and Heusser, 1954; Heusser, 1954; 1956) to identify glacier limits and variations. Some subsequent visits were made by the ACC (Gray, 1962) but little new scientific information was added. In 1922, Palmer (1924a) estimated the firn line at 2,400 m; today it is closer to 2,600 m. Because the ice field has a low gradient, any change of the firn limit will have far-reaching effects on the glacier's mass balance.

### ***Waitabit Ridge* (PC6)**

Nestled in between the Mummery and Barnard Dent Groups is *Waitabit Ridge* (fig. 1, PC6). The maximum elevation is in the center of the Ridge in Robinson Peaks (2,925 m), but the average tends to be on the order of 2,600 m. Only one glacier is visible, a 1.5-km-long ice body flowing to the northwest in the section adjoining the Campbell Icefield.

### **Blackwater Range (PC7)**

In the Blackwater Range (fig. 1, PC7), the elevations are lower than those of *Waitabit Ridge*, but there is a small glacier (<1 km$^2$) in a south-facing cirque between Felucca and Blackwater (2,732 m) Mountains. The range runs parallel to the Rocky Mountain Trench, with one spur pointing eastward along Bluewater Creek. Northward is a small, unnamed range, running from Frigate Mount to the large artificial water body of Bush Arm. It rises to 2,800 m and has two small glaciers.

### ***Forbes Group* (PC8)**

North and west of Forbes Creek and Howse River lies the *Forbes Group* (fig. 1, PC8), centered on the 3,612-m peak of that name. Elevations in the *Forbes Group* exceed 3,000 m, and several are greater than 3,200 m. The area is heavily glacierized and forms part of the Mons Icefield (<30 km$^2$), which spreads out along the range between Mount Outram and Mons Peak. Much of the ice drains through Mons Glacier, which was joined with neighboring Southeast Lyell Glacier in 1902 (Outram,1905). In 1918, the two glaciers were 300 m apart. Between 1918 and 1953, Mons Glacier receded 1,100 m horizontally and 350 m vertically (Field, 1979). Part of the ice field drains westward from the Continental Divide. Several glaciers, including the East, West, and Sir James Glaciers, are on the order of 3 km long. Termini generally lie between 2,300 and 2,500 m asl, though the ice field ELA is thought to be about 2,450 m.

### *Lyell Group* (PC9)

The *Lyell Group* (fig. 1, PC9) consists of two ranges separated by the valleys of Lyell and Arctomys Creeks. In the southern part of the *Lyell Group* glaciers are scattered in cirques along the ridge that runs from Mount Erasmus (3,265 m) up to the main body of Lyell Icefield (fig. 8). To the west, this ridge trends to the southwest and Rostrum Peak (3,322 m), along which there are numerous glaciers, 1- to 2-km long, in southeast-facing cirques. The focal point here is Lyell Icefield itself, with its outlet glaciers—East, Southwest, and Southeast Lyell Glaciers, that cover an area of about 50 km$^2$. The bulk of the ice field spreads southward from Mount Lyell (3,500 m) before flowing east and west from the Continental Divide and pushing tongues of ice well below 2,000 m. The ELA is probably about 2,500 m asl.

#### Southeast Lyell Glacier

The Southeast Lyell Glacier (fig. 18) flows eastward from Lyell Icefield (figs. 7, 8). The accumulation area of the Southeast Lyell Glacier extends along the provincial boundary some 9 km between Mount Lyell and Division Mountain at elevations ranging from 2,440 to 3,050 m. As recently as 1902, the Southeast Lyell Glacier was connected with Mons Glacier (Outram, 1905), but, subsequently, the Mons Glacier receded so far up valley as to be scarcely visible (Field and Heusser, 1954). The glacier is strongly broken and crevassed where it travels steeply downward, and a prominent, broad, lateral moraine exists along the northern edge. In 1858, the Southeast Lyell Glacier so intrigued James Hector (1861) of the Palliser Expedition, the first European to investigate this area, that he left a detailed description of it that Thorington used to establish a datum from which to

***Figure 18.****—Terrestrial photograph of Southeast Lyell Glacier, an outlet glacier from the approximately 50-km$^2$ Lyell Icefield. The glacier has a steep, crevassed surface. The first recorded observation was in 1858. The glacier receded gradually from 1858 until about 1930, and then more rapidly since then, probably because the terminus was resting in a lake from about 1930 to 1953 (Field and Heusser, 1954) (fig. 9). Glacier 4*5DAC–89, Glacier Atlas of Canada, Plate 7.4, North Saskatchewan Glacier Inventory, Area 4*5D, Inland Waters Branch, Department of Energy, Mines and Resources, 1970, scale 1:500,000. Photograph taken in August 1953 by William O. Field, American Geographical Society, is courtesy of Calvin J. Heusser, Professor Emeritus, New York University.*

measure frontal recession (Gardner, 1972). Following Hector's visit, the positions of the terminus were recorded in 1902 by Outram (1905), in 1918 by the Interprovincial Boundary Survey (Interprovincial Boundary Commission, 1924), and in 1926, 1930, and 1944 by Thorington (1927, 1932, 1945). Heusser (1956) dated the moraines to 1841, 1855, 1885, 1894, 1902, and 1906. In 1947, the DWPB visited the glacier to see whether it might be suitable for inclusion in their network. It was found to have receded so much that what was left of the forefoot was too steep for their purpose (McFarlane, 1947), although it was photographed and a reference baseline established (Meek, 1948a, b). Glacier limits and variations for the Southeast Lyell Glacier were documented by an AGS expedition in 1953 using photographic and botanical techniques (Field and Heusser, 1954; Heusser, 1954, 1956). The AGS expedition concluded, on the basis of field observations, that the reason for the rapid recession since 1930 was a proglacial lake in which the terminus was situated for much of the 1930 to 1953 period. By 1953, the terminus was 60 m beyond the lakeshore and some 4 m above its surface. Available information of the retreat of the Southeast Lyell Glacier is plotted in figure 9.

North of Lyell Icefield is another mountain block running east from Mount Amery (3,329 m) across the ice-covered divide to Cockscomb Mountain (3,140 m). Ice flows east and west from the Continental Divide, pushing down to below 2,400 m in fairly large glaciers such as the *Rice Glaciers* group (2–3 km long) and to below 2,200 m in the Alexandra Glaciers (5.5 and 4 km long) (fig. 19), which were joined in 1918. This ice mass, which might more properly be called the *Alexandra Icefield*, covers an area of about 25 km$^2$. Average peak elevations are usually well above 3,000 m asl. The western part of the *Lyell Group* consists of up to two dozen small cirque and niche glaciers, averaging 1 km in length and about 0.5 km$^2$ in area, on either side of the ridges in that part of the range.

### Unnamed Range (—)

Between Bush River and Prattle Creek, south of the western extension of the Columbia Icefield, is an umbrella-shaped range with no name. Its axis is almost 40 km long and 5 km wide at its narrowest, whereas the arc of the umbrella frame is 25 km long. Peak elevations range between 2,500 and 2,800 m in the south, and as much as 3,100 m in the north. Some glaciers, as much as 1.5 km$^2$ in area, are scattered along the ridge of the shaft, but the majority are concentrated in the northerly part of the range. On the eastern side, facing the headwaters of Bush River, is an elongated ice apron spread along 8 km of the range. Other glaciers in this sector take the form of cirque glaciers or small ice fields with outlet glaciers ranging from 2 to 4 km in length and about 4 km$^2$ in area. Whereas some glaciers push their snouts below 2,000 m asl, some as low as 1,710 m, most terminate at about 2,300 m.

### Vertebrate Ridge (PC10)

Vertebrate Ridge (fig. 1, PC10) extends to the northwest about 20 km; its main feature is a 7-km$^2$ ice field centered on Stovepipe Mountain (2,804 m). A 4-km-long outlet glacier drains from the ice field northward to an elevation of 2,000 m. The southern part of the ice field is drained to the east by a glacier reaching to 1,800 m. Heights along the ridge are generally about 2,550 to 2,650 m in elevation.

### Kitchen Range (PC11)

Parallel to Vertebrate Ridge, and marking the western edge of the *Park Ranges* in this section, is the 30-km-long Kitchen Range (fig. 1, PC11).

Summit elevations range between 2,800 and 2,950 m. About eight glaciers are situated on either side of the main ridge, the largest being a 4-$km^2$ ice mass east of Poker Mountain. Lower ice limits vary between 2,025 and 2,530 m, and glacier lengths are generally less than 1.5 km.

### *Columbia Icefield Group* (PC12)

Seen from space, the Columbia Icefield (fig. 1, PC12) (figs. 7, 20), about midway between Lake Louise and Jasper, appears as an extensive snow-covered upland with comparatively little relief. Shaped like a stylistic "T," it runs almost 40 km from east to west, and 28 km from northwest to southeast. Its area depends on how many of the peripheral ice masses are included, but an acceptable figure would be 325 $km^2$. It is situated on a plateau 3,000–3,325 m in elevation that dips slightly to the south and culminates in the Snow Dome (fig. 21), a gently-sloping 3,520-m peak, completely covered with ice and snow, which is the hydrographic apex of the continent, draining into three oceans (Freeman, 1925; Lang, 1943). Harmon and Robinson (1981) provided a poetic and pictorial commentary on the beauties of the area. Numerous peaks more than 3,500 m asl fringe

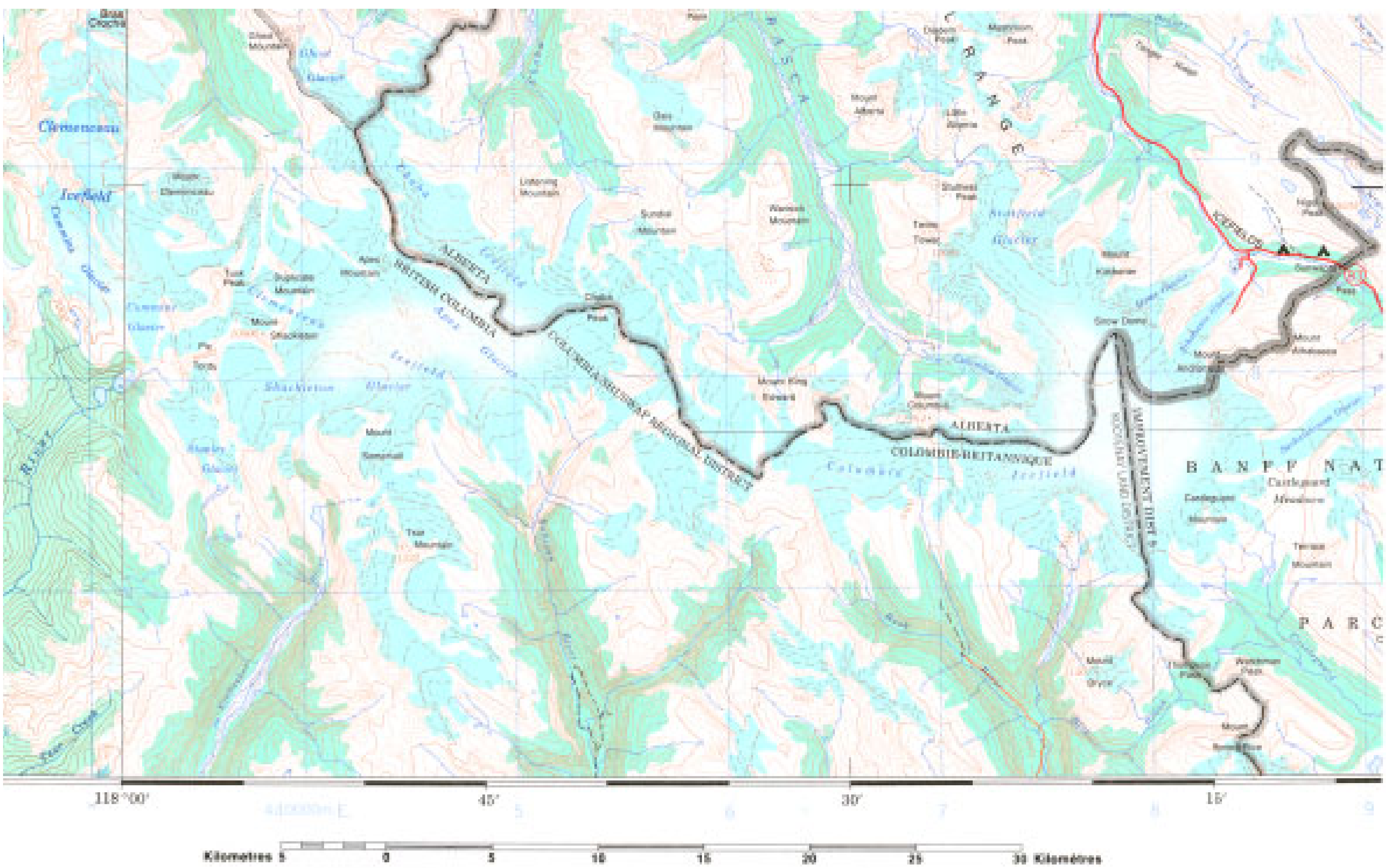
***Figure 19.****—High-angle oblique aerial photograph of West Alexandra Glacier and* South Alexandra Glacier*. The glaciers were joined before 1918. Glacier 4*5DAE–32, 33, 34, 35, Glacier Atlas of Canada, Plate 7.4, North Saskatchewan Glacier Inventory, Area 4*5D, Inland Waters Branch, Department of Energy, Mines and Resources, 1970, scale 1:500,000. The University of Washington photograph F2–131, taken 7 August 1961 by Austin Post, U.S. Geological Survey, is courtesy of Robert M. Krimmel, USGS.*

the Columbia Icefield, so that ice flowing to the margin of the ice field forms huge cliffs above high rock walls and avalanches to the base of the rock walls to form reconstituted glaciers (Boles, 1974). The ice discharges radially through outlet glaciers; the three largest (Columbia, Athabasca, and Saskatchewan Glaciers) flow in deeply incised valleys. There are many other small ones such as Stutfield, Dome, and the *Castleguard Glaciers* [*I, II, III*, *IV*; see footnote 2 in table 1] (Baranowski and Henoch, 1978). Several have been studied in some detail and will be discussed further. Not only is the Columbia Icefield (fig. 7) the largest ice field in the Rocky Mountains, but together with the Clemenceau and Chaba Icefields, it drapes the peaks, mainly along the Continental Divide, in a continuous glacier cover for more than 60 km.

A comprehensive inventory of the glaciers (some of which are listed in table 5) and of the landforms in the Columbia Icefield area, particularly near the Athabasca (figs. 7, 20) and Dome Glaciers, was undertaken by Baranowski and Henoch (1978) and Kucera and Henoch (1978). Detailed geomorphological maps were prepared at scales of 1:25,000 and 1:2,500. Unfortunately, little is known about the bulk of the ice field that lies in British Columbia.

Several federal government agencies and university departments undertook a joint project in 1977 to map the surface of the ice field and to calculate the amount of water held in its snow and ice (Canada, Energy, Mines and Resources, 1978). Preliminary findings showed that the part feeding the Athabasca and Saskatchewan Glaciers (figs. 7, 20) was thinner than previously thought (100–365 m). Surveyors used stereoscopic, vertical aerial photography and an Inertial Survey System (ISS) to fix additional

***Figure 20.***—*Mosaic of reduced segments of the 1:250,000-scale topographic maps of the Brazeau Lake and Canoe River quadrangles (83C and 83D) showing the area around Columbia and Clemenceau Icefields. ©1995 and 1986. Produced under licence from Her Majesty the Queen in Right of Canada, with permission of Natural Resources Canada.*



ground control points on the ice. The aerial survey aircraft also carried a thermal infrared (IR) line-scanner from which radiometric temperature isolines at 1°C were to be plotted. One of the thermal IR images generated was used for the cover of a new map of the Columbia Icefield (Canada, Environment Canada, 1980).

The accessibility of the Columbia Icefield, particularly the Athabasca and Saskatchewan Glaciers, and the availability of a fairly good historical sequence of observations, probably favored its selection as the site for a wide variety of glaciological studies. These have included investigations of glacier chemistry, glacier flow, depth measurement, photogrammetry, resistivity, sediment transport, and temperature, among others. Each will

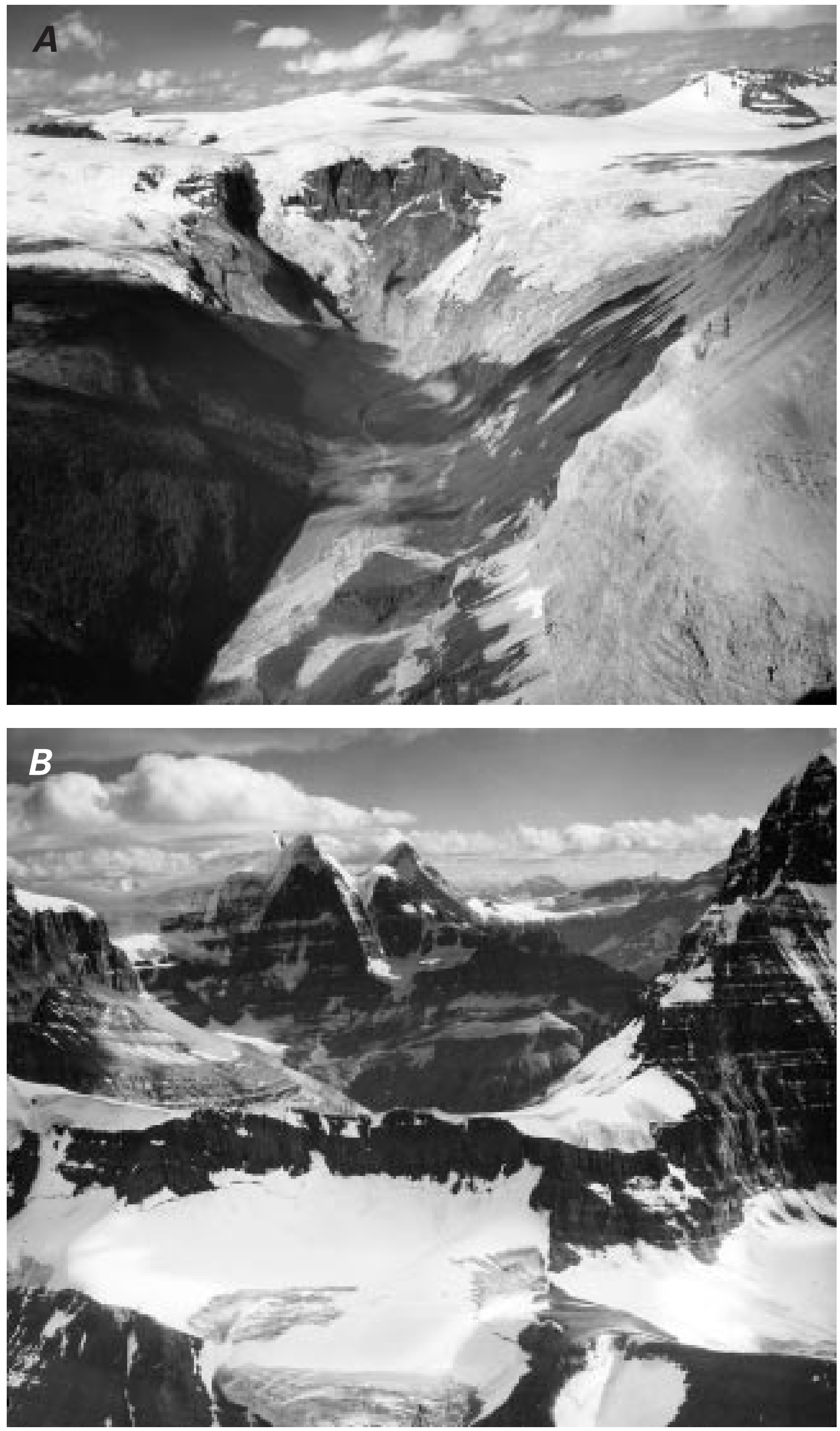



***Figure 21.****—High-angle oblique aerial photographs of the Columbia Icefield, the largest ice field in the Rocky Mountains, having an area of more than 300 km$^2$. Together with Clemenceau and Chaba Icefields, it provides continuous glacier-ice cover along the Continental Divide for more than 60 km.* **A**, *Columbia Icefield from the south looking up Bryce Creek to Snow Dome. U.S. Geological Survey photograph F642–115.* **B**, *The northern part of Columbia Icefield. Twins Tower is in the center. U.S. Geological Survey photograph K641–44. Both photographs taken 21 August 1964 by Austin Post, U.S. Geological Survey, are courtesy of Robert M. Krimmel, USGS.*

TABLE 5.—*Characteristics of glaciers in the vicinity of Athabasca Glacier*

| Glaciers | Area (square kilometers) | Length (kilometers) | Elevations (meters) Top | Bottom | Debris-cover (square kilometers) |
|---|---|---|---|---|---|
| Dome | 5.92 | 5.7 | 3200 | 1980 | 2.16 |
| Stutfield | 5.68 | 5.2 | 2740 | 1770 | 3.41 |
| Kitchener | 2.17 | 2.8 | 3020 | 2070 | 1.35 |
| Little Athabasca | 2.03 | 2.4 | 3290 | 2290 | |
| Sunwapta | 0.97 | 2.3 | 3140 | 2300 | |
| Athabasca trib. (E) | 0.75 | 1.7 | 2940 | 2350 | |
| Athabasca trib. (W) | 0.50 | 1.3 | 3050 | 2380 | |
| Stutfield trib. | 0.43 | 1.0 | 2320 | 2090 | |
| Kitchener trib. | 0.39 | 1.2 | 2860 | 2510 | |
| Little Dome | 0.16 | 0.6 | 2590 | 2440 | |
| Nigel Peak | 0.15 | 0.8 | 2700 | 2470 | |

be discussed in the context of those parts of the Columbia Icefield on which the work was carried out.

### *Castleguard Glaciers*

The southern limit of the Columbia Icefield is marked by a group of glaciers (collectively known as the *Castleguard Glaciers* [*I, II, III, IV*; see footnote 2 in table 1] (fig. 7)) at the head of Castleguard River. Livingston and Field visited them in 1949 and numbered them I to IV from northeast to southwest. *Castleguard Glacier IV* (fig. 22), the principal southern outlet glacier of the Columbia Icefield was called *South Glacier* by Ford (1983) and his colleagues from McMaster University working on the *Castleguard Cave* system. *Castleguard Glacier I*, situated at 2,300–2,700 m asl, was first photographed by the Interprovincial Boundary Survey in 1918 and subsequently by others in 1919, 1923, 1924, and 1949. Until 1924, it abutted a massive moraine which probably formed near the turn of the century (Denton, 1975). *Castleguard Glaciers II* and *III* have shrunk enormously since the 1920's, as has *Castleguard Glacier IV*. Ice fronts have receded an average of 500 m since the end of the "Little Ice Age." Sporadic observations by the McMaster group indicate a reduced average recession of the *Castleguard Glaciers* of about 20 m from 1967 to 1981. This is a key alpine karst locality, because the cave and glacier systems are still in contact. Recent work has focused on the karst cave system (Ford, 1975, 1983), subglacial chemical deposits (Hallet, 1976a, b, 1977; Hallet and Anderson, 1980), and the interaction between glaciers and the limestone bedrock (Smart, 1983, 1984, 1986).

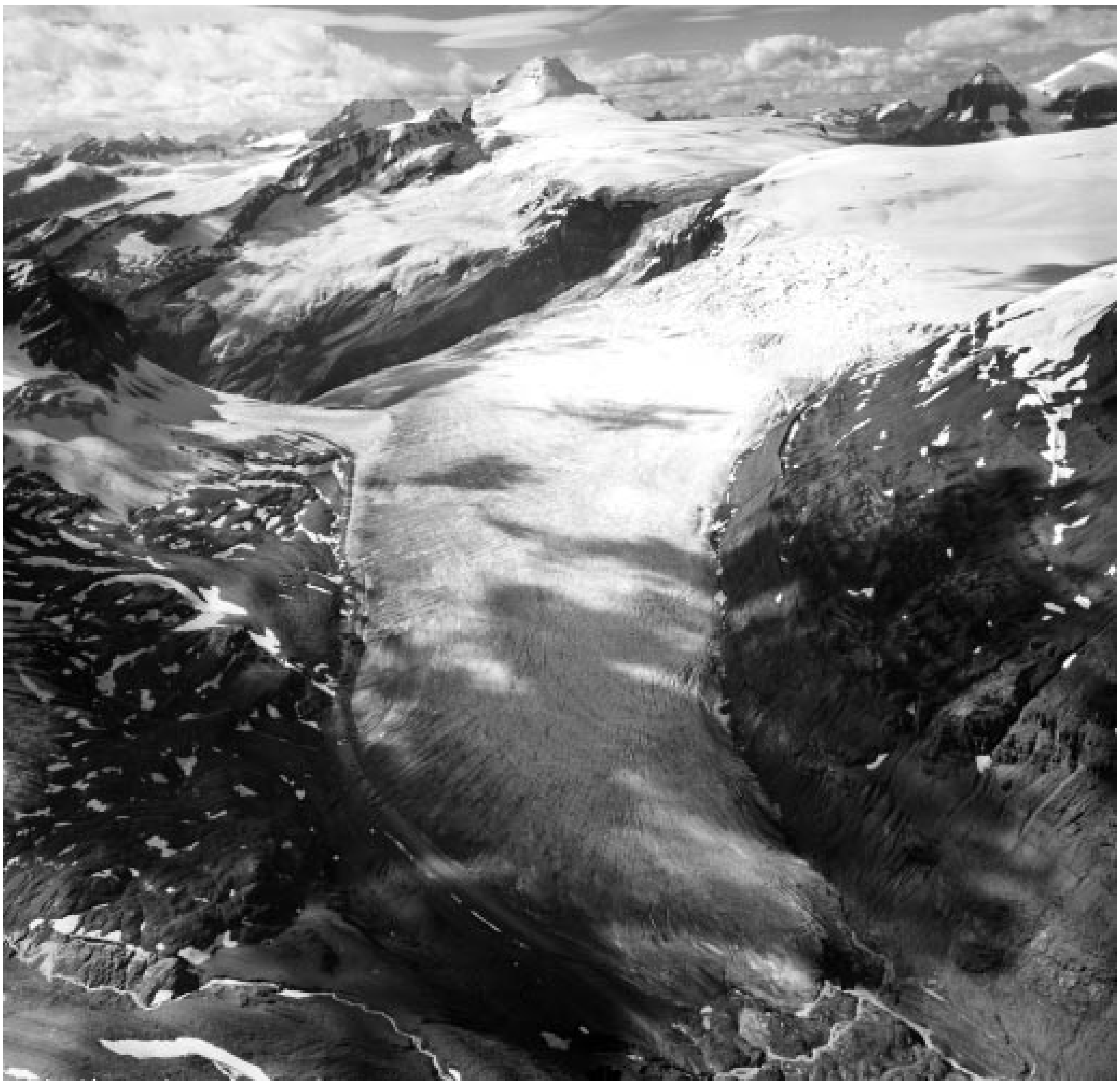
### Saskatchewan Glacier

The next major outlet glacier from the Columbia Icefield, the Saskatchewan Glacier (figs. 7, 20, 23) is about 13 km long and some 30 $km^2$ in area. It declines gradually from east to northeast, without ice falls, to its terminus at 1,800 m. Several tributary glaciers were formerly active in providing nourishment, although by the late 1980's only one of these supplied the Saskatchewan Glacier. The ELA lies almost at the junction of the ice field and outlet tongue and ranges from 2,440 to slightly more than 2,530 m. Based on ice discharge, Meier (1960) computed the annual accumulation to be 1 m water equivalent (w.e.) and its gradient 13 mm $m^{-1}$ below the firn limit, indicating a high degree of activity. Average ablation ranged from 1 m $a^{-1}$ near the ice field through 2.6 m $a^{-1}$ to 4 m $a^{-1}$ at the snout. The ice was 442 m thick 8 km upglacier and, because of the valley's marked U-shape and very steep walls, was as much as 305 m thick, even quite close to the margin (Meier, 1960).

*Figure 22.*—*High-angle oblique aerial photograph of* Castleguard Glacier IV*, the principal southern outlet glacier of the Columbia Icefield. This glacier and the other Castleguard Glaciers have receded considerably since the 1920's. Glacier 4*5DAE–47, Glacier Atlas of Canada, Plate 7.4, North Saskatchewan Glacier Inventory, Area 4*5D, Inland Waters Branch, Department of Energy, Mines and Resources, 1970, scale 1:500,000. Photograph K642–108, taken 21 August 1964 by Austin Post, U.S. Geological Survey, is courtesy of Robert M. Krimmel, USGS.*

In 1953, the American Geographical Society expedition used photographic and botanical techniques to determine the history of the Saskatchewan Glacier (Field and Heusser, 1954; Heusser, 1954, 1956). It withdrew from its terminal moraine in 1893 and by the time of their visit had retreated 1,364 m. The rate of recession from 1948 to 1953 was quite fast at 55 m $a^{-1}$.

In 1945, the Saskatchewan Glacier was investigated by the DWPB Calgary office. At this time the toe was very irregular and the surface of the glacier very rough. The position of the snout and changes in its areal extent were measured every year, and a set of plaques was placed on the ice surface to measure velocity; in 1950, the measurement interval became biennial. Detailed reports were prepared by the DWPB as internal documents, but some results were published (Lang, 1943; McFarlane, 1946b; Meek, 1948a, b; McFarlane and others, 1950; Collier, 1958). In the mid-1960's, following recommendations made at the Glacier Mapping



Symposium, the Water Survey of Canada began to use terrestrial photogrammetry to determine volumetric change, with results as shown in table 6 (Campbell and others, 1969; Reid, 1972; Reid and Charbonneau, 1972, 1975, 1979, 1981; Reid and others, 1978). Snout and plaque surveys were continued in the intervening years by the Calgary office of the Water Survey of Canada (WSC) (Warner and others, 1972; Canada, Environment Canada, 1976, 1982), but all were terminated by 1980 (fig. 9).

Meier (1960) measured the velocities on the surface and at depth, the surface and bedrock topography, and the ablation and flow structures in a project designed to test theories of glacier flow. Summer velocities were generally greater than annual ones, though there were significant velocity fluctuations in the short-term and there was even intermittent backward movement. Maximum surface velocities of 117 m $a^{-1}$ at the firn limit decreased unevenly downglacier to 3.5 m $a^{-1}$ at the snout. The flow law of ice was determined by analysis of a 140-m-deep vertical-velocity profile and a surface transverse-velocity profile. Three main classes of structural ice features were distinguished: (1) primary sedimentary layering,

***Figure 23.***—*High-angle oblique aerial photograph of Saskatchewan Glacier, a major eastward-flowing outlet glacier from the Columbia Icefield. The glacier is about 13 km long, has an area of 30 km$^2$, and has been studied since 1945 (see text). Glacier 4*5DAF–18, Glacier Atlas of Canada, Plate 7.4, North Saskatchewan Glacier Inventory, Area 4*5D, Inland Waters Branch, Department of Energy, Mines and Resources, 1970, scale 1:500,000. Photograph K642–102, taken 21 August 1964 by Austin Post, U.S. Geological Survey, is courtesy of Robert M. Krimmel, USGS.*

TABLE 6.—*Changes in the area and volume of the snout of Saskatchewan Glacier, 1965–1979*

| Changes | 1965–67 | 1967–69 | 1969–71 | 1971–73 | 1973–75 | 1975–77 | 1977–79 |
|---|---|---|---|---|---|---|---|
| Volume ($m^3$x$10^6$) | –43.96 | +12.45 | –44.11 | –30.85 | –10.75 | –3.09 | –23.88 |
| Surface height (m) | –6.51 | +1.89 | –6.84 | –4.51 | –1.76 | –0.53 | –3.73 |
| Terminus (m) | –33.80 | –28.00 | –9.60 | –23.00 | –45.40 | –53.60 | –91.20 |
| Snout elevation(m asl) | 1,786 | 1,789 | 1,789 | 1,790 | 1,790 | 1,790 | 1,790 |
| Area ($km^2$) | 6.75 | 6.58 | 6.45 | 6.84 | 6.10 | 5.84 | 6.40 |

(2) secondary flow foliation, and (3) secondary cracks and crevasses. Meier (1958) also studied crevasse patterns as part of this general study of flow. Preliminary results showed that crevasse formation was preceded by a buildup in extension rate. Crevasses then formed so as to relieve the extension rate on intercrevasse blocks. Intense deformation resulting in pure shear preceded an extending crevasse. No crevasses deeper than 30 m were observed.

Rigsby's (1958, 1960) fabric diagrams did not show preferred orientations as strong as those for other temperate glaciers. Any strong patterns observed were thought to be in the more extensively metamorphosed, presumably older, ice flowing from depth. Melt recrystallization probably changed the strong orientation of crystals from a single maximum with optic axes normal to the foliation plane to 3–4 maxima, none of which necessarily coincided with the pole of the foliation plane.

Sharp and Epstein (1958) and Epstein and Sharp (1959) analyzed the oxygen-isotope ratios in different firn strata and found differences that reflected the elevation of accumulation, seasonal influences, differences among individual storms, and subsequent diagenetic changes. Ice along the centerline showed an irregular trend to lower ratios downglacier, which was thought to reflect ice transport along flow lines from different parts of the accumulation area.

McPherson and Gardner (1969) observed large cross-valley topographic highs, composed of till, in front of the Saskatchewan Glacier, which were old landforms emerging from beneath the ice. They might have been interpreted as end moraines. If so, they were not disturbed when overridden during the neoglacial advance.

### Columbia Glacier

The Columbia Glacier (figs. 7, 20, 24), 8.5 km in length and about 16 $km^2$ in area, is the major outlet glacier flowing from the northwest section of the ice field, draining ice as well from the western slopes of Snow Dome and the eastern slopes of Mount Columbia (3,747 m). Columbia Glacier drops rapidly from the plateau area over a major ice fall, which creates a series of very well-defined ogives, to flow in a 0.6- to 0.7-km-wide glacier to an elevation of about 1,500 m. Its ELA lies at about 2,140 m. Habel (1902), Schaffer (1908), Palmer (1924–1926, 1925), Field (1949), and Field and Heusser (1954) recorded the location of the terminus in 1901, 1907, 1920, 1924, 1948, and 1953. The Interprovincial Boundary Survey photographed the glacier in 1919 (Interprovincial Boundary Commission, 1924). Heusser (1954) established a chronology of recessional moraines and dated the outer one at 1724 and others at 1842, 1854, 1864, 1871, 1907, 1909, and 1919; he concluded that the glacier had retreated 394 m between 1724 and 1924. A plot of the recession data is given in figure 9; it assumes no change from 1725 to 1850. Baranowski and Henoch (1978) observed that the Columbia Glacier had advanced as much as 1 km from 1966 to 1977. Since the Columbia Icefield map was published, the glacier has advanced farther to completely fill the large proglacial lake, a distance of some 800 m (Parks

Canada, oral commun., 1986). The glacier is not being surveyed regularly, so it is not known whether this advance is continuing.

### Athabasca Glacier

The most-visited glacier in Canada is without a doubt the Athabasca Glacier (figs. 20, 25). Situated only 1 km from the Icefields Parkway, which passes through Banff and Jasper National Parks, it is one of the primary destinations for tourists and tours. It has also become the focus of Parks Canada interpretive program and provides, through the Brewster snowmobiles, one of the few easy opportunities for the general public to get up on the ice. However, most would probably identify it as the Columbia Icefield. Its accessibility and the need for information about it have led to numerous scientific studies, which are summarized below.

The 6.5-km-long glacier leaves the ice field at 2,800 m, descends in a series of three ice falls as it passes over successive rock thresholds and continues as a gentle 1-km-wide tongue with a slope of 3–7° to its terminus at 1,925 m asl. It cuts through the axis of a gentle anticline and is flanked by walls of limestone, dolostone, and shale. Crevasses are well developed in the lower two ice falls and extend almost across the entire width of the glacier. Kucera (1987) measured 15 of the largest crevasses and found them to be no deeper than 36 m. Part of the glacier front is formed by moraine-covered ice that continues up valley, forming about two-fifths of

***Figure 24.****—High-angle oblique aerial photograph of Columbia Glacier, a major outlet glacier draining the northwest section of the Columbia Icefield, including the western slopes of Snow Dome (off left side of photograph) and the eastern slopes of Mount Columbia (off right side of photograph). The glacier drops over a major ice fall (center of photograph) creating ogives. The glacier receded rapidly from the 1920's to the 1960's (fig. 9), but has advanced about 2 km between 1966 and 1986. Glacier 4*7AAG–71, Glacier Atlas of Canada, Inland Waters Branch, Department of Energy, Mines and Resources, scale 1:500,000. Photograph K641–42, taken 21 August 1964 by Austin Post, U.S. Geological Survey, is courtesy of Robert M. Krimmel, USGS.*

the glacier along the northwest side. Benoît and others (1984) published a key to the photointerpretation of features on and around the Athabasca and Dome Glaciers. Elements that are important for the analysis of remote-sensing imagery, such as the characteristics of various features, their texture, and reflectivity are all discussed. This study complements an earlier glaciological and geomorphological investigation by Kucera and Henoch (1978). Howarth (1983) and Howarth and Ommanney (1983) reported some difficulty in interpreting Landsat scenes for this area.

It is surprising that no systematic annual mass-balance studies have been carried out on the Athabasca Glacier. However, geochemical studies within the 2,600–2,700-m elevation band were used by Butler and others (1980) to estimate a net annual mass balance here of 1.5 and 2.4–2.7 m w.e., respectively, for 1976–77 and 1977–78. Average snowfall on the ice field is estimated to be more than 7 m, and the ELA is at about 2,600 m asl. Holdsworth and others (1985) obtained an 11.5-m core from the top of Snow Dome to evaluate the site for a deep core drilling. Preliminary analysis indicated a lack of evidence of regular seasonal variations in the stable-isotope data but evidence of percolation and homogenization of the isotopic and chemical constituents. It is clear that the overall mass-balance trend during the 20th century has been strongly negative. In 1870, the glacier was about 1.5 times its present total volume ($1{,}013 \times 10^6$ m$^3$) and 2.5 times its area ($6 \times 10^6$ m$^2$ vs. $2.6 \times 10^6$ m$^2$). The average rates of decrease in volume

***Figure 25.****—High-angle oblique aerial photograph of Athabasca Glacier, the most visited glacier in Canada. The 6.5 km glacier drains the Columbia Icefield to the northeast and has been studied extensively (see text). Glacier 4*7AAF–4, Glacier Atlas of Canada, Inland Waters Branch, Department of Energy, Mines and Resources, scale 1:500,000. Photograph K64L–133, taken 21 August 1964 by Austin Post, U.S. Geological Survey, is courtesy of Robert M. Krimmel, USGS.*

have declined: $3.2x10^6$ $m^3$ $a^{-1}$ for 1870–1971 to $2.5x10^6$ $m^3$ $a^{-1}$ for 1959–1971 (Kite and Reid, 1977). Ice volume has also been reconstructed by Mayewski and others (1979) as shown in table 7.

Observations of the retreat of the terminus of the Athabasca Glacier have been carried out for many years and are shown in table 8. Figure 26 shows the position of the terminus of Athabasca Glacier in 1952 and 1977. Hermann Woolley and J. Norman Collie visited and named Athabasca Glacier in 1898, at which time it coalesced with the Dome Glacier. Athabasca Glacier was photographed in 1908 (Schaffer, 1908) and again in 1919 (Interprovincial Boundary Commission, 1924). Field photographed it in 1919. In 1945, the DWPB commenced a series of annual surveys from their Calgary office. The position of the snout and the changes in the areal extent of Athabasca Glacier were measured every year, and a set of plaques was placed on the ice surface to measure velocity. Detailed reports were prepared as internal documents (McFarlane, 1945, 1946b, 1947; McFarlane and May, 1948; MacFarlane and others, 1949; May and others, 1950; Carter, 1954; Carter and others, 1956; Fowler and others, 1958; Chapman and

*__Figure 26.__—Two photographs of the receding terminus of the Athabaska Glacier, Jasper National Park, Alberta.* **A**, *View in 1952 by A. MacS. Stalker, Geological Survey of Canada, Photograph GSC 147803.* **B**, *View in 1977 from Applied Hydrology Division, Environment Canada, Photograph GSC 203797–M. Modified from figure 9 in Prest, V.K., 1983, p. 20. ©Produced under licence from Her Majesty the Queen in Right of Canada, with permission of Natural Resources Canada.*

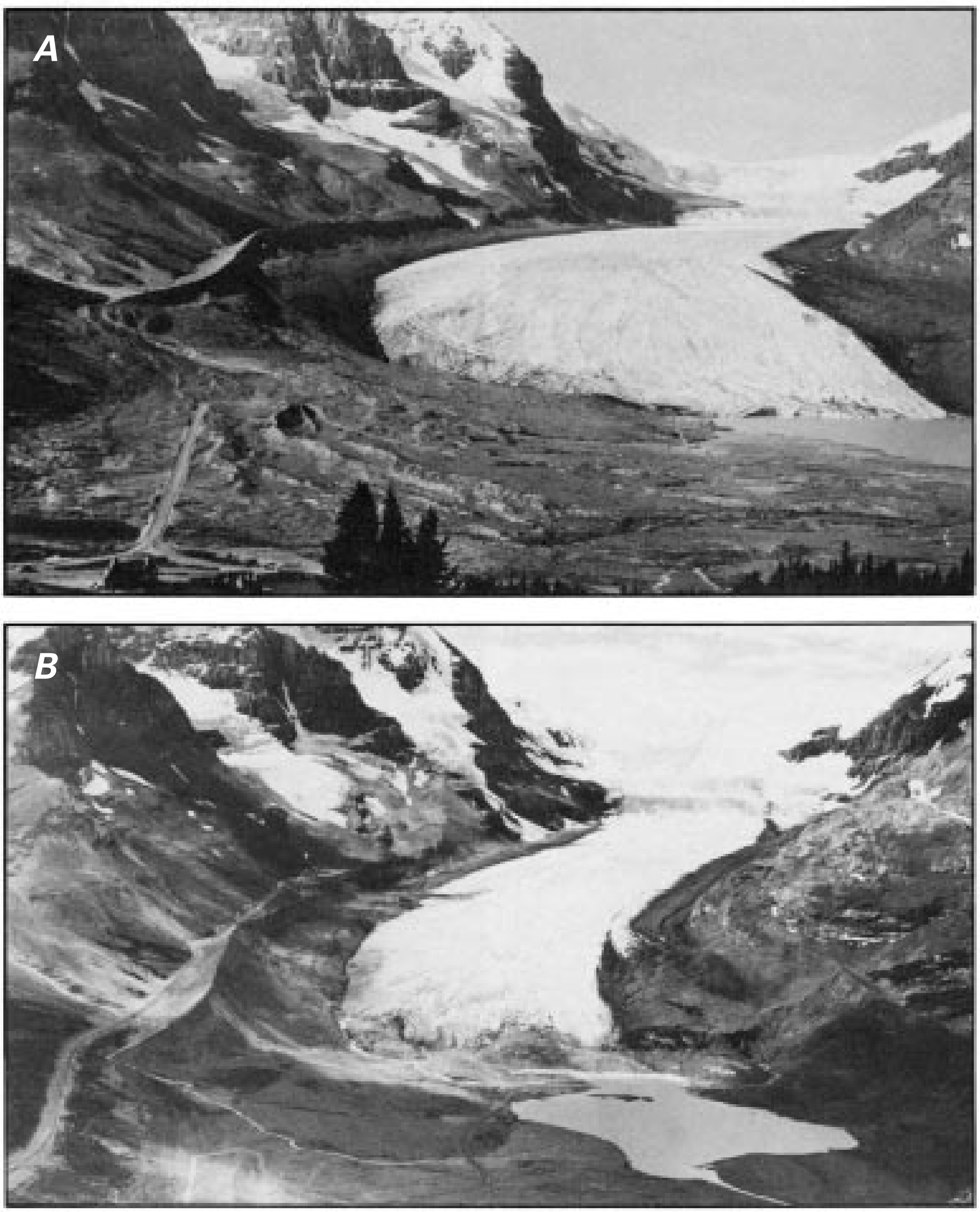


TABLE 7.—*Recession and volume changes of Athabasca Glacier, 1870–1970 (from Mayewski and others, 1979)*

| Date | Retreat (meters $a^{-1}$) | Area Loss (square kilometers $a^{-1}$) | Volume Loss (cubic kilometers $a^{-1}$) |
|---|---|---|---|
| 1870–1877 | 6 | 0.025 | 0.0024 |
| 1877–1882 | 11 | 0.011 | 0.0030 |
| 1882–1886 | 11 | 0.011 | 0.0014 |
| 1886–1900 | 6 | 0.022 | 0.0020 |
| 1990–1908 | 5 | 0.023 | 0.0015 |
| 1908–1922 | 4 | 0.018 | 0.0033 |
| 1922–1938 | 13 | 0.035 | 0.0035 |
| 1938–1945 | 27 | 0.043 | 0.0069 |
| 1945–1950 | 27 | 0.033 | 0.0068 |
| 1950–1956 | 21 | 0.028 | 0.0062 |
| 1956–1960 | 38 | 0.040 | 0.0043 |
| 1960–1965 | 8 | 0.019 | 0.0040 |
| 1965–1970 | 4 | 0.013 | 0.0026 |

others, 1960; Davis and others, 1962; Davies and others, 1964, 1966, 1970; Glossop and others, 1968), but some results were published (McFarlane, 1946a; Meek, 1948a, b; McFarlane and others, 1950; Collier, 1958).

Following experimental aerial photogrammetric surveys of the Athabasca Glacier in 1959 and 1962 (Reid, 1961), the University of New Brunswick examined the use of terrestrial photogrammetry for measuring the melt of the Athabasca Glacier (Konecny, 1963, 1966; Reid and Paterson, 1973). From 1959 to 1962 the surface was reduced an average of 1.7 m, and the glacier lost $3.936 \times 10^5$ $m^3$, representing a 35 percent contribution to average annual streamflow (Reid and Paterson, 1973). The Water Survey of Canada then switched to a program of terrestrial surveys every 2 years (Campbell and others, 1969; Reid, 1972; Reid and Charbonneau, 1972, 1975, 1979, 1981; Reid and others, 1978) for the measurement of volumetric change (table 8); snout and plaque surveys were continued in the intermediate years by the Calgary office (Warner and others, 1972; Canada, Environment Canada, 1976, 1982). Paterson (1966) showed that the difference between individually surveyed markers and map heights was less than three times the theoretical error, or about 15 percent of the contour interval. Additional surveys were made of the Athabasca Glacier in August 1977 as part of a program to remap the Columbia Icefield and surrounding areas and to test the relatively new orthophoto-mapping process. Young and others (1978) reported that there was little to choose amongst the various techniques, although the orthophoto mapping might be faster and cheaper and produced a digital-terrain model in computer-compatible form of use for further computations. Errors in the three methods ranged from about 1–2 m on the lower glacier to about 10–20 m on the upper.

Some other records are also available from Field, who revisited the glacier in 1948, 1949, 1953 and 1963 (Denton, 1975). He and Heusser, using photographic and botanical techniques (Field and Heusser, 1954; Heusser, 1954, 1956), were able to develop the history further. Athabasca Glacier reached its maximum about 1714 and began to withdraw from different parts of its end moraine in 1721 and 1744. It readvanced in the first half of the 19th century, reaching almost to its maximum extent. Recession began between 1841 and 1866 and has continued with minor fluctuations marked by moraines formed about 1841, 1900, 1908, 1925, and 1935.

The glacier has been used as a test area for a variety of depth-measurement techniques, some of which have been designed to provide information for physical studies of glacier flow.

Kanasewich (1963) used gravity techniques to obtain ice-thickness values along eight transverse profiles, whereas Paterson and Savage (1963a) used seismic waves to determine depths for 2- km downglacier from the lowest ice fall. During the summer of 1959, five holes were drilled into the glacier with a prototype hotpoint drill (Stacey, 1960). Rossiter (1977) tested a 1–32 MHz radio interferometry depth-sounding technique on Athabasca Glacier. High scattering levels above 8 MHz were attributed to water-filled cavities within the glacier on the order of 3–6 m in width, having typical separations of 10–30 m. Strangway and others (1974) found that at 1, 2, and 4 MHz the ice had a dielectric constant of about 3.3,

TABLE 8.—*Changes in the area and volume of the snout of Athabasca Glacier, 1959–1979*

| Changes | 1959–62 | 1962–65 | 1965–67 | 1967–69 | 1969–71 | 1971–73 | 1973–75 | 1975–77 | 1977–79 |
|---|---|---|---|---|---|---|---|---|---|
| Volume ($m^3 \times 10^6$) | –1.76 | –3.07 | +3.10 | +0.66 | –16.76 | +6.19 | –6.13 | –6.50 | –2.79 |
| Surface height (m) | –0.68 | –1.35 | +1.36 | +0.29 | –7.71 | +2.49 | –2.45 | –2.61 | –1.09 |
| Terminus | –38.1 | –36.3 | –10.6 | –20.4 | –14.9 | –6.0 | –19.0 | +7.8 | –7.0 |
| Snout elevation (m asl) | | | 1930 | 1930 | 1935 | 1930 | 1953 | 1941 | 1944 |
| Area ($km^2$) | 2.57 | 2.28 | 2.28 | 2.28 | 2.17 | 2.48 | 2.50 | 2.49 | 2.56 |

corresponding to that for ice near 0°C. Measured depths were not always consistent with previous seismic, gravity, and borehole results. Radio-echo-sounding has featured prominently in depth investigations. A sophisticated mobile system linked to fixed transponders (Goodman, 1970, 1975) provided results that agreed within 14 m with the seismic and borehole measurements of Savage and Paterson (1963). Repetitive soundings at individual locations revealed the presence of intraglacier structures that appeared to be related to changing hydrological or glaciological conditions within the glacier (Goodman, 1973). Waddington and Jones (1977), using a 1–5 MHz radio-echosounder, sampled the accumulation area of the Athabasca Glacier from below Castleguard Mountain northward to the ice falls and westward to the divide. They found depths ranging from 100 to 365 m. Contour maps of ice thickness and basal elevations have been produced by Trombley (1986), based on 300 depth measurements of the lower 3.6 km of the glacier with a portable radio-echosounder. A summary of some of the results, based on Paterson (n.d.) and Trombley (1986) is given in table 9.

Measurements show that in the ablation area, below the lowermost ice fall, the longitudinal and transverse profiles of ice thickness are geometrically regular and simple. A bedrock depression and two bedrock rises influence the flow. The ice is thickest (>320 m) in the deepest part of the depression, which appears to be a relic valley carved by what is now a small hanging glacier. Removal of the glacier would create a chain of paternoster lakes (Kanasewich, 1963).

In an interesting variant on their seismic study, Neave and Savage (1970) used natural seismic activity to monitor icequakes. These appeared as single events in the zone of marginal crevasses resulting from extensional faulting near the glacier surface. Swarms of icequakes were occasionally recorded that were distinguished from the crevasse-forming icequakes by their intense activity (20 events $s^{-1}$), by their distribution along a line several hundred meters long, and by their location, crossing the crevasse-free center strip of the glacier. Propagation velocities on the order of 30 m $s^{-1}$ were observed. Not only did the individual events in a swarm migrate across glacier, but they also appeared to migrate downglacier at a velocity of about 30 m $h^{-1}$.

TABLE 9.—*Depths of Athabasca Glacier [based on Paterson (n.d.) and Trombley (1986)]*

| Elevation (m asl) | Depth (meters) | Year of measurement | Elevation (meters asl) | Depth (meters) | Year of measurement |
|---|---|---|---|---|---|
| 2036 | 60 | 1979 | 2231 | 250 | 1960 |
| 2048 | 73 | 1960 | 2232 | 322 | 1959–61 |
| 2115 | 176 | 1979 | 2234 | 316 | 1966–67 |
| 2122 | 194 | 1959–61 | 2234 | 298 | 1966–67 |
| 2130 | 195 | 1979 | 2235 | 314 | 1959–61 |
| 2135 | 209 | 1959–61 | 2237 | 265 | 1966–67 |
| 2141 | 209 | 1966–67 | 2237 | 251 | 1979 |
| 2195 | 248 | 1959–61 | 2238 | 297 | 1966–67 |
| 2202 | 210 | 1979 | 2238 | 300 | 1979 |
| 2206 | 235 | 1960 | 2239 | 306 | 1979 |
| 2228 | 310 | 1979 | 2240 | 306 | 1979 |
| 2229 | 319 | 1979 | 2240 | 308 | 1966–67 |
| 2229 | 318 | 1979 | 2240 | 311 | 1966–67 |
| 2229 | 315 | 1979 | 2250 | 311 | 1966–67 |
| 2230 | 291 | 1979 | 2250 | 312 | 1979 |
| 2230 | 313 | 1966–67 | 2250–55 | 309 | 1966–67 |

It is possible to tell from velocity measurements that ice now at the tongue of the Athabasca Glacier fell as snow on the ice field 150–200 years ago. Observations in 1959 and 1960, along the center line of the glacier, showed that ice velocity varied from 74 m $a^{-1}$ below the ice fall to 15 m $a^{-1}$ at the terminus and that the longitudinal strain rate varied from –0.1 to 0.0 $a^{-1}$ (Savage and Paterson, 1963, 1965). Paterson (1962) found that the longitudinal strain rate was not constant with depth and at 100 m was slightly greater than at the surface. He concluded that the quasi-viscous Glen flow law provided the best fit to the available data (Paterson and Savage, 1963b). Ice takes about 2 years to travel down the lowest ice fall, corresponding to a velocity there of about 130 m $a^{-1}$. Seasonally unexpected velocity variations 2.5 km upglacier were explained by variations in the amount of water available at the bed for lubrication, being positively correlated with streamflow from the lake, with a lag of 3–4 days (Paterson, 1964). However, Meier (1965) pointed out that measurements on meltwater discharge from Athabasca Glacier by Mathews (1964a, 1964b) showed that maximum runoff occurs within a few hours of maximum melt. Paterson (1965) replied that some runoff may be delayed. Short-term velocity variations have been studied by Kucera (1971, 1987), using time-lapse photography. Ice within 60 m of the terminus is moving at an average rate of 57 mm $d^{-1}$ (20.8 m $a^{-1}$) and, during the summer, as much as 5 mm $h^{-1}$. During a two-and-a-half month period, ice descended the lowest ice fall at a velocity of about 0.35 m $d^{-1}$, or 125 m $a^{-1}$. The glacier moves faster in summer than in winter and seems to move faster during the day than at night.

The velocity of ice deep within Athabasca Glacier has been measured in a number of boreholes. Savage and Paterson (1963), Paterson (1970), and Raymond (1971b) demonstrated that the upper part of the glacier is moving faster than the base. Velocity varies little with depth in the upper half of the borehole (209 m deep), but in the lower half, velocity decreases but at an increasing rate as the bottom is approached. Savage and Paterson (1963, 1965) estimated basal slip in two boreholes to be 30 m $a^{-1}$ and 3 m $a^{-1}$. These boreholes lie along the same streamline and are separated by only six times the average depth. Raymond (1971a) applied a new method for determining the three-dimensional velocity field of the Athabasca Glacier. His measurements of ice deformation at depth revealed the pattern of flow in a nearly complete cross section of a valley glacier (Raymond, 1971b). He found that the relative strength of marginal and basal shear strain-rate was opposite to that expected. He further developed methods for determining the distributions of stress and effective viscosity in a glacier (Raymond, 1973) that did not support the results obtained by Paterson and Savage (1963a, b).

Using two different techniques, Reid and Paterson (1973) determined that the average annual loss of ice is $14.7 \times 10^6$ $m^3$, equivalent to $13.4 \times 10^6$ $m^3$ $a^{-1}$, or about 35 percent of the average annual streamflow measured at the gauging station. This compares to Collier's figure of 10–20 percent (Collier, 1958). The figure for glacier-melt contribution is much higher. Reid (1972) determined the 20-year average for mid-May to the end of October to be $35.1 \times 10^6$ $m^3$. Collier (1958) pointed out how effective glacier melt is in sustaining streamflow in August and September. The addition of 106 percent to the drainage area in Edmonton only increased the September 1955 flow by 1 percent (Collier, 1958).

Mathews (1964a) developed a moderately successful regression equation relating discharge of the Sunwapta River to temperature in Jasper. Correlations commonly better than +0.8 and reaching +0.96 were obtained for individual periods of from 1 to 2 months. He concluded that the daily streamflow was related, first, to the temperatures of the current day and, second, to the temperatures of the previous few days. There were pronounced diurnal fluctuations in meltwater flow from Athabasca Glacier (Mathews, 1964a)

An interesting feature of the streamflow record noted by Mathews (1964a) was the occurrence of jökulhlaups. These interrupted the normal diurnal cycle and were apparently unrelated to weather conditions. Records covering 13 summers showed at least 10 glacier-outburst floods having a discharge volume of 250,000 $m^3$ or more and one flood that released 1,400,000 $m^3$ of water. Because there are no ice-dammed lakes near the Athabasca Glacier, the water must have been stored within the glacier itself. Drainage of the floodwaters from a single chamber within the ice would certainly have caused some surface subsidence of the ice, but this was not observed. Mathews (1964a) concluded that the water must have been contained in a number of smaller cavities. Such cavities were noticed by Savage and Paterson (1963) during their drilling program in 1962. In 1968, they punctured a cavity at a depth of 9.2 m (Paterson and Savage, 1970). Water gushed from the borehole for about 55 s, indicating an excess pressure of at least 25 kPa. This pressure was thought to have been generated by the reduction in volume of the cavity caused by freezing of some of the water within it. Other evidence of unusual flows is provided by Kucera (1987), who reported that a meltwater stream near the snowmobile access road tripled in discharge from 0800 to 1600 h during one day in August 1980. Conditions were clear and air temperatures increased from 1 to 8°C during the same period.

During periods of high discharge, the meltwater streams carry a heavy sediment load, shifting position and migrating across the "Sunwapta" delta throughout the summer (Kucera, 1971, 1987). The sequence of WSC glacier maps shows that the delta has advanced 40 m into Sunwapta Lake, an effective sediment trap, during a 14-yr period. During one 24-h period in 1957, an estimated 380 tonnes of sediment and 190 tonnes of sand were brought into the lake by two glacier streams. Of this amount, only 4–7 tonnes of the sediment and none of the sand left by way of the Sunwapta River (Mathews, 1964b).

Particle-size distribution, roundness, striations, fabric, and lithologic composition have been used to distinguish between basal till, lateral- and recessional-moraine tills, ablation till, and outwash (Mills, 1977a, 1977b, 1977c). Glacial debris in a 120-m-wide zone in front of the Athabasca Glacier is not spread haphazardly across the forefield but, rather, occurs as low discontinuous ridges 0.7–2 m high that lie 2–20 m apart and trend roughly parallel to the glacier front. These are annual moraines produced by an advance of ice during the winter months. Measurements by Kucera since 1967 indicate that although the glacier advances 6–10 m during the winter months, the rate of retreat during the ablation season has slowed from 18–30 m to 10–16 m in recent years. This explains why the annual moraines are now spaced more closely together than in the past; for example, the position of the 1977 moraine lies only 2 m from the 1976 annual moraine (Kucera, 1987).

On the west side of Sunwapta Lake, the toe of the Athabasca Glacier consists of a dirty ice cliff. Rock debris, 1–2 m thick, extends upglacier along the western margin. Supraglacial debris cover, such as that also found on the neighboring Dome Glacier, creates significant problems in the interpretation of remote sensing imagery for these areas. The cliff is marked by rills that collect ice-and-rock fragments that cascade down the steep ice front: the slope of 40° has been maintained for several years (Kucera, 1987).

Some other aspects of the Athabasca Glacier have also been studied. Paterson (1971, 1972) determined that the temperature in the ablation area of Athabasca Glacier is about –0.5°C at a depth of 10 m. Below 17 m, it is slightly below the calculated pressure-melting point. The observed temperature regime is accounted for partly by heat produced by ice deformation and partly by freezing of water within the ice. The required water content is between 0.5 and 1 percent and is thought to be water trapped between grains when the ice formed from firn. Clee and others (1969) investigated the mechanism of internal friction of ice near its melting point by observing the attenuation of elastic waves. They decided that attenuation appears to be best explained by grain-boundary slip. Watt and Maxwell (1960) measured the electrical properties of snow and glacier ice and concluded that their properties were appreciably different from pure ice. Keller and Frischknecht (1960, 1961) used electrical resistivity. Stanley (1965) found that most of the lower part of the glacier, below the ice falls, is composed of either fine or coarse bubbly ice in alternating layers. Cryoconite holes have been described by Wharton and Vineyard (1983). They observed seven species of pennate diatoms and several species of green algae in the holes, probably transported onto the glacier from nearby aquatic and terrestrial sources.

### Dome Glacier

Dome Glacier is poorly nourished in comparison to Athabasca Glacier. Dome Glacier's bifurcated terminus is fed largely by avalanching from Snow Dome. Most of the surface of Dome Glacier is covered by ablation, lateral, and medial moraines, which make it difficult to determine its true areal extent. The basic characteristics of Dome Glacier are given in table 5. The ablation moraine is commonly less than 1 m thick and the ice beneath is clean. Stream courses usually follow the margin of rubble-covered ice, but Kucera (1987) observed one on the glacier in a channel 4 m wide and 3 m deep which dropped to a depth of about 10–15 m to become an englacier stream leaving a route marked by abandoned moulins up to 3 m in diameter. Probably because of the insulating moraine cover, Dome Glacier has receded comparatively less than the Athabasca Glacier, with which it coalesced at one time. Starting about 1875, it receded 530 m from 1875 to 1919 and 318 m from 1919 to 1953. At least four recessional moraines appear between the terminal moraine remnants and the present ice front: 1900, 1908, 1913, and 1918 (Heusser, 1954).

### *Boundary Glacier*

The *Boundary Glacier* is a 2-km-long cirque glacier, 1.18 $km^2$ in area. It is located on the divide between the Saskatchewan and Athabasca watersheds and on the boundary between Banff and Jasper National Parks. It flows from the slopes of Mount Athabasca at 3,320 m asl to a low-gradient accumulation basin at 2,750 m and thence to two ice tongues at 2,365 m asl. The ELA lies at about 2,730 m. Gardner and Jones (1985) and Gardner (1987) have studied the sediment budget and bergschrund/randkluft erosion here. Sloan (1987) reported that debris deposition along the 350-m tongue is at a rate of 4,400 kg $d^{-1}$. A retreat of 810 m from the "Little Ice Age" maximum has been determined. Intermediate snout positions have been mapped (fig. 9). This is one of the few glaciers in the Rockies for which there is recent evidence of a significant advance.

### *Hilda Glacier*

*Hilda Glacier* is a small cirque glacier fed largely by avalanching from the eastern slopes of Mount Athabasca (3,491 m). It is about 2.5 km long, 1.35 $km^2$ in area. It has a large debris-rich proglacial area 1 km long that starts at the prominent Neoglacial moraine (2,055 m), rises to the snout at 2,170 m, and thence to the upper accumulation area at 2,900 m. The glacier surface is covered by a thin mantle of supraglacier debris supplied by rockfalls and avalanches. According to Heusser (1954), retreat began around 1790, but he made no measurements because the lower end of the glacier was hidden by debris (Field and Heusser, 1954). During 1977 and 1978, while the glacier was still receding, a study of sediment supply and transport was initiated (Hammer and Smith, 1983). When seen by Heusser (1956), the lower part was a boulder mass with humps and pockets that gave the appearance of concentric “waves” in several places. This morainal complex characterizes the mass as an incipient rock glacier. In the continuum from glacier (mostly ice) to rock glacier (mostly rock fragments), the morainal complex falls into the rock glacier classification. Folds of soil that have been pushed up along the down-valley periphery suggest that the mass continues to exhibit motion.

### Winston Churchill Range (PC13)

Stretching north-northeast from the Columbia Icefield some 30 km to the fork in the Athabasca and Sunwapta Rivers is the Winston Churchill Range (fig. 1, PC13). Summit elevations in the main part of the range exceed 3,100 m and reach a maximum at Mount Alberta (3,619 m). The *Diadem Icefield* includes a number of individual glaciers around Mounts Alberta and Woolley, extends northward in a continuous 10-km mass from Diadem Peak to Mount McGuire, and encompasses Gong Glacier (3.5 km) to the west. Lying outside this ice field are additional small glaciers, usually located in deep cirques on north- to northeast-facing slopes. Glaciers average 2 to 3 km in length, up to 1 $km^2$ in area, and have snouts close to 2,000 m. A characteristic of this region is the large amount of morainal debris lying on and around many of the glacier termini, in a number of cases grading into classic rock glaciers. Stutfield and Collie (1903) concluded that the rock glaciers were formed from massive rockfalls from the limestone cliffs at some time in the past.

### *Chaba Group (PC14)*

Northwest of the Columbia Icefield, and contiguous with it and the Clemenceau Icefield, lies the Chaba Icefield (fig. 20). This 97-$km^2$ irregular, elongated ice mass runs along and beyond the Continental Divide for some 27 km. Its northeast side drains into the Athabasca River through a number of outlet glaciers, chief of which are Chaba Glacier (9-km long), *West Chaba Glacier* (7 km long) and Misty Glacier (3.5 km long). The ice field and its environs include some 30 glaciers that range from 1 to 3 km in length, with snouts reaching to elevations of 2,000–2,300 m asl. The ELA probably lies at about 2,300 m, some 500 m below the regional glaciation level established by Østrem (1966). J.M. Thorington, in one of the few reports from this area, reported a recession of 170 m from the 1927 position established by the Harvard University group in 1936 (McCoubrey, 1938). Summit elevations in the central portion of the ice field exceed 3,100 m. Northward, toward Fortress Lake and Wood River, summit elevations decline to below 2,800 m.

### *Clemenceau Icefield Group (PC15)*

Previous writers have stated confidently that the Columbia Icefield is the largest in the Rocky Mountains, yet the Clemenceau Icefield (figs. 7, 20), including its outliers south of Tsar Mountain (*Clemenceau Icefield Group*; fig. 1, PC15), is only slightly smaller (313 $km^2$). It is linked to both the Chaba and Columbia Icefields (figs. 7, 20) by Wales Glacier, which has one major accumulation basin in each ice field. Most of the drainage is through two outlet glaciers: (1) a major compound glacier on the northern part of the ice field that reaches a maximum length of 13 km and consists of the Tusk, Clemenceau, and Duplicate Glaciers, whose cumulative moraines have created an extensive debris-covered tongue that feeds Clemenceau Creek and (2) Apex Glacier, a triangular-shaped outlet glacier that flows 13.5 km south from the mountain of the same name. The larger outlet glaciers push down to below 1,500 m asl, with one debris-covered tongue reaching to 1,035 m. The ELA is about 2,200 m and the glaciation level at 2,700 m. The highest point of this ice field is appropriately Mount Clemenceau (3,630 m); most of the other major peaks in the group exceed 3,000 m. The isolation and inaccessibility of the region have inhibited glaciological research, visits being limited to a few climbing parties.

### ***Fryatt Group*** **(PC16)**

West of the Athabasca River and north of Fortress Lake and Alnus Creek is the *Fryatt Group* (fig. 1, PC16), a series of mountain ridges stretching to the northeast some 15 km from a 30–km ridge that follows the provincial boundary. Apart from Catacombs Mountain (3,292 m), elevations in the southern part are generally below 3,000 m but rise northward to about 3,100 m, attaining a maximum at Mount Fryatt (3,361 m). Most of the glaciers lie in northeast-facing cirques below the boundary ridge; they are <2 km long and terminate between 2,000 and 2,100 m. A 5–km-long glacier flows north and northwestward from Catacombs Mountain. Around Mount Fryatt the glaciers are shorter and at higher elevations.

### ***Whirlpool Group*** **(PC17)**

The ranges surrounding Whirlpool River, west of the *Fryatt Group* and north of Clemenceau Icefield, have been referred to as the *Whirlpool Group* (fig. 1, PC17). The *Whirlpool Group* consists of two separate blocks, or ranges, divided by the valley of the Whirlpool River and Athabasca Pass, which for many years was a major fur-trade thoroughfare that effectively split the Hooker and Mount Brown Icefields (fig. 4). The former ice field is an irregular mass of contiguous glaciers covering about 90 $km^2$ and includes the Kane, Hooker, North Alnus, South Alnus, and Serenity Glaciers, each about 4 to 5 km long, as well as the main body of the ice field itself. Other glaciers in this part of the group tend to be 1 to 2 km long. Several snouts push down to 1,800 m or lower. Apart from contributions to Whirlpool River, the glaciers drain west through Fortress Lake and Wood River. Mount Brown Icefield is a more regular ice mass <5 $km^2$ in area. Glaciers in the northern extension of the range, south of Simon Creek, tend to be slightly smaller than those to the south and include several debris-covered tongues and rock glaciers. Some descriptions of the glaciers around Athabasca Pass date from the time of the fur traders. Scott Glacier was first observed by David Douglas in 1827 (Douglas, 1914). Schafer (1954) reported that its retreat began in 1780 and that by 1924 the glacier had contracted 650 m. In 1952, the Alpine Club of Canada (1953) reported that the lower part of Scott Glacier, which in 1924 covered a large part of the outwash plain, had almost disappeared after a recession of some 1.2 km in 28 years (fig. 9). Despite early miscalculations of the elevation of Mount Brown that led to suggestions that it might be the highest peak in the Rocky Mountains, its highest point is only 2,799 m asl. Summit elevations are generally lower here than in the *Park Ranges* to the east. Although some peaks in and around the Hooker Icefield exceed 3,200 m asl, most are below 3,000 m, and northward they tend to even lower elevations.

### **Unnamed Ranges (—)**

West of the Clemenceau Icefield, the Whirlpool, and the *Fraser-Rampart Group*s, and south of the Selwyn Range, is a group of unnamed ranges that mark the western limits of the *Park Ranges* in this section. Individual ranges within the group generally trend to the southwest; runoff from the ranges drains into what used to be the Canoe River in the Rocky Mountain Trench but what is now Canoe Reach of the artificial McNaughton Lake. West of Clemenceau Icefield, there are numerous small glaciers, usually <1 km in length, that terminate between 2,200 and 2000 m, along with some evidence of debris-covered tongues and rock glaciers. The largest glaciers in the southern section are no larger than 1 $km^2$ in area. Average peak heights are usually below 2,700 m, considerably lower than in the ranges to the east. Østrem's (1966) investigations put the regional glaciation level at 2,500–2,600 m.

The central section of the unnamed ranges, west of the Hooker and Mount Brown Icefields, contains one range with much larger ice bodies than those found in the southern part of the unnamed ranges, including a contiguous mass of glacier ice that is about 17 $km^2$ in area and lies south of the Mount Brown Icefield. However, as in the area in the southern part of the unnamed ranges, the other ranges have a profusion of small glaciers; usually in well-developed cirques, <1.5 km long and about 0.5 $km^2$ in area. Most end below 2,200 m, with several reaching as low as 1,700 m. Large moraines are much in evidence. Peaks here are slightly higher, some exceeding 3,000 m asl, but most are in the 2,600- to 2,800-m range.

The final, northern section of these unnamed ranges consists of mountains within and west of Mount Robson Provincial Park (fig. 4) bounded by Fraser River and Ptarmigan Creek. Peaks here are lower than to the south, with the highest rising to just over 2,800 m asl. Most of the ice is concentrated in a small ice field about 6 $km^2$ in area. Lengths of the some 15 glaciers here range from 0.5 to 1.5 km, with two at 2.5 km. Snouts are between 2,100 and 2,300 m asl.

### ***Cavell Group*** **(PC18)**

Just west of the Banff-Jasper Highway rises the impressive Mount Edith Cavell (3,363 m), named after a First World War nurse who was shot for helping Allied troops trapped behind enemy lines to escape. It is the focal point of the *Cavell Group* (fig. 1, PC18), a small range with summit elevations ranging from 2,800 m to more than 3,000 m and with a number of small glaciers and rock glaciers that terminate as low as 2,100 m and that are from 0.5 to 2 km in length. A trail leads from the highway to the foot of Angel Glacier.

#### Angel Glacier

On the north side of Mount Edith Cavell lies a group of ice masses that at one time formed part of the same glacier. The lower part, a reconstituted, debris-covered ice mass, is known as *Cavell Glacier*. The long, thin ice stream, which once joined to the upper Angel Glacier, was known as Ghost Glacier; appropriately this glacier has now vanished. Angel Glacier, named for the two "wings" of ice adhering to the slopes of Mount Edith Cavell (Lang, 1943), occupies a cirque with a collection area of 0.89 $km^2$. The bulk of the ice mass lies between 2,250 and 2,600 m (fig. 27). According to Østrem (1966, 1973b), the glaciation level is at about 2,600 m asl, with the equilibrium line altitude some 300 m below. This implies that Angel Glacier has a generally positive balance; something that seems to be confirmed by the small hanging glacier (150–190 m long) that flows from it; frequent ice falls confirm its active nature.

#### *Cavell Glacier*

The lower *Cavell Glacier* is a gently sloping, heavily debris-laden mass of ice barely reaching 2,000 m asl; its snout is at 1,750 m. The glacier thus lies entirely below the equilibrium line altitude and survives thanks to its heavy, insulating debris cover and the shelter from the Sun provided by the neighboring mountains. Curiously, this was one of the glaciers selected by the DWPB in 1945 for routine surveys, which was abandoned in 1947 when it was realized that the tongue was completely separated from the accumulation area and hence that the debris-covered tongue was not representative (McFarlane, 1945, 1946a, b, 1947; Meek, 1948b). Field and

***Figure 27.***—*Terrestrial photograph of Angel Glacier on the north slope of Mount Edith Cavell, Cavell Group, Alberta, in August 1953, taken by William O. Field, American Geographical Society. Photograph and caption courtesy of Calvin J. Heusser, Professor Emeritus, New York University.*

Heusser (1954) reckoned that the glacier started to retreat in 1733 and that the separation of the lower glacier took place in the 1920's; they also noted a substantial reduction in volume. Heusser (1956) established moraine positions for 1723, 1783, 1871, and 1901. Early measurements were made by E.M. Kindle in 1927 and E.L. Perry in 1929.

Luckman (1976, 1977) attempted to establish the Neoglacial history of this and neighboring areas. Based on ground measurements and aerial photographs, a tentative reconstruction of the recent recessional history of *Cavell Glacier* has been determined (fig. 9).

### *Portal-MacCarib Group* (PC19)

North of Astoria River is the small *Portal-MacCarib Group* (fig. 1, PC19). It is 13.5 km long, trends southwest from the Athabasca River, has summit elevations near 2,750 m, and has a few small glaciers and rock glaciers.

### Trident Range (PC20)

The northernmost mountain block in the interior part of the central *Park Ranges* is Trident Range (fig. 1, PC20). It is bounded on the north by the Miette River and on the east by the Athabasca River. At the junction of the Miette and Athabasca Rivers is Jasper, one of the famous resort towns of the Rockies. Numerous small glaciers and rock glaciers can be found here, ranging in length up to 1.5 km, but none is much bigger than 0.5 $km^2$ in area. Apart from one rock glacier that pushes below 2,000 m, the lower limits of the glaciers is in the range of 2,300–2,400 m. Østrem's (1966) map shows a lowering of the glaciation level here to below 2,600 m, possibly caused by storm tracks being channeled through Yellowhead Pass. Whereas average peak elevations are 2,600–2,800 m, a few rise to about 3,000 m.

### *Fraser-Rampart Group* (PC21)

Between the Tonquin Valley and the Fraser River lies a heavily glacierized mountain range, the *Fraser-Rampart Group* (fig. 1, PC21), centered on what might be called the *Bennington Icefield*. The *Fraser-Rampart Group* extends 13 km north from Mastodon Mountain to join The Ramparts, a bastion that extends about 10 km from east to west. At the base of The Ramparts are very extensive rock-glacier formations. Furthermore, there are substantial debris-covered ice features associated with many of the glacier tongues. Bennington Peak and Mount Geikie rise to more than 3,200 m, and the other peaks range from 2,900–3,100 m asl. Some of the larger glaciers that form part of *Bennington Icefield* are the Fraser (3.5 km), Mastodon (4.4 km), Simon (4.8 km), Eremite (2.7 km), and Scarp (2.8 km) Glaciers that end at 1,800–2,000 m. These are 2 to 4 $km^2$ in size, but the majority are 1 $km^2$ or less and have higher termini, at 2,200–2,400 m. Several studies have been carried out on glaciers in this group, including the Bennington Glacier, *Para Glacier,* and *Paragon Glacier*. The latter is a tongue-shaped glacier about 300 m wide and 1 km long with an area of roughly 0.3 $km^2$. Although its terminus is now at 2,000 m asl, it formerly coalesced with the *Bennington Icefield*. In 1982, its ELA was 2,250 m, about the same as on the Bennington Glacier (McCarthy, 1985).

#### Bennington Glacier

The Bennington Glacier is a fairly large alpine glacier, about 5 km in length, with a spectacular series of “Little Ice Age” moraines from which it has retreated some 1,300 m. The Bennington Glacier descends 1,600 m in elevation from the west face of Mount Fraser. In the early 1980’s, the firn line was at about 2,130 m. Retreat can be determined from available photographs. The earliest photograph, taken in 1921 by the Interprovincial Boundary Commission, gave a post-“Little Ice Age” recession of 250 m. McCarthy (1985) reconstructed the history and the development of the forefield of Bennington Glacier through a comprehensive lichenometric study that paid particular attention to eight moraine complexes and an ice-front esker. The recessional history of the Bennington Glacier is plotted in figure 9.

#### *Para Glacier*

The *Para Glacier* is a small cirque glacier about 2 km in length on the east side of Parapet Peak. It flows into Chrome Lake. The main stream of ice flows east and is fed by a steep and much-broken ice fall from the eastern arête of Bennington Peak. There is very little debris on the glacier. Initial observations made by C.G. Wates in 1933 (Wheeler, 1934) and McCoubrey (1938) plotted in figure 9 were apparently filed with the American Geographical Society (Denton, 1975).

### *Meadow-Clairvaux Group* (PC22)

The mountains that form the southern slopes of Yellowhead Pass are part of the small *Meadow-Clairvaux Group* (fig. 1, PC22). The *Meadow-Clairvaux Group* is situated west of the Trident Range and Meadow Creek and is separated from Selwyn Range by the valley of the Fraser River. Peaks here do not rise above 3,000 m in elevation but generally lie close to 2,600–2,900 m asl. The 10 glaciers here, such as the Vista, Clairvaux, and Meadow Glaciers, are small ($<1.5$ $km^2$) in area, terminate below 2,300 m, and include a number of rock- and debris-covered features.

### Selwyn Range (PC23)

The last major feature in this central part of the *Park Ranges* is the Selwyn Range (fig. 1, PC23), which lies between the Fraser and Canoe Rivers and extends as a series of transverse ridges, about 25 km wide, toward the northwest for more than 60 km. Peaks here tend to be lower than in many other parts of the *Park Ranges* discussed so far. Average elevations are close to 2,600 m; the highest peak reaches to just over 2,800 m. About 40 small glaciers and ice fields are scattered throughout the range, though most are found in the three southernmost transverse ridges. The largest of the ice fields is some 3 $km^2$ in area. The glaciers average about 1 km in length with snouts between 2,100 and 2,300 m. The regional glaciation level lies between 2,600 and 2,700 m.

## Continental Ranges [North—Yellowhead Pass to Muskwa Ranges (M)]

The final section of the Continental Ranges lies north of Yellowhead Pass. The indistinct zone of the Foothills marks the eastern boundary, while the western boundary continues as the Rocky Mountain Trench, which contains the Fraser River. Except for the area around Mount Robson, elevations of the mountain ranges generally decrease farther to the north. The mountains themselves becoming less distinct and less glacierized than those to the south that have just been described. In addition, the isolation and inaccessibility of this part of the Continental Ranges has meant that far fewer geographical names are available to aid in their description. The glaciers are usually of the small, mountain variety. They are larger and more numerous in the mountains along and west of the divide around Mount Robson, in the *Swiftcurrent Icefield*, and northward in the vicinity of the Resthaven Icefield (figs. 28, 29).

### Front Ranges (North) (FN)

The Front Ranges here (fig.1, FN) are narrow and long; they include the Boule, Bosche, De Smet, Hoff, Berland, Persimmon, and Starlight Ranges and one called The Ancient Wall. North of these ranges are additional unnamed ranges before the northern limit at Mount May and the valley of the Kakwa River.

#### Boule Range (FN1)

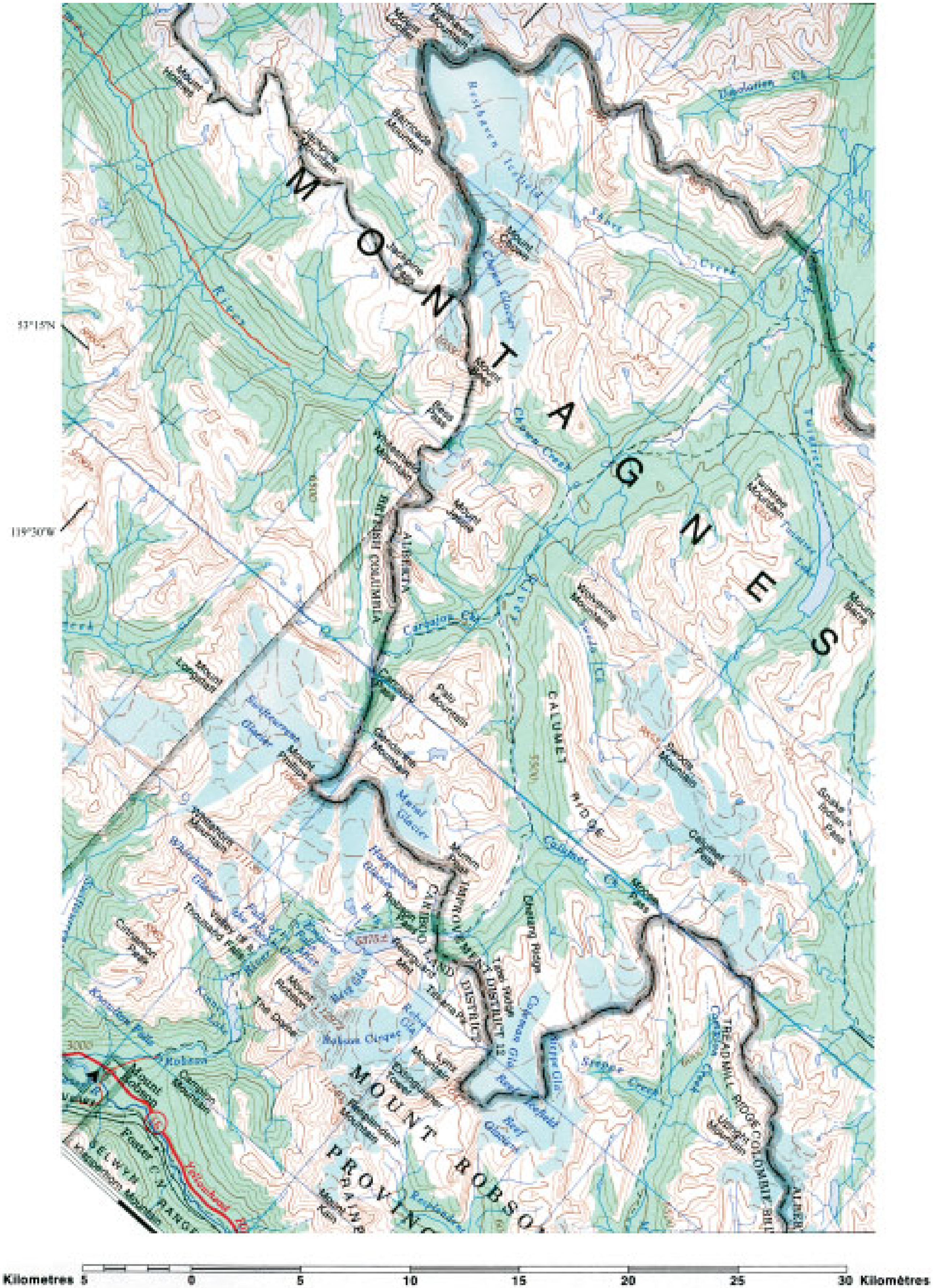
Lying between Moosehorn Creek and the Rocky Mountain Foothills, Boule Range (fig. 1, FN1) is the easternmost section of this part of the Front Ranges. It is just over 20 km in length and is 3 to 5 km wide. Because summit elevations generally lie below 2,300 m and only reach a maximum of 2,429 m in Mount Kephala, it is not surprising there is no permanent ice cover here.

#### Bosche Range (FN2)

Slightly longer (25 km) than the Boule Range to the east, the Bosche Range (fig. 1, FN2) is bounded on the west by the Snake Indian River. Peak heights average around 2,400 m, and therefore glaciers are not in evidence.

#### De Smet Range (FN3)

The innermost of the three parallel ranges that form the southern section of the northern Front Ranges, the De Smet Range (fig. 1, FN3) consists of a series of mountains and ridges strung out over 30 km as a northwesterly extension of the Jacques Range. Elevations here also average about 2,300 to 2,400 m, so there is no evidence of glacierization.


MONTAGNES
53°15'N
119°30'W
Resthaven Icefield
Chown Glacier
Chown Creek
Carcajou Ck
CALUMET RIDGE
Calumet Ck
Mural Glacier
Robson Cirque
Berg Gla
Coleman Gla
Reef Glacier
Snowbird Pass
BRITISH COLUMBIA
ALBERTA
Kilometres 5 0 5 10 15 20 25 30 Kilomètres

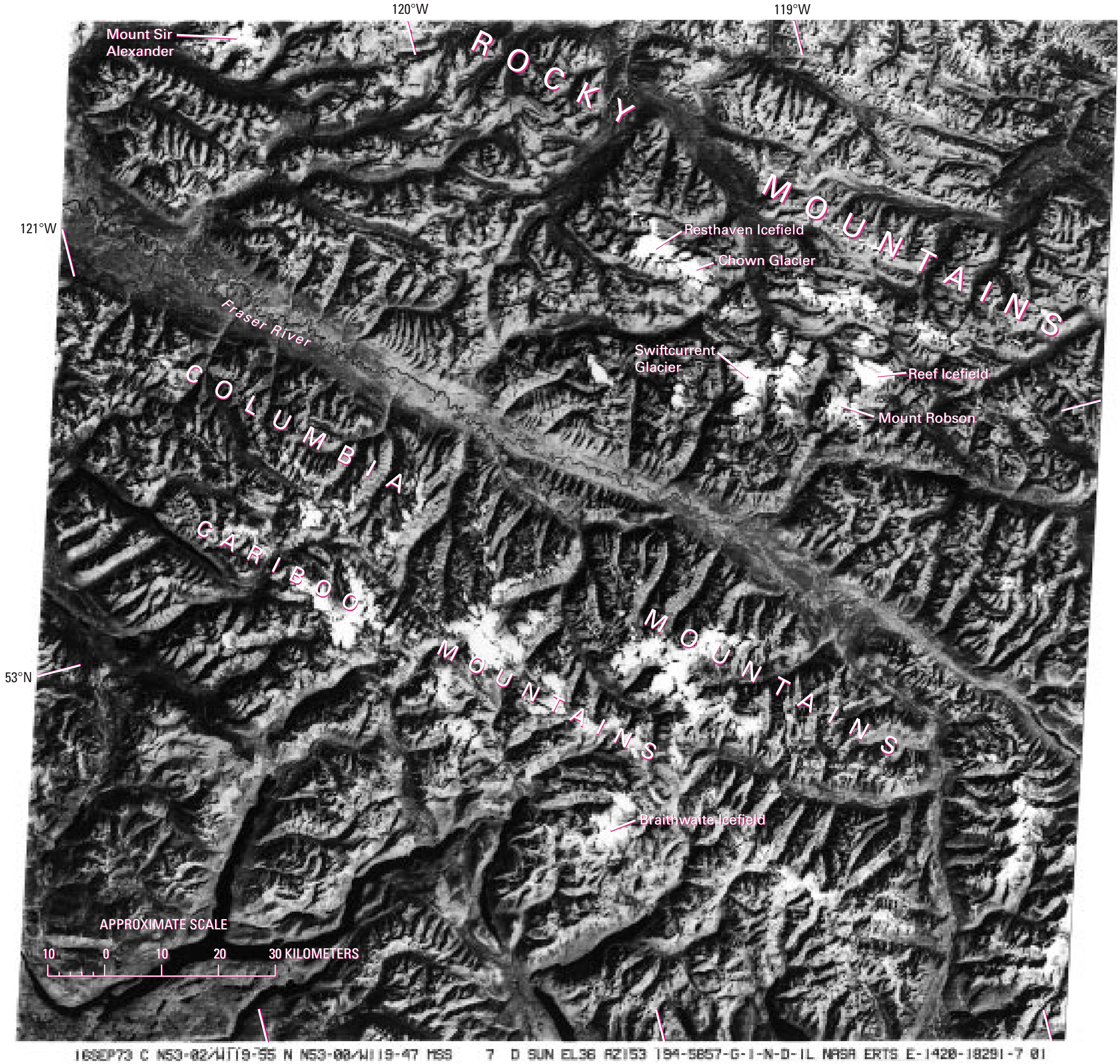



***Figure 28.****—(opposite page) Segment of the 1:250,000-scale topographic map (Mount Robson, 83E) of Mount Robson and environs, Jasper National Park, Alberta, and Mount Robson Provincial Park, British Columbia, showing ice fields along the divide from Reef Icefield to Resthaven Icefield. ©1988. Produced under licence from Her Majesty the Queen in Right of Canada, with permission of Natural Resources Canada.*

***Figure 29.****—Annotated Landsat 1 MSS image of part of the glacierized northern Rocky Mountains from Mount Robson (3,954 m), the highest mountain in the Canadian Rockies, to Mount Sir Alexander (3,291 m), and the northern Columbia Mountains (Cariboo Mountains), British Columbia, east and west of the Fraser River, respectively. Landsat image (1420–18291, band 7; 16 September 1973; path 50, Row 23) from the EROS Data Center, Sioux Falls, S. Dak.*

### Hoff Range (FN4)

North of Wildhay River lies the Hoff Range (fig. 1, FN4), another in a series of many parallel, northwest-trending ranges that comprise the Front Ranges. The maximum elevation is 2,440 m on Mount Campion, but most of the higher peaks are 100 m or more lower. No glaciers are found in this range.

### Berland Range (FN5)

The Berland Range (fig. 1, FN5), which lies between the Hoff and Persimmon Ranges, has two peaks more than 2,600 m asl but no evidence of a present-day ice cover. As with the Hoff Range, there are mountains north of Berland River that seem to be a natural extension of the Hoff Range, although that name is not now applied to them.

### Persimmon Range (FN6)

The next parallel range to the west is the 50-km-long Persimmon Range (fig. 1, FN6) having peak elevations on the order of 2,500 to 2,800 m. As currently applied, the northern limit of this range appears to be the valley of Sulphur River, though that of the Smoky River, 15 km to the north, represents a more significant physiographic break.

### Starlight Range (FN7)

West of Rock Creek is the Starlight Range (fig. 1, FN7), which forms part of a mountain block whose northern boundary is marked by the valley of the South Sulphur River. Peaks lie below 2,500 m asl, so this area is also unglacierized. Although unnamed, an extension of the Starlight Range extends northwestward to the valley of the Smoky River, paralleling the Persimmon Range, with similar heights and no glaciers.

### The Ancient Wall (FN8)

The final range in this transect is known as The Ancient Wall (fig.1, FN8). It forms a massive rampart overlooking Blue Creek and has heights comparable to those in the eastern ranges. The extension of the mountain block of which this forms a part is northwestward to the deeply incised Rockslide Creek and northward to Hardscrabble Creek. Summit elevations are below 2,800 m and no glaciers are visible.

### Unnamed Ranges (—)

The remaining groups in the northern Front Ranges are unnamed. North and east of the Smoky and Muddywater Rivers and south of Sheep Creek is what might be called the *Llama Group.* The summit elevations are below 2,500 m, and there are no glaciers. North of the *Llama Group* and south of Kakwa River is the last of the mountain blocks in the Front Ranges. Mount May at 2,450 m asl is representative of the average height of the peaks in this area. Lack of adequate precipitation and low elevation account for the fact that there are no glaciers here.

## *Park Ranges* (North) (PN)

The northern section of the *Park Ranges* (fig. 1, PN), the last group of mountains of the Continental Ranges, includes the Victoria Cross and Rainbow Ranges, the *Robson*, the *Whitehorn*, and *Resthaven Group*s, and Treadmill Ridge. As in the Front Ranges in this northern section of the Continental Ranges, there are several other significant unnamed ranges and groups. They extend as far as the *Sir Alexander Peaks* and Jarvis Creek, a headwater tributary of McGregor River and include the Reef Icefield, the

*Swiftcurrent Icefield*, the Resthaven Icefield, and significant ice accumulations around Mount Robson and Mount Sir Alexander (fig. 29).

### Victoria Cross Ranges (PN1)

The Victoria Cross Ranges (fig. 1, PN1), 30 by 20 km in size, lie northwest of Jasper and south of Snaring River. Summit elevations generally rise westward from 2,500–2,600 m near the Athabasca River to more than 2,900 m in the section facing Treadmill Ridge. These elevations influence the distribution of the few existing glaciers. In the southern part of the ranges are well-developed cirques with tarns. In the west, overlooking Miette River, are several glaciers 0.5 $km^2$ in area, and one as large as 1 $km^2$. These glaciers terminate at around 2,000 m asl.

### Unnamed Ranges (—)

Between the De Smet Range and The Ancient Wall in the east and the Victoria Cross Ranges and Treadmill Ridge in the west is an 80-km-long mass of mountains and ranges without a collective name that straddles the boundary between the *Park Ranges* and Front Ranges. Peaks heights average between 2,700 and 2,900 m, with a slight trend to lower elevations toward the northwest. Only one peak exceeds 3,000 m asl. More than 25 glaciers are scattered through a section just north of the Victoria Cross Ranges. Seven of these are more than 1 km in length, but most are 0.5 km or less in length, and only one glacier exceeds 1 $km^2$ in area. Between Snake Indian and Monte Cristo Mountains, at the northern end of these ranges, is a small ice field about 5 $km^2$ in area. Five of the associated glaciers are >1 km long and have termini 2,300 m asl.

### Treadmill Ridge (PN2)

The provincial boundary, which in this section of the Rocky Mountains still lies on the Continental Divide, follows Treadmill Ridge (fig. 1, PN2) from Yellowhead Mountain in the south to Twintree Mountain in the north; streams from Treadmill Ridge drain eastward into Snaring River and westward into the Fraser River. Summit elevations increase northward from the 2,400 to 2,500-m range, through 2,600 to 2,800 m in the middle section, to a maximum of 3,003 m at Swoda Mountain. Increased glacierization of Treadmill Ridge follows this trend. A few small ice masses, <0.5 $km^2$ in area, can be seen in the southern section. The middle section contains almost 50 glaciers. They average between 0.5 and 1.5 km in length, terminate between 2,100 and 2,300 m, and the larger ones tend to lie on the eastern side of the divide. About 10 $km^2$ of the ice is concentrated around Upright Mountain. The densest glacier cover is in the north, between Calumet Peak and Swoda Mountain. Here, numerous glaciers cover almost 20 $km^2$ in area and include ones more than 3.5 km in length. The termini of the glaciers are located between 2,300 and 1,950 m asl. According to Østrem (1966), the glaciation level here is more than 2,700 m asl.

### *Robson Group* (PN3)

The *Robson Group* (fig. 1, PN3) lies between Moose River on the east and the Smoky and Robson Rivers on the west. Mount Robson will be discussed below, as it lies within the subsidiary Rainbow Range. Peaks here are not unusually high, averaging less than 2,800 m, although Lynx Mountain does rise to 3,140 m asl. Glaciers are concentrated in Reef Icefield and its associated outlet glaciers, the Steppe, Coleman, and Reef Glaciers and cover about 24 $km^2$. The largest of these is Coleman Glacier with a length of 7.1 km. A northern outlier, about 6 $km^2$ in area, lies south of Moose Pass. Some of the larger glaciers extend below 2,000 m asl but most end between 2,100 and 2,200 m.

### Rainbow Range (PN4)

The southern part of the *Robson Group*, a block of mountains extending some 30 km in a northwest direction, is known as the Rainbow Range (fig. 1, PN4). This part contains Mount Robson (fig. 30), at 3,954 m the highest mountain in the Rocky Mountains and thus one of the best known to Canadians. Although Resplendent Mountain exceeds 3,400 m asl, the other peaks in the range are less than 2,900 m. The western and southern sides of Mount Robson are so precipitous that little snow adheres to them. However, on the northeastern side, avalanching ice and snow contribute to a number of glaciers, of which the largest is Robson Glacier. Mist (2.5 km) and Berg (3.3 km) Glaciers discharge northward from the mountain; Berg Glacier produces small icebergs in the lake at its foot (1,638 m), which gives rise to both its name and that of the lake. A number of small glaciers lie along the ridge southeast of Resplendent Mountain and north toward the Reef Icefield. They average less than 2.5 km long and most end below 2,000 m.

#### Robson Glacier

Robson Glacier (fig. 30) heads in a magnificent snow-filled cirque (Robson Cirque) and flows for 7 km northeast and north to terminate in a small proglacial lake at about 1,700 m asl. Subsidiary ice streams join from Resplendent Mountain and Extinguisher Tower. Robson Glacier was visited by an American Geographical Society expedition in 1953. Glacier limits and variations were documented using photographic and botanical techniques (Field and Heusser, 1954; Heusser, 1954, 1956). Although Heusser (1956) dated moraines to 1801, 1864, 1891, 1907, 1912, 1922, 1931, Watson (1983) and Luckman (1986) resampled some of his sites and concluded, based on lichenometric evidence, that some of the trees had been likely overridden by ice advances in the late 12th or 13th centuries. Some recession values, including those reported by Wheeler (1915b, 1923), are given in figure 9. Coleman (1910) observed that the uplift of some warm air masses from the west by the 3,000 vertical meters of Mount Robson led to almost daily falls of snow on the summit and that this heavy precipitation must compensate for the small accumulation area of Robson Glacier.

### *Whitehorn Group* (PN5)

The last large group of glaciers in this area is found northwest of Mount Robson in the 20 by 15 km *Whitehorn Group* (fig. 1, PN5). Peaks here range from 2,800 m asl to well over 3,000 m and include Whitehorn Mountain (3,395 m) and Mount Phillips (3,249 m). The glacier cover stretches in an almost continuous mass from Mural Glacier in the east past the two large mountains to the western edge of the group. This ice cover has been referred to as the *Swiftcurrent Icefield* after the largest of the outlet glaciers, the 7.5-km long Swiftcurrent Glacier, which pushes down to 1,814 m asl close to the tree line. Other outlet glaciers range in length from 3 to 5 km and most end below 2,000 m.

### Unnamed Ranges (—)

The western part of the northern *Park Ranges*, between the valley of the Fraser River, which flows in the Rocky Mountain Trench, and the *Whitehorn* and *Resthaven Groups* consists of a number of unnamed ranges and groups. Generally the peaks are lower in this western part, on the order of 2,500 to 2,800 m asl. One higher area at the head of Horsey Creek contains a small ice field and some small local glaciers just less than 10 $km^2$ in size. Two small glaciers also lie in cirques below Whiteshield Mountain between the *Swiftcurrent Icefield* and Resthaven Icefields.

***Figure 30.***—*High-angle oblique aerial photograph of Mount Robson (3,954 m) and Mount Robson Glacier looking toward the southwest into Robson Cirque on 22 August 1964. The upper part of Berg Glacier can be seen on the right, partly hidden by Rearguard Mountain. U.S. Geological Survey photograph F642 taken by Austin Post is courtesy of Robert M. Krimmel, USGS.*

### *Resthaven Group* (PN6)

One of the most significant major ice accumulations in the northern *Park Ranges* in the *Resthaven Group* (fig. 1, PN6) is the Resthaven Icefield and associated glaciers (fig. 31), including the Chown Glacier, which covers nearly 50 km$^2$. It lies on the provincial boundary between the Smoky and Jackpine Rivers. Many peaks rise above 3,000 m asl, the two tallest being Mounts Bess (3,215 m) and Chown (3,331 m). The glaciers lie predominantly east of the divide. The two major units are the ice field itself, more than 10 km in length, and Chown Glacier, 7.2-km long. These two glaciers penetrate to quite low elevations, terminating below 1,600 m asl. The ELA is likely to be about 2,400 m.

### Unnamed Ranges (—)

Although the northern boundary of the *Resthaven Group* runs westward from Short Creek, the natural physiographic boundaries of the group lie farther north, extending to the junction of the Smoky and Jackpine Rivers. Despite one peak of 3,019 m, average elevations are below 2,600 m. The glacier-ice cover consists of a few small outliers of the Resthaven Icefield. Two outliers are about 2 km long and the other <0.5 km long.

*Figure 31.—High-angle oblique aerial photograph of an outlet glacier from Resthaven Icefield, taken on 8 August 1961 looking toward the west-northwest. The cloud-shrouded summit of Resthaven Mountain is in the background. Prominent ogives downglacier from the ice fall are visible. U.S. Geological Survey photograph F313 taken by Austin Post is courtesy of Robert M. Krimmel, USGS.*

**Other Unnamed Ranges (—)**

The largest area of unnamed mountains in the Continental Ranges can be found in the northwestern corner of the northern *Park Ranges*. This area is bounded on the south by the broad valley of the Jackpine River, on the west by the Rocky Mountain Trench, and on the north by a broad valley containing the McGregor River. Peak elevations average between 2,300 and 2,450 m and the highest peak here is only 2,650 m. Physiographically, the mountains could be divided into a number of individual ranges. Most of the glaciers in these unnamed ranges are very small and are scattered through the northeastern part of the mountains close to the large ice field around the *Sir Alexander Peaks*. Three exceed 1 km in length and, of these, the largest is the Wishaw Glacier at 3 $km^2$. There are also a handful of glaciers about 0.5 km long in the central part.

***Sir Alexander Peaks* (PN7)**

The northern limit of the Continental Ranges (fig. 2, PN), *Sir Alexander Peaks* (fig. 2, PN7), is marked by one major ice field centered on Mount Sir Alexander (3,291 m) and two smaller ones farther north. Although one other mountain exceeds 3,000 m, summit elevations generally lie between 2,550 and 2,900 m, increasing slightly toward the northwest. The *Sir Alexander Icefield* fills the range lying between the valley of the McGregor River, to the south, and Jarvis Creek, which forms the boundary between the *Park Ranges* and Hart Ranges. Glacier ice covers some 65 $km^2$ and includes the *Kitchi*, *Menagerie*, and *Castle Glaciers*. Several glaciers more than 4 km in length can be found here with snouts pushing to below 1,600 m asl. The ELA lies below 2,000 m, the lowest ELA documented in the Rocky Mountains. Immediately north, above Kitchi Creek, lies a small ice field (<10 $km^2$) with several outliers, and to the northeast, south of Edgegrain Creek, is a 5-$km^2$ glacier flowing north from Mount St. George. Again, there are several other small glaciers in the vicinity, most of which are 0.5 to 0.7 km long. Terminus elevations are usually between 1,750 and 1,950 m. The other significant ice body lies in the northwest sector of the *Sir Alexander Peaks*, radiating from an unnamed peak (2,858) between Mount Dimsdale (2,805) and Cheguin Mountain (2,470 m). It covers an area of about 25 $km^2$ and consists of a number of glaciers longer than 3 km. One of these, flowing due north, has a snout at 1,250 m asl, although the norm is between 1,600 and 2,000 m.

## Hart Ranges (H)

Up to the Hart Ranges (fig. 2, H), we have discussed only about half of the total areal extent of the Canadian Rocky Mountains. However, we have now reached a geographic location where there are far fewer glaciers and very little information in the literature on which to base a comprehensive discussion of the glacierization of the other half of the Rocky Mountains in Canada. The climber's guide dismisses this northern portion in a scant three pages, and Denton (1975) states that there are no glaciers marked on the maps from here to the Peace River, the northern boundary of the Hart Ranges.

The Hart Ranges extend northwestward from the *Park Ranges* (North) for some 275 km and are bounded laterally by the Rocky Mountain Foothills and the Rocky Mountain Trench. There is a steady decline in average peak elevations northward from about 2,800 m asl just north of the *Sir Alexander Peaks* to a low of about 2,000 m around Mount Reynolds in the center of the ranges before the elevations begin to increase as the Hart Ranges near the Peace River. The decline in glacierization of the southern part of the Hart Ranges is reflected in the elevation of the glaciation level determined by Østrem (1972); the elevation of the glaciation level declines from 2,400 m asl at the boundary with the Continental Ranges to 2,100 m in the center of the Hart Ranges.

Despite Denton's (1975) conclusion, there are, in fact, a number of glaciers in the Hart Ranges. In the area immediately east of the Dezaiko Range, between Narraway River and Hanington Creek on the east and Herrick Creek on the west, are dozens of small glaciers. The highest peaks here range from 2,500 to 2,900 m with glacier snouts terminating between 1,700 and 1,900 m asl. The glacier ice lies on both sides of the main Rocky Mountain spine with somewhat larger glaciers, on the order of 5 to 7 $km^2$ in area, on the western slopes. Average glacier lengths are from 1.5 to 2.5 km. North of Framstead Creek, several small glaciers can be found southeast of *Mount Pulley* (2,470 m). Most are less than 2 km in length and range up to 2.5 $km^2$ in area. To the east, between Framstead Creek and *Red River Creek*, is a glacierized outlier with several small ice masses, all having areas less than 0.5 $km^2$.

Just to the northeast of the Dezaiko Range lies the aptly named Ice Mountain, which has two fairly large ice fields about 4 $km^2$ and 8 $km^2$ in area, respectively. The largest glacier has an ice stream more than 6 km long that flows from 2,350 m to 1,400 m asl. The mountain is isolated from the main range.

## Dezaiko Range (H1)

The Dezaiko Range (fig. 2, H1) has three small glaciers, each about 1 $km^2$ in area, situated around Mount Hedrick in the central part of the range. Maximum elevations here are more than 2,000 m, and the lower limit of permanent ice lies between 1,650 and 1,850 m asl.

## Misinchinka Ranges (H2)

Herrick Creek cuts through the Rocky Mountains, forming the boundary between the Dezaiko and Misinchinka Ranges (fig. 2, H2). Both ranges have a northwest trend and parallel the Rocky Mountain Trench for some 250 km, terminating at the northern limit of the Hart Ranges, where the Peace River separates them from the Muskwa Ranges. Thanks to a major hydroelectric development, this limit can be clearly seen on Landsat images where the Peace Reach of Williston Lake follows the Peace River valley. The eastern limits are not well-defined, being marked by a number of river valleys such as those of Imperial Creek and the Anzac, Misinchinka, and Pine Rivers. These ranges have no glaciers according to modern topographical maps.

## Pioneer Range (H3)

In the Pioneer Range (fig. 2, H3), the Monkman (5 $km^2$ in area), Parsnip (14 $km^2$ in area) (fig. 32), and Vreeland (2 $km^2$ in area) Glaciers can all be found, together with other small glaciers, on the southwestern part of the range, where the maximum elevation is found at Mounts Barton (2,400 m) and Vreeland (2,440 m). [See section "Mapping Glaciers in the *Interior Ranges* and Rocky Mountains with Landsat Data" for a further discussion of Monkman and Parsnip Glaciers.] These glaciers represent the most significant ice fields in the Hart Ranges.

## Murray Range (H4)

By following the divide northward to the Murray Range (fig. 2, H4), one can find two small glaciers (<1 $km^2$) east of Sentinel Peak (2,500 m) and one (<0.5 $km^2$) in a sheltered spot northeast of Mount Dudzic (2,150). About 18 km to the northeast of the Murray Range, there are a few more small scattered ice bodies around Alexis Peak (2,123 m). Here the average maximum elevation of the peaks hovers around 2,000 m asl. This sector marks the northern limit of glaciers within the Hart Ranges.

***Figure 32.**—Photograph of Parsnip Glacier, Hart Ranges, northern Rocky Mountains, British Columbia. © 2000. Produced under licence from Her Majesty the Queen in Right of Canada, with permission of Natural Resouces Canada. Photograph No. A89S1, taken August 1989 by David Seeman, Canadian Forest Service, formerly with the Geological Survey of Canada.*

*Figure 33.*—*Annotated Landsat 1 MSS image mosaic showing the Muskwa Ranges, the northernmost part of the Canadian Rocky Mountains, including Mount Roosevelt (2,815 m), Mount Lloyd George (about 2,990 m), and the Lloyd George Icefield. There is substantial glacier cover in the area and the Lloyd George Icefield is more than 70 km$^2$. The Landsat images (1750–18535 and 1750–18542, band 7; 12 August 1974; Path 56, Rows 19 and 20) are from the EROS Data Center, Sioux Falls, S. Dak.*

## Muskwa Ranges (M)

The northernmost part of the Rocky Mountains is known as the Muskwa Ranges (fig. 2, M, and fig. 33), which contain many unnamed glaciers (fig. 34). From the Finlay and Peace Reaches of Williston Lake, the ranges extend in a northwesterly direction for some 500 km to their northern boundary, where the Liard River flows eastward to join the Mackenzie River. The ranges are bounded on the east by the Foothills, which at this latitude are a less-easily defined transition zone, and on the west by the northern Rocky Mountain Trench, here occupied by the Kechika and Finlay Rivers and Williston Lake.

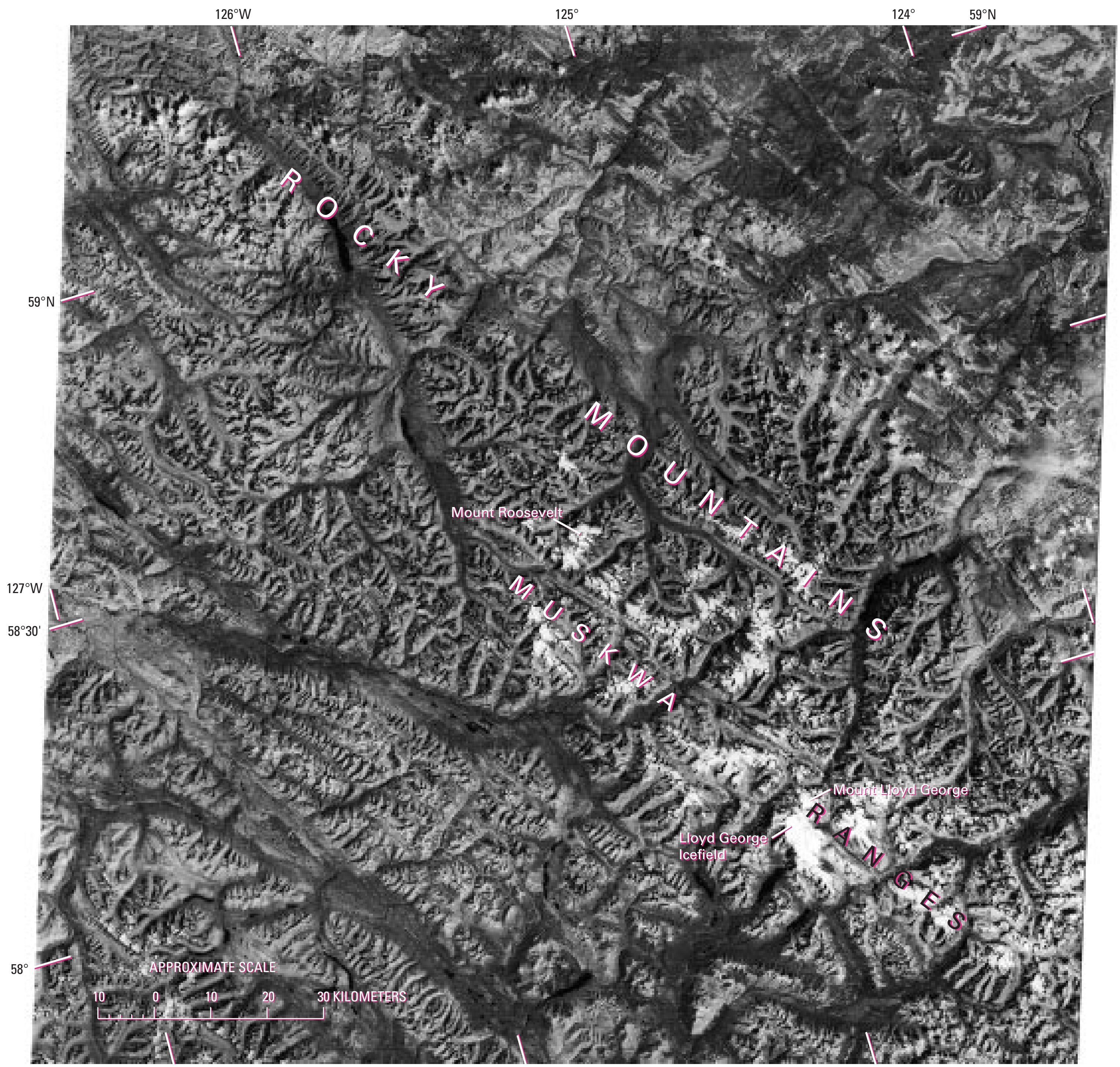


***Figure 34.***—*Terrestrial photograph of an unnamed glacier in the Muskwa Ranges, northern Rocky Mountains. ©2000. Produced under licence from Her Majesty the Queen in Right of Canada, used with permission of Natural Resources Canada. Photograph A 89S2, taken August 1989 by David Seeman, Canadian Forest Service, formerly with the Geological Survey of Canada.*

The first significant concentration of glaciers in the Muskwa Range is in the vicinity of the Great Snow Mountain Area (fig. 2, M4). Several groups of glaciers are found northward from the Great Snow Mountain Area along the main divide extending to the next concentration of glaciers in the Lloyd George Icefield—the final agglomeration in what the Climber's Guide (Putnam and others, 1974) calls the *Roosevelt-Churchill-Stalin Group*. With the name change of *Mount Stalin* to Mount Peck, this area will be referred to here as the *Allies Group* to reflect the remaining names of the Allied commanders and the numerous peak names that record the conferences they and other leaders attended.

The southern section of the Muskwa Ranges is a fairly broad, dissected mountain region with peaks trending from more than 2,200 m asl on the eastern side to an average of less than 2,000 m in the west, where many river valleys cut into the ranges. The block containing the Deserters (fig. 2, M1) and Akie Ranges (fig. 2, M2) is separated from the rest of the Muskwa Ranges by the broad valleys of the Ospika and Akie Rivers. The western section of the Muskwa Ranges, from the Truncate Range (fig. 2, M3) north of Akie River valley to the Tochieka Range (fig. 2, M5) and thence to Rabbit Plateau, is all free of glacier ice. East of Deserters Range, there are a few small glaciers on the eastern side of the main ranges below Mount Robb (2,500 m) and Mount Kenny (2,677 m). The largest is about 1.5 km$^2$ in area.

As the Great Snow Mountain Area (fig. 2, M4) is approached, summit elevations increase and the glaciation level rises from 2,500 to 2,600 m asl. Around Mount McCusker (2,592 m) there are some small glaciers, all less than 0.5 km$^2$ in area, lying in entrenched, east-facing valleys. Immediately south of Great Snow Mountain Area there are several small glaciers (<0.5 km$^2$) and ice fields. About 2 km$^2$ of ice is spread out along the eastern slope of Mount Helen, and another small ice field (1.5 km$^2$) lies southwest of Redfern Lake. However, most of the glacier ice in this section of the Muskwa Ranges is found just to the north.

## Great Snow Mountain Area (M4)

The glacier cover in the Great Snow Mountain area (fig. 2, M4) can be divided conveniently into a northern component around Great Snow Mountain and a southern one centered on Mount Ulysses, separated by the valley of the Besa River and a tributary of Akie River. The former will here be called the *Great Snow Icefield* and the latter the *Odyssey Icefield*, reflecting the Homeric theme established in the local names. The fact that ice covers an area of more than 58 $km^2$ here is not properly reflected in Denton's (1975) observation that there are small glaciers in the vicinity. Østrem's (1972) map places the glaciation level here at close to 2,600 m.

#### *Odyssey Icefield*

Glaciers 3 to 4 km in length flow from Mount Ulysses (3,024 m) and the adjoining ridge to Cyclops Peak and Mount Penelope. The total area of ice here is about 38 $km^2$, of which outliers contribute about 4 $km^2$. The ice field includes Achaean Glacier (3.5 $km^2$), a 4-km-long glacier dropping to 1,600 m in elevation from the summit of Mount Penelope, and Ithaca Glacier, a broad ice mass on the northern side of *Odyssey Icefield*, covering over 7 $km^2$ and terminating at about 1,840 m asl.

#### *Great Snow Icefield*

East from Great Rock Peak (2,931 m), a number of small cirque glaciers and ice streams are found on either side of the ridges stretching to Redfern Mountain and Mount Stringer (2,795 m). Outliers here and to the west cover about 7 $km^2$ in area. The main ice field lies north and west of Great Snow Mountain and has an area in excess of 20 $km^2$, including two glaciers about 4 $km^2$ in area. Termini generally lie between 1,800 and 2,000 m asl.

## *Lloyd George Group* (M6)

A major concentration of glaciers is found around Mount Lloyd George (approximately 2,990 m in elevation on the U.S. aeronautical chart ONC D–12), about 50 km to the northwest. In between are several small glaciers and ice fields, ranging in size up to 5 $km^2$, lying on either side of the divide between the Prophet and Muskwa Rivers on the east and the North Kwadacha River on the west.

### Lloyd George Icefield

The Lloyd George Icefield (fig. 35) is bounded by the Warneford and Tuchodi Rivers. It extends about 19 km north to south and 13 km east to west. Peaks in this area range from 2,700 to over 2,900 m asl. The ice field covers about 70 $km^2$, much less than the area of 116 $km^2$ estimated by Odell (1949). Even with the attendant glaciers to the north and west, including McConnell Glacier (1.85 $km^2$), the total ice cover only approaches 180 $km^2$ in area.

An account of a visit to the *Lloyd George Group* (fig. 2, M6) has been given by Odell (1948, 1949), who reported on Llanberis Glacier, described as the main outlet glacier from the Lloyd George Icefield. This small glacier (2.7 $km^2$) flows westward towards Haworth Lake. He concluded that there had been no advance of the glacier since the end of the last "Ice Age" and that recession to its present snout position, 800 m from the moraine, had been slow. Much more ice is in fact drained from the ice field by the Kwadacha (15.5 $km^2$) and Lloyd George (10 $km^2$) Glaciers to the east. The latter lies on the divide between Mount Smythe and Mount Lloyd George; two-thirds of the ice drains to the south and one-third northward where it lies parallel to, but some 2 km to the east of, Quentin Glacier (2 $km^2$).

At the base of Mount Glendower, Odell's party discovered a large dying glacier, Stagnant Glacier (1 $km^2$), which filled the floor of the canyon and which was covered with a thick blanket of moraine, on the surface of which were growing plants up to 4.5-m high. The glacier is 3.5 km in length, 400 m wide, and has an upper limit at 1,800 m asl and a snout at about 1,350 m. Dead ice could be seen in thermokarst depressions and along the glacier margins. Odell observed that meltwater issuing from the glacier was of moderate amount and scarcely turbid.


The final glacierized area within the Muskwa Ranges is situated just north of Lloyd George Icefield, in and around the *Allies Group*.

*Figure 35.—Segment of the 1:250,000-scale topographic map of the Ware quadrangle (94F) showing the glacierized area around Mount Lloyd George, Muskwa Ranges, northern Rocky Mountains. ©1990. Produced under licence from Her Majesty the Queen in Right of Canada, with permission of Natural Resources Canada.*

## *Allies Group* (M7)

The *Allies Group* (fig. 2, M7) consists of four main mountain masses about equally covered in glaciers. Running the full length of the group on the eastern side is the Tower of London Range, bounded by Wokkpash Creek and separated from the rest of the group by the Racing River valley. To the west, and in the center, is the Battle of Britain Range. South of this, across the valley of a tributary of Gataga River, is an unnamed mountain mass with glaciers extending from Savio Mountain to Sicily Mountain. Because there are several Italian names here, this range will be referred to as the *Italy Range*. North of the Battle of Britain Range, separated by Churchill Creek, is the last mountain block of this group; glaciers extend from Tehran Peak northward to Mount Roosevelt and Delano Creek. For convenience this will be referred to as the *Allied Leaders Range* because of the association of Churchill and Roosevelt. No mention has previously been made of glaciers in this area by either Denton (1975) or Gadd (1986), which is surprising considering that the glacierized area here amounts to almost 200 km$^2$. However, Østrem (1972) did plot a glaciation level for this region rising toward the east from 2,600 to 2,700 m asl and shows many glaciers at the head of Racing River.

### Battle of Britain Range

About 37 km$^2$ of this range is covered by glaciers. The glaciers lie within the hydrological basins of Churchill Creek and of rivers draining northeastward to Racing River and southwestward to Gataga River. Summit elevations along this divide, from Churchill Peak to the Exploration and Lindisfarne Peaks, range from 2,200 m to more than 2,600 m asl. Most of the glaciers are between 1 km$^2$ and 3 km$^2$ in area, but the largest is almost 5 km in length and 4.5 km$^2$ in area. Glaciers tend to be situated on the northern slopes of the northeast- to southwest-trending Battle of Britain Range.

### Tower of London Range

The area of ice in the Tower of London Range is about 30 km$^2$; glaciers are situated on either side of the main range line running from Mount Aida northward to Fusilier Peak. Mountain heights rise to a maximum of 2,815 m at Mount Peck. Glaciers range in size from 0.5 to 2 km$^2$ to two glaciers at about 4 km$^2$, including Fusilier Glacier, to the largest, Wokkpash Glacier, at 9 km$^2$, a compound glacier consisting of four “ice streams” and well-developed medial moraines. Some 5 km$^2$ of glacier ice is found outside the range to the east.

### *Italy Range*

Summit elevations in this range are comparable to those in the Tower of London Range, rising to a maximum of 2,853 m at King Peak. The glaciers, many of which exceed 2 km$^2$ in area, lie on either side of the main divide, which trends to the southwest. They cover a total area of almost 55 km$^2$. The largest glacier (8 km$^2$) is more than 10 km long and flows northward from Sicily Mountain.

### *Allied Leaders Range*

This range can be divided into three sections. The southern section, centered on Tehran Peak (2,734 m) lies south of Grizzly Pass; the largest glacier in this section is about 5 km$^2$ in area. In the central section, extending eastward from Mount Caen (2,762 m) through Normandy Mountain (2,856 m) to Falaise Mountain (2,743 m), glaciers covering an area of 15 km$^2$ are spread out on both sides of the divide; the largest glacier is 3.7 km$^2$ in area. The final section, south of Delano Creek, extends from Scheldt Mountain (2,759 m) through Mount Roosevelt (2,815 m) to the east. Glaciers cover more than 20 km$^2$ with two exceeding 4 km$^2$.

Total glacier-ice cover in the *Allied Leaders Range* is about 45 km$^2$. The largest glaciers extend to about 1,700 m, but most terminate between 1,800 and 1,900 m asl.

## North and West of *Allies Group*

Outside the *Allies Group*, glaciers are found up to 10 km to the west. Glaciers cover some 23.5 km$^2$ with one glacier 5.5 km$^2$ in size.

Finally, there are still a few glaciers in the Muskwa Ranges up to 30 km to the northwest of the *Allies Group*. The main concentration is a few kilometers north in the vicinity of Yedhe Mountain (2,685 m), where 8 km$^2$ of ice lies on the east slope, flowing down to elevations below 2,000 m and scattered in patches toward Toad River.

West of Toad River, and north of Gataga River, are several moraine and rock-glacier systems amongst which can be found a few small glaciers amounting in total to less than 1 km$^2$ of exposed ice. The northern limit of glaciers in the Muskwa Ranges lies at 58°25'N. The remaining mountain blocks (fig. 2), Stone Range (fig. 2, M8), Sentinel Range (fig. 2, M9), Terminal Range (fig. 2, M10), and Rabbit Plateau (fig. 2, M11), are unglacierized.

## References Cited


Alpine Club of Canada, 1953, Changes in Scott Glacier—1924–1952: Canadian Alpine Journal, v. 36, p. 168.

Bahr, D.B., and Dyurgerov, M.[B.], 1999, Characteristic mass-balance scaling with valley glacier size: Journal of Glaciology, v. 45, no. 149, p. 17–21.

Baranowski, Stanislav, and Henoch, W.E.S., 1978, Glacier and landform features in the Columbia Icefield area, Banff and Jasper National Parks, Alberta, Canada: Ottawa, Environment Canada, Inland Waters Directorate, Glaciology Division, (Supplementary report on a study carried out for Parks Canada), 175 p. (with maps)

Batterson, M.J., 1980, Contemporary frontal moraine formation in the Yoho Valley, British Columbia: St. John's, Newfoundland, Department of Geography, Memorial University of Newfoundland, M.Sc. thesis, 150 p.

Benoît, Isabelle, Champoux, A., Ommanney, S., and Dubois, J.-M.M., 1984, Clef pour la photo-interprétation des glaciers tempérés (le glacier Athabasca, Canada): Photo Interprétation, no. 84–4, p. 29–32.

Bigras, S.C., 1978, Glacier des Poilus: Ottawa, Carleton University, Department of Geography, B.A. thesis, 86 p.

Binda, G.G., Johnson, P.G., and Power, J.M., 1985, Glacier control of suspended-sediment and solute loads in a Rocky Mountain basin, *in* Water Quality Evolution within the Hydrological Cycle of Watersheds, Canadian Hydrology Symposium No. 15, 1984, Québec, 10–12 June 1984, Proceedings: National Research Council of Canada, Associate Committee on Hydrology, NRCC No. 24633, v. 1, p. 309–327.

Boles, Glen, 1974, The Columbia Ice Field: Canadian Alpine Journal, v. 57, p. 33–34.

Boles, G.W., Kruszyna, R., and Putnam, W.L., 1979, The Rocky Mountains of Canada—American Alpine Club, Alpine Club of Canada Climber's Guide, 7th ed.: New York, American Alpine Club, and Banff, Alberta, Alpine Club of Canada, 473 p.

Bray, J.R., 1964, Chronology of a small glacier in eastern British Columbia: Science, v. 144, no. 3616, p. 287–288.

———1965, Forest growth and glacier chronology in north-west North America in relation to solar activity: Nature, v. 205, no. 4870, p. 440–443.

Bray, J.R., and Struick, G.J., 1963, Forest growth and glacial chronology in eastern British Columbia and their relation to recent climatic trends: Canadian Journal of Botany, v. 41, no. 8, p. 1245–1271.

B.C. Mountaineer, 1939, Glacier crashes in Banff National Park: The B.C. Mountaineer, v. 17, no. 2, p. 2–3.

Brugman, M.M., 1989, Mining glaciers on Mount Cline, Alberta; an assessment: Saskatoon, Sask., Environment Canada, National Hydrology Research Institute, Hydrology Division, NHRI Contribution No. 89054, 25 p.

Brunger, A.G., 1966, The Drummond, Hector and Peyto Glaciers—Their wastage and deposits: Edmonton, Alberta, University of Alberta, Department of Geography, M.Sc. thesis, 100 p.

Brunger, A.G., Nelson, J.G., and Ashwell, I.Y., 1967, Recession of the Hector and Peyto Glaciers—Further studies in the Drummond Glacier, Red Deer Valley area, Alberta: Canadian Geographer, v. 11, no. 1, p. 35–38.

Butler, Dana, Lyons, W.B., Hassinger, J.[M.], and Mayewski, P.A., 1980, Shallow core snow chemistry of Athabasca Glacier, Alberta: Canadian Journal of Earth Sciences, v. 17, no. 2, p. 278–281.

Campbell, P.I., Reid, I.A., and Shastal, John, 1969, Glacier surveys in Alberta: Ottawa, Department of Energy, Mines and Resources, Water Survey of Canada, Inland Waters Branch Report Series No. 4, 16 p.

Canada, Energy, Mines and Resources, 1978, Surveying Columbia Icefield. How big is the Columbia Icefield? Is it shrinking or growing? Swelling or reducing river systems? New techniques help find out: GEOS, Winter, p. 9–12.

Canada, Environment Canada, 1976, 1974–1976 survey of the Athabasca and Saskatchewan Glaciers: Calgary, Alberta, Environment Canada, Inland Waters Directorate, Western Region, Calgary District Office, Water Survey of Canada, Internal report, 36 p.

———1980, Columbia Icefield: Ottawa, Department of Energy, Mines and Resources, Surveys and Mapping Branch, map, scale 1:50,000, produced by National Hydrology Research Institute, Inland Waters Directorate and Parks Canada, Western Region, Department of the Environment.

———1982, 1978–1980 survey of the Athabasca and Saskatchewan Glaciers: Calgary, Alberta, Environment Canada, Inland Waters Directorate, Calgary District Office, Water Survey of Canada, Internal Report, 36 p.

Canadian Permanent Committee on Geographical Names, 1985, Gazeteer of Canada—British Columbia, 3rd ed.: Ottawa, Canada Department of Energy, Mines, and Resources, 281 p.

———1988, Gazeteer of Canada—Alberta, 3rd ed.: Ottawa, Canada Department of Energy, Mines, and Resources, 64 p.

Carter. R.L., 1954, Study of glaciers in Banff and Jasper National Parks, 1952 and 1954: Calgary, Alberta, Department of Mines and Resources, Forests and Scientific Services Branch, Dominion Water and Power Bureau, Report No. 2160–(52 and 54), surveys under the direction of R.D. May, mimeo, 32 p.

Carter, R.L., Blair, R.V., Fowler, E.D., and Thorson, K.M., 1956, Study of glaciers in Banff and Jasper National Parks, 1956: Calgary, Alberta, Department of Northern Affairs and National Resources, Water Resources Branch, Report No. 2160–(56), mimeo, 27 p.

Cavell, Edward, 1983, Legacy in ice—The Vaux family and the Canadian Alps: Banff, Alberta, Altitude Publishing, 98 p.

Chapman, E.F., Morton, G.H., Thorson, K.M., McGeachy, D.A., Elder, V.S., and Loeppky, K.D., 1960, Survey of glaciers in Banff and Jasper National Parks, 1960: Calgary, Alberta, Department of Northern Affairs and National Resources, Water Resources Branch, Report No. 2160–(60), mimeo, 31 p.

Church, Michael, and Gilbert, Robert, 1975, Proglacial fluvial and lacustrine environments, *in* Jopling, A.V., and MacDonald, B.C., eds., Glaciofluvial and glaciolacustrine sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication No. 23, p. 22–100.

Clee, T.E., Savage, J.C., and Neave, K.[G.], 1969, Internal friction in ice near its melting point: Journal of Geophysical Research, v. 74, no. 4, p. 973–980.

Coleman, A.P., 1903, The Brazeau Ice-field: Geographical Journal, v. 21, no. 5, p. 502–510.

———1910, Geology and glacial features of Mt. Robson: Canadian Alpine Journal, v. 2, no. 2, p. 108–113.

Collie, J.N., 1899, Climbing in the Canadian Rockies: Alpine Journal, v. 19, no. 144, p. 441–446.

Collier, E.P., 1958, Glacier variation and trends in run-off in the Canadian Cordillera, *in* General Assembly of Toronto, v. 4, September 3–14, 1957: Association Internationale d'Hydrologie Scientifique Publication No. 46, p. 344–357.

Collins, D.N., 1982, Flow-routing of meltwater in an alpine glacier as indicated by dye tracer tests: Bern, Beitrage zur Geologie der Schweiz—Hydrologie, v. 28, no. 2, p. 523–534.

Collins, D.N., and Young, G.J., 1979, Separation of runoff components in glacierized alpine watersheds by hydrochemical analysis, *in* Canadian Hydrology Symposium 79, Cold Climate Hydrology, Vancouver, B.C., 10–11 May 1979, Proceedings: Ottawa, National Research Council of Canada (NRCC 17834), Associate Committee on Hydrology, p. 570–581.

———1981, Meltwater hydrology and hydrochemistry in snow- and ice-covered mountain catchments: Nordic Hydrology, v. 12, no. 4–5, p. 319–334.

Davies, K.F., Froelich, C.R., Heinze, L., and Kerber, R., 1966, Surveys of glaciers on the eastern slope of the Rocky Mountains in Banff and Jasper National Parks, 1966: Calgary, Alberta, Department of Northern Affairs and National Resources, Water Resources Branch, Report No. 2160–(66), mimeo, 30 p.

Davies, K.F., Loeppky, K.D., Sapp, E., and Wagner, H.M., 1964, Survey of glaciers on eastern slope of Rocky Mountains in Banff and Jasper National Parks, 1964: Calgary, Alberta, Department of Northern Affairs and National Resources, Water Resources Branch, Report No. 2160–(64), mimeo, 21 p.

Davies, K.F., Warner, L.A., Anderson, J.E., and Dahl, B.M., 1970, Survey of glaciers on the eastern slopes of the Rocky Mountains in Banff and Jasper National Parks—1970 report: Calgary, Alberta, Department of Energy, Mines and Resources, Inland Waters Branch, Water Survey of Canada Division, Internal Report, 29 p.

Davis, D.A., Loeppky, K.D., Sapp, E., and Adams, R.E., 1962, Study of glaciers on eastern slope of Rocky Mountains in Banff and Jasper National Parks, 1962: Calgary, Alberta, Department of Northern Affairs and National Resources, Water Resources Branch, Report No. 2160–(62), mimeo, 32 p.

Denton, G.H., 1975, Glaciers of the Canadian Rocky Mountains, *in* Field, W.O., ed., Mountain Glaciers of the Northern Hemisphere, v. 1: United States Army Cold Regions Research and Engineering Laboratory, p. 603–653.

Derikx, Leo, 1973, Glacier discharge simulation by ground-water analogue, *in* Symposium on the Hydrology of Glaciers, Cambridge, 7–13 September 1969, Association Internationale d'Hydrologie Scientifique Publication No. 95, p. 29–40.

———1975, The heat balance and associated runoff from an experimental site on a glacier tongue, *in* Snow and Ice Symposium, Moscow, August 1971, Proceedings: IAHS-AISH Publication No. 104, p. 59–69.

Derikx, L., and Loijens, H.[S,], 1971, Model of runoff from glaciers, *in* Hydrology Symposium No. 8, v. 1: Canada National Research Council, Associate Committee on Geodesy and Geophysics, Subcommittee on Hydrology, p.153–199.

Douglas, David, 1914, Journal kept by David Douglas during his travels in North America, 1823–1827: London, Wesley, 364 p.

Dyurgerov, M.B., and Bahr, D.B., 1999, Correlations between glacier properties—Finding appropriate parameters for global glacier monitoring: Journal of Glaciology, v. 45, no. 149, p. 9–16.

Epstein, Samuel, and Sharp, R.P., 1959, Oxygen-isotope variations in the Malaspina and Saskatchewan Glaciers: Journal of Geology, v. 67, no. 1, p. 88–102.

Field, W.O., 1949, Glacier observations in the Canadian Rockies, 1948: Canadian Alpine Journal, v. 32, p. 99–114.

———1979, Freshfield Glacier, 1953: Ottawa, Environment Canada, National Hydrology Research Institute, Snow and Ice Division, Unpublished report, 45 p.

Field, W.O., Jr., and Heusser, C.J., 1954, Glacier and botanical studies in the Canadian Rockies, 1953: Canadian Alpine Journal, v. 37, p. 128–140.

Foessel, D.G., 1974, An analysis of the temperature distribution over the Peyto Glacier, Alberta: Guelph, Ontario, Guelph University, Department of Geography, M.Sc. thesis, 137 p.

Föhn, P.M.B., 1973, Short-term snow melt and ablation derived from heat- and mass-balance measurements: Journal of Glaciology, v. 12, no. 65, p. 275–289.

Ford, D.C., 1975, Caving six miles under an Alberta glacier: Canadian Geographical Journal, v. 91, no. 4, p. 20–24.

———ed., 1983, Castleguard Cave and Karst, Columbia Icefields area, Rocky Mountains of Canada—A symposium: Arctic and Alpine Research, v. 15, no. 4, p. 425–560.

Fowler, E.D., Chapman, E.F., Thorson, K.M., and Rainsberry, K.C., 1958, Study of glaciers in Banff and Jasper National Parks, 1958: Calgary, Alberta, Department of Northern Affairs and National Resources, Water Resources Branch, Report No. 2160–(58), unpublished, 29 p.

Freeman, L.R., 1925, On the roof of the Rockies: Toronto, Ontario, McClelland and Stewart, 270 p.

Gadd, B., 1986, Handbook of the Canadian Rockies; geology, plants, animals, history and recreation from Waterton Glacier to the Yukon: Jasper, Alberta, Corx Press, 876 p.

Gardner, J.[S.], 1972, Recent glacial activity and some associated landforms in the Canadian Rocky Mountains, *in* Slaymaker, H.O., and McPherson, H.J., eds., Mountain Geomorphology—Geomorphological Processes in the Canadian Cordillera: Vancouver, Tantalus Research Limited, B.C. Geographical Series no. 14, p. 55–62.

———1977, The Wenkchemna Glacier: Canadian Alpine Journal, v. 60, p. 58–59.

———1978a, Wenkchemna Glacier—Ablation complex and rock glacier in the Canadian Rocky Mountains: Canadian Journal of Earth Sciences, v. 15, no. 7, p. 1200–1204.

———1978b, What glaciers do for western Canada: Canadian Geographical Journal, v. 96, no. 1, p. 28–33.

———1983, Accretion rates on some debris slopes in the Mt. Rae area, Canadian Rocky Mountains: Earth Surface Processes and Landforms, v. 8, no. 4, p. 347–355.

———1987, Evidence for headwall weathering zones, Boundary Glacier, Canadian Rocky Mountains: Journal of Glaciology, v. 33, no. 113, p. 60–67.

Gardner, J.S., and Jones, N.K., 1985, Evidence for a Neoglacial advance of the Boundary Glacier, Banff National Park, Alberta: Canadian Journal of Earth Sciences, v. 22, no. 11, p. 1753–1755.

Glossop, J., Morton, G.H., Anderson, J.E., Slobosz, F., and Clayton, V., 1968, Survey of glaciers on the eastern slope of the Rocky Mountains in Banff and Jasper National Parks, 1968: Calgary, Alberta, Department of Energy, Mines and Resources, Inland Waters Branch, Water Survey of Canada, Report No. 2160–(68), mimeo, 29 p.

Goodison, B.[E.], 1972a, An analysis of climate and runoff events for Peyto Glacier, Alberta: Ottawa, Environment Canada, Water Resources Branch, Inland Waters Directorate Scientific Series No. 21, 29 p.

———1972b, The distribution of global radiation over Peyto Glacier, Alberta: Ottawa, Environment Canada, Water Resources Branch, Inland Waters Directorate Scientific Series No. 22, 22 p.

Goodman, R.H., 1970, Radio-echo sounding on temperate glaciers—A Canadian view, *in* Gudmandsen, P.[E.], ed., Proceedings of the International Meeting on Radio Glaciology, May 1970: Lyngby, Technical University of Denmark, Laboratory of Electromagnetic Theory, p. 135–146.

———1973, Time-dependent intraglacier structures: Journal of Glaciology, v. 12, no. 66, p. 512–513.

———1975, Radio echo sounding on temperate glaciers: Journal of Glaciology, v. 14, no. 70, p. 57–69.

Gottlieb, Lars, 1980, Development and applications of a runoff model for snowcovered and glacierized basins: Nordic Hydrology, v. 11, no. 5, p. 255–272.

Gray, J.K., 1962, The Mummery and Freshfield Glaciers: Canadian Alpine Journal, v. 45, p. 27–33.

Habel, Jean, 1898, The north fork of the Wapta: Appalachia, v. 8, no. 4, p. 327–336.

——1902, At the western source of the Athabaska River: Appalachia, v. 10, no. 1, p. 28–43.

Hallet, Bernard, 1976a, Deposits formed by subglacial precipitation of $CaCO_3$: Geological Society of America Bulletin, v. 87, no. 7, p. 1003–1015.

———1976b, The effect of subglacial chemical processes on glacier sliding: Journal of Glaciology, v. 17, no. 76, p. 209–221.

———1977, Subglacial chemical deposits and the composition of basal ice, *in* Isotopes and Impurities in Snow and Ice Symposium, proceedings of the Grenoble Symposium, August/September 1975: IAHS-AISH, Publication No. 118, p. 289–292.

Hallet, Bernard, and Anderson, R.S., 1980, Detailed glacial geomorphology of a proglacial bedrock area at Castleguard Glacier, Alberta, Canada: Zeitschrift für Gletscherkunde und Glazialgeologie, v. 16, no. 2, p. 171–184.

Hammer, K.M., and Smith, N.D., 1983, Sediment production and transport in a proglacial stream—Hilda, Alberta, Canada: Boreas, v. 12, no. 2, p. 91–106.

Hamper, M.J., and Smith, N.D., 1983, Suspended sediment transport in glacier-fed Lake Louise, Alberta, Canada [abs.]: Geological Society of America 17th Annual Meeting, North-Central Section, Madison, Wisconsin, 28–29 April 1983, Abstracts with Programs, v. 15, no. 4, March, p. 227.

Harmon, Don, and Robinson, Bart, 1981, Columbia Icefield—A solitude of ice: Banff, Alberta, Altitude Publishing Ltd., 103 p.

Hector, James, 1861, On the geology of the country between Lake Superior and the Pacific Ocean and between the 48th and 54th parallels of latitude: Quarterly Journal of the Geological Society of London, v. 17, p. 388–445.

Henoch, W.E.S., 1967, Surface measurements of glacierized area in Canada: Ottawa, Department of Energy, Mines and Resources, Water Research Branch, Glaciology Section, Unpublished report, 4 p.

———1971, Estimate of glaciers' secular (1948–1966) volumetric change and its contribution to the discharge in the upper North Saskatchewan River basin: Journal of Hydrology, v. 12, no. 2, p. 145–160.

Henoch, W.E.S., and Croizet, J.L., 1976, The Peyto Glacier map—A three-dimensional depiction of mountain relief: The Canadian Cartographer, v. 13, no. 1, p. 69–86.

Heusser, C.J., 1954, Glacier fluctuations in the Canadian Rockies: General Assembly of Rome, International Association of Hydrological Sciences, International Union of Geodesy and Geophysics, IASH Publication No. 39, p. 493–497.

———1956, Postglacial environments in the Canadian Rocky Mountains: Ecological Monographs, v. 26, no. 4, p. 263–302.

Hickson, J.W.A., 1915, Notes of trip to the Saskatchewan River and Freshfield Glacier (1913): Canadian Alpine Journal, v. 6, p. 93–98.

Hobson, G.D., and Jobin, Claude, 1975, A seismic investigation—Peyto Glacier, Banff National Park and Woolsey Glacier, Mount Revelstoke National Park: Geo-exploration, v. 13, no. 2, p. 117–127.

Holdsworth, Gerald, 1984, Preliminary report on the dynamics and hydrology of Cathedral Glacier, Yoho National Park, B.C.: Calgary, Alberta, Environment Canada, National Hydrology Research Institute, Internal Report, 19 p.

Holdsworth, Gerald, Krouse, H.R., Shakur, A., and Peake, E., 1985, Reconnaissance of an ice core site, Columbia Ice Fields, Alberta: Calgary, Alberta, Environment Canada, Inland Waters Directorate, National Hydrology Research Institute, Internal report, 22 p.

Holdsworth Gerald, Power, J.[M.], and Christie, R.[O.], 1983, Radar ice thickness measurements on Peyto Glacier: Ottawa, Environment Canada, National Hydrology Research Institute, Snow and Ice Division, Internal report, 18 p.

Howarth, P.J., 1983, Evaluation of Landsat digital data for providing glaciological data: Ottawa, Environment Canada, National Hydrology Research Institute, Snow and Ice Division, Perennial Snow and Ice Section, Final report, Contract No. KN107–1–4656, March, 43 p.

Howarth, P.J., and Ommanney, C.S.L., 1983, Landsat digital data for updating glaciological information on topographic and glacier inventory maps, *in* Wellar, B.S., ed., Auto-Carto 6—Automated Cartography—International Perspectives on Achievements and Challenges, v. 2: p. 504–513.

IAHS/UNEP/UNESCO, 1988, Fluctuations of glaciers, 1980–1985, v. 5: Zürich, World Glacier Monitoring Service.

———1993, Fluctuations of glaciers, 1985–1990, v. 6: Zürich, World Glacier Monitoring Service.

———1999, Glacier mass balance bulletin, no. 5: Zürich, World Glacier Monitoring Service.

IAHS/UNESCO, 1998, Fluctuations of glaciers, 1990–95, v. 7: Zürich, World Glacier Monitoring Service.

Ice Age Co., The 1989 Cline Glacier ice mining project—Environmental impact assessment: Edmonton, Alberta, August, The Ice Age Co., Inc., 62 p.

Interprovincial Boundary Commission, 1924, Report of the Commission appointed to delimit the boundary between the Provinces of Alberta and British Columbia, Part II: Ottawa, Office of the Surveyor General, 155 p. (with maps)

Jackson, J.A., ed., 1997, Glossary of geology; 4th ed.: Alexandria, VA, American Geological Institute, 769 p.

Jackson, L.E., Jr., 1979a, A catastrophic glacial outburst flood (jökulhlaup) mechanism for debris flow generation at the Spiral Tunnels, Kicking Horse River basin, British Columbia: Canadian Geotechnical Journal, v. 16, no. 4, November, p. 806–813.

———1979b, Mystery flood solved—CPR records revealed the 1978 catastrophe was not unique...were other debris flows also triggered by jökulhlaups?: Ottawa, GEOS, Summer, Department of Energy, Mines and Resources, p. 2–4.

———1980, New evidence on the origin of the September 6, 1978 jökulhlaup from Cathedral Glacier, British Columbia: Geological Survey of Canada Paper No. 80–1B, p. 292–294.

Johnson, P.G., and Power, J.M., 1985, Flood and landslide events, Peyto Glacier terminus, Alberta, Canada, 11–14 July 1983: Journal of Glaciology, v. 31, no. 108, p. 86–91.

———1986, The role of high magnitude run-off events in glacierized basins: International Symposium "Glacier Mass-balance, Fluctuations and Run-off", Alma-Ata, 30 September–5 October 1986, Proceedings: Moscow, Soviet Geophysical Committee, Academy of Sciences of the U.S.S.R., Data of Glaciological Studies No. 58, p. 82–87, 195–200.

Kanasewich, E.R., 1963, Gravity measurements on the Athabasca Glacier, Alberta, Canada: Journal of Glaciology, v. 4, no. 35, p. 617–631.

Kearney, M.C., 1981, Late Quaternary vegetation and environments of Jasper National Park, Alberta: London, Ontario, University of Western Ontario, Department of Geography, Ph.D. thesis, 318 p.

Keller, G.V., and Frischknecht, F.C., 1960, Electrical resistivity studies on the Athabasca Glacier, Alberta, Canada: Journal of Research, National Bureau of Standards, v. 64D, no. 5, p. 439–448.

———1961, Induction and galvanic resistivity studies on the Athabasca Glacier, Alberta, Canada, *in* Raasch, G.O., ed., Geology of the Arctic, v. 2: Toronto, Ontario, University of Toronto Press, p. 809–832.

Kennedy, S.K., 1975, Sedimentation in a glacier-fed lake: Chicago, University of Illinois at Chicago Circle, Department of Geological Sciences, M.Sc. thesis, 55 p.

Kite, G.W., and Reid, I.A., 1977, Volumetric change of the Athabasca Glacier over the last 100 years: Journal of Hydrology, v. 32, no. 3–4, February, p. 279–294.

Kodybka, R.J., 1982, History of the Yoho Glacier, British Columbia: Canadian Alpine Journal, v. 65, p. 56–57.

Konecny, Gottfried, 1963, Glacier surveys in western Canada: Photogrammetric Engineering, v. 30, no. 1, p. 64–82.

———1966, Applications of photogrammetry to surveys of glaciers in Canada and Alaska: Canadian Journal of Earth Sciences, v. 3, no. 6, p. 783–798.

Konovalov, V.G., 1987, Methods of calculation and remote-sensing measurements for the spatial distribution of glacier annual mass balance: Journal of Glaciology, v. 33, no. 114, p. 212–217.

Krouse, H.R., 1974, Stable isotopes in the study of snow and ice resources, *in* Advanced Concepts and Techniques in the Study of Snow and Ice Resources—An interdisciplinary symposium, Monterey, California, 2–6 December 1973: Washington, D.C., National Academy of Sciences, p. 651–660.

Krouse, H.R., Hislop, R.[W.P.], Brown, H.M., West, K.[E.], and Smith, J.L., 1977, Climatic and spatial dependence of the retention of D/H and $O^{18}/O^{16}$ abundances in snow and ice of North America, *in* Isotopes and impurities in snow and ice, Proceedings of the Grenoble Symposium, August/September 1975: IAHS-AISH Publication No. 118, p. 242–247.

Kucera, R.E., 1971, What happens in front of a glacier: Ottawa, National Science Film Library, Research film, 16 mm, 15 minutes, listed in Cinematography in Research.

———1976, Exploring glaciers and mountains—Guide to Lake Louise and Moraine Lake: Canmore, Alberta, High Country, Box 5000, 61 p.

———1987, Exploring the Columbia Icefield, Rev. ed.: Canmore, Alberta, High Country, Box 5000, 64 p.

Kucera, R.E., and Henoch, W.E.S., 1978, Glacier and landform features in the Columbia Icefield area, Banff and Jasper National Parks, Alberta, Canada: Ottawa, Environment Canada, Inland Waters Directorate, Glaciology Division, Unpublished study carried out for Parks Canada, 131 p. (with maps)

Lang, A.H., 1943, Glaciers of the Rockies and Selkirks: Canadian Geographical Journal, v. 26, no. 2, p. 56–67.

Lawby, C.P., Smith, D.J., Laroque, C.P., and Brugman, M.M., 1994, Glaciological studies at Rae Glacier, Canadian Rocky Mountains: Physical Geography, v. 15, no. 5, p. 425–441.

Leonard, E.M., 1981, Glaciolacustrine sedimentation and Holocene glacial history, northern Banff National Park, Alberta: Boulder, Colorado, University of Colorado, Ph.D. thesis, 271 p.

———1985, Glaciological and climatic controls on lake sedimentation, Canadian Rocky Mountains: Zeitschrift für Gletscherkunde und Glazialgeologie, v. 21, no. 1–2, p. 35–42.

———1986a, Use of lacustrine sedimentary sequences as indicators of Holocene glacial history, Banff National Park, Alberta, Canada: Quaternary Research, v. 26, no. 2, p. 218–231.

———1986b, Varve studies at Hector Lake, Alberta, Canada, and the relationship between glacial activity and sedimentation: Quaternary Research, v. 25, no. 2, p. 199–214.

Letréguilly, Anne, 1988, Relation between the mass balance of western Canadian mountain glaciers and meteorological data: Journal of Glaciology, v. 34, no. 116, p. 11–18.

Loijens, H.S., 1974, Streamflow formation in the Mistaya River basin, Rocky Mountains, Canada: Proceedings of the Western Snow Conference, 42nd Annual Meeting, Anchorage, Alaska, p. 86–95.

Luckman, B.H., 1976, Glacial geomorphology at Mount Edith Cavell: London, Ontario, University of Western Ontario, Department of Geography, submitted to Parks Canada, Department of Indian Affairs and Northern Development, Unpublished report, 70 p.

———1977, Lichenometric dating of Holocene moraines at Mount Edith Cavell, Jasper, Alberta: Canadian Journal of Earth Sciences, v. 14, no. 8, p. 1809–1822.

———1986, Reconstruction of Little Ice Age events in the Canadian Rocky Mountains: Géographie Physique et Quaternaire, v. 40, no. 1, p. 17–28.

Luckman, B.H., and Crockett, K.J., 1978, Distribution and characteristics of rock glaciers in the southern part of Jasper National Park: Canadian Journal of Earth Sciences, v. 15, no. 4, p. 540–550.

Luckman, B.H., Frazer, G.W., Hamilton, J.P., and Harry, D.G., 1984, Field activities in the Canadian Rockies in 1983: London, Ontario, University of Western Ontario, Department of Geography, Report to Parks Canada and Mount Robson Provincial Park, 26 p.

Mathews, W.H., 1964a, Discharge of a glacial stream, *in* General Assembly of Berkeley, Symposium on Surface Waters, 19–31 August 1963: Association Internationale d'Hydrologie Scientifique Publication No. 63, p. 290–300.

———1964b, Sediment transport from Athabasca Glacier, Alberta, *in* General Assembly of Berkeley, Continental Erosion, Precipitation, Hydrometry, Humidity and Soil, August 19–31, 1963: Association International d'Hydrologie Scientifique Publication No. 65, p. 155–165.

May, R.D., Blair, R.V., and Harry, R.M., 1950, Study of glaciers in Banff and Jasper National Parks, 1950: Calgary, Alberta, Department of Mines and Resources, Surveys and Engineering Branch, Dominion Water and Power Bureau, Report No. 2160–(50), Unpublished, 34 p.

Mayewski, P.A., Pregent, G., Armstrong, T., Brown, P., Butler, D., Hassinger, J., Deschke, P., Palais, J., and Trombley, T., 1979, Results of the 1978 Athabasca Glacier Expedition: Durham, New Hampshire, University of New Hampshire, Department of Earth Science, Glaciology Report Series, 56 p.

McCarthy, D.P., 1985, Dating Holocene geomorphic activity of selected landforms in the Geikie Creek Valley, Mount Robson Provincial Park, British Columbia: London, Ontario, University of Western Ontario, Department of Geography, M.Sc. thesis, 303 p.

McCoubrey, A.A., 1938, Glacier observations, 1936 and 1937: Canadian Alpine Journal, v. 25, p. 113–116.

McFarlane, W.T., 1945, Study of glaciers in Banff, Yoho and Jasper National Parks, 1945: Vancouver, B.C., Department of Mines and Resources, Surveys and Engineering Branch, Dominion Water and Power Bureau, Report No. 2160–(45), Unpublished, 23 p.

———1946a, Glacier investigation in Banff, Yoho and Jasper National Parks: Canadian Alpine Journal, v. 29, no. 2, p. 265–273.

———1946b, Study of glaciers in Banff and Jasper National Parks, 1946: Vancouver, B.C., Department of Mines and Resources, Surveys and Engineering Branch, Dominion Water and Power Bureau, Report No. 2160–(46), Unpublished, 34 p.

———1947, Study of glaciers in Banff and Jasper National Parks 1947: Vancouver, B.C., Department of Mines and Resources, Surveys and Engineering Branch, Dominion Water and Power Bureau, Report No. 2160–(47), Unpublished, 40 p.

McFarlane, W.T., Blair, R.V., and Ozga, W.J., 1949, Study of glaciers in Banff and Jasper National Parks, 1949: Calgary, Alberta, Department of Mines and Resources, Surveys and Engineering Branch, Dominion Water and Power Bureau, Report No. 2160–(49), Unpublished, 34 p.

———1950, Glacier survey in Banff and Jasper National Parks, 1949: Canadian Alpine Journal, v. 33, p. 120–126.

McFarlane, W.T., and May, R.D., 1948, Study of glaciers in Banff and Jasper National Parks, 1948: Calgary, Alberta, Department of Mines and Resources, Surveys and Engineering Branch, Dominion Water and Power Bureau, Report No. 2160–(48), Unpublished, 32 p.

McPherson, H.J., and Gardner, J.S., 1969, The development of glacial landforms in the vicinity of the Saskatchewan Glacier: Canadian Alpine Journal, v. 52, p. 90–96.

Meek, Victor, 1948a, Glacier observations in the Canadian Cordillera: Canadian Geographical Journal, v. 37, no. 5, p. 190–209.

———1948b, Glacier observations in the Canadian Cordillera, *in* General Assembly of Oslo: IASH Publication No. 30, v. 2, p. 264–275.

Meier, M.F., 1958, The mechanics of crevasse formation, *in* General Assembly of Toronto, v. 4, September 3–14, 1957: Association Internationale d'Hydrologie Scientifique Publication No. 46, p. 500–508.

———1960, Mode of flow of Saskatchewan Glacier, Alberta, Canada: U.S. Geological Survey Professional Paper 351, 70 p.

———1965, Correspondence—Comments on Paterson's paper "Variations in velocity of Athabasca Glacier with time": Journal of Glaciology, v. 5, no. 41, p. 761–762.

Mills, H.H., 1977a, Basal till fabrics of modern alpine glaciers: Geological Society of America Bulletin, v. 88, no. 6, p. 824–828.

———1977b, Differentiation of glacier environments by sediment characteristics; Athabasca Glacier, Alberta, Canada: Journal of Sedimentary Petrology, v. 47, no. 2, p. 728–737.

———1977c, Textural characteristics of drift from some representative cordilleran glaciers: Geological Society of America Bulletin, v. 88, no. 8, p. 1135–1143.

Mokievsky-Zubok, Oleg, Ommanney, C.S.L., and Power, J.[M.], 1985, NHRI glacier mass balance, 1964–1984 (Cordillera and Arctic): Ottawa, Environment Canada, National Hydrology Research Institute, Surface Water Division, Glacier Section, NHRI internal report, 59 p.

Munro, D.S., 1975, Energy exchange on a melting glacier: Hamilton, Ontario, McMaster University, Department of Geography, Ph.D. thesis, 182 p.

Munro, D.S., and Davies, J.A., 1976, Diurnal energy flux variations and glacier surface hydrology, *in* Lvovitch, M.I., Kotlyakov, V.M., and Rauner, Yu.L., eds., International Geography '76, Section 2: Climatology, Hydrology, Glaciology: International Geographical Congress 23rd, 22–26 July 1976, Proceedings, p. 75–77.

———1977, An experimental study of the glacier boundary layer over melting ice: Journal of Glaciology, v. 18, no. 80, p. 425–436.

Munro, D.S., and Young, G.J., 1982, An operational net shortwave radiation model for glacier basins: Water Resources Research, v. 18, no. 2, p. 220–230.

Nakawo, Masayoshi, and Young, G.J., 1982, Estimate of glacier ablation under a debris layer from surface temperature and meteorological variables: Journal of Glaciology, v. 28, no. 98, p. 29–34.

Neave, K.G., and Savage, J.C., 1970, Icequakes on the Athabasca Glacier: Journal of Geophysical Research v. 75, no. 8, p. 1351–1362.

Nelson, J.G., Ashwell, I.Y., and Brunger, A.G., 1966, Recession of the Drummond Glacier, Alberta: Canadian Geographer, v. 10, no. 2, p. 71–81.

Odell, N.E., 1948, Stagnant glacier in British Columbia: Journal of Glaciology, v. 1, no. 4, p. 191.

———1949, Exploration of the Lloyd George Mountains in British Columbia: Canadian Geographical Journal, v. 38, no. 1, p. 48–63.

Ohmura, Atsumu, Kasser, Peter, and Funk, Martin, 1986, Parameterization of glacierization for a climate model: ISLSCP Conference, Rome, Italy, 2–6 December 1985, Proceedings; European Space Agency, Report ESA SP–248, p. 113–123.

Ommanney, C.S.L., 1971, Glacier surveys by District personnel of the Water Survey of Canada. 1. The Victoria Glacier: Ottawa, Department of the Environment, Inland Waters Branch, Glaciology Division, Glacier Inventory Note No. 6, 18 p.

———1972a, Glacier inventory, *in* Guidebook to the international symposia on the role of ice and snow in hydrology, Banff, Alberta, 6–20 September 1972: Canadian National Committee for the International Hydrological Decade, p. 84–87.

———1972b, Glacier surveys by District personnel of the Water Survey of Canada. 2. Peyto Glacier: Ottawa, Department of the Environment, Inland Waters Directorate, Water Resources Branch, Glaciology Division, Glacier Inventory Note No. 7, 20 p.

———1984, Bibliographic information on the Freshfield, Lyell and Mons Glaciers, Alberta: Ottawa, Environment Canada, National Hydrology Research Institute, Surface Water Division, Glacier Inventory Project, Internal report, 9 p.

———1989, Glacier atlas of Canada, limited ed.: Saskatoon, Saskatchewan, Environment Canada, National Hydrology Research Institute, Scientific Information Division, 2 p. (with 52 maps)

Osborn, G.D., 1975, Advancing rock glaciers in the Lake Louise area, Banff National Park, Alberta: Canadian Journal of Earth Sciences, v. 12, no. 6, p. 1060–1062.

Østrem, Gunnar, 1966, The height of the glaciation limit in southern British Columbia and Alberta: Geografiska Annaler, v. 48A, no. 3, p. 126–138.

———1972, Height of the glaciation level in northern British Columbia and southeastern Alaska: Geografiska Annaler, v. 54A, no. 2, p. 76–84.

———1973a, Runoff forecasts for highly glacierized basins, *in* The role of snow and ice in hydrology, Proceedings of the Banff Symposia, September 1972: IAHS-AISH Publication No. 107, v. 2, p. 1111–1132.

———1973b, The transient snowline and glacier mass balance in southern British Columbia and Alberta, Canada: Geografiska Annaler, v. 55A, no. 2, p. 93–106.

Østrem, Gunnar, and Arnold, K.C., 1970, Ice-cored moraines in southern British Columbia and Alberta, Canada: Geografiska Annaler, v. 52A, no. 2, p. 120–128.

Østrem, Gunnar, and Stanley, A.D., 1969, Glacier mass balance measurements, a manual for field and office work: A guide for personnel with limited backgrounds in glaciology, prepared jointly by the Canadian Department of Energy, Mines and Resources, and the Norwegian Water Resources and Electricity Board, Norwegian edition 129 p.

Outram, J., 1905, In the heart of the Canadian Rockies: New York, Macmillan, 466 p.

Palmer, Howard, 1924a, Observations on the Freshfield Glacier, Canadian Rockies: Journal of Geology, v. 32, no. 5, p. 432–441.

———1924b, The Freshfield Glacier, Canadian Rockies: Smithsonian Miscellaneous Collection, Publication No. 2757, v. 76, no. 11, p. 1–16.

———1924–26, Travels and ascents among the highest Canadian Rockies: Appalachia, v. 16, no. 3, p. 257–277.

———1925, The first ascent of Mt. King Edward, Canadian Rockies, with a note on Mt. Alberta: The Alpine Journal, v. 37, no. 231, p. 306–315.

Papertzian, V.C., 1973, A study of rock glaciers in Banff National Park, Canada: Kingston, Ontario, Queen's University, Department of Geology, B.Sc. thesis, 107 p.

Paterson, W.S.B., 1962, Observations on the Athabasca Glacier and their relation to the theory of glacier flow: Vancouver, British Columbia, University of British Columbia, Department of Physics, Ph.D. thesis, 158 p.

———1964, Variations in the velocity of Athabasca Glacier with time: Journal of Glaciology, v. 5, no. 39, p. 277–285.

———1965, Correspondence—Reply to Meier's letter on "Variations in velocity of Athabasca Glacier with time": Journal of Glaciology, v. 5, no. 42, p. 875–876.

———1966, Test of contour accuracy on a photogrammetric map of Athabasca Glacier: Canadian Journal of Earth Sciences, v. 3, no. 6, p. 909–915.

———n.d. [ca. 1968], Canadian drilling program—Summary of deep drilling in glaciers in Canada: Department of Energy, Mines and Resources, Unpublished report, 14 p.

———1970, The sliding velocity of Athabasca Glacier, Canada: Journal of Glaciology, v. 9, no. 55, February, p. 55–63.

Paterson, W.S.B., 1971, Temperature measurements in Athabasca Glacier, Canada: Journal of Glaciology, v. 10, no. 60, p. 339–349.

———1972, Temperature distribution in the upper layers of the ablation area of Athabasca Glacier, Alberta, Canada: Journal of Glaciology, v. 11, no. 61, p. 31–41.

Paterson, W.S.B., and Savage, J.C., 1963a, Geometry and movement of the Athabasca Glacier: Journal of Geophysical Research, v. 68, no. 15, p. 4513–4520.

———1963b, Measurement on Athabasca Glacier relating to the flow law of ice: Journal of Geophysical Research, v. 68, no. 15, p. 4537–4543.

———1970, Excess pressure observed in a water-filled cavity in Athabasca Glacier, Canada: Journal of Glaciology, v. 9, no. 55, p. 103-107.

Power, J.M., and Young, G.J., 1979a, Application of an operational hydrologic forecasting model to a glacierized research basin: Proceedings, Third Northern Research Basin Symposium Workshop, The State of the Art in Transposable Watershed Models, convened by the IHP Regional Working Group on Northern Research Basins, 10–15 June 1979, Québec City, Québec, Abstract No. 11. Also - Ottawa, Environment Canada, Snow and Ice Division, Preprint, 20 p.

———1979b, Application of the UBC watershed model to Peyto Glacier basin, *in* Canadian Hydrology Symposium 79, Cold Climate Hydrology, Vancouver, B.C., 10–11 May 1979, Proceedings: Ottawa, Ontario, National Research Council of Canada (NRCC 17834), Associate Committee on Hydrology, p. 217–228.

Prantl, F.A., and Loijens, H.S., 1977, Nuclear techniques for glaciological studies in Canada, *in* Isotopes and Impurities in Snow and Ice Symposium, proceedings of the Grenoble Symposium, August/September 1975: IAHS-AISH Publication No. 118, p. 237–241.

Prest, V.K., 1983, Canada's heritage of glacial features: Ottawa, Geological Survey of Canada, Miscellaneous Report 28, 119 p.

Putnam, W.L., Kruszyna, R., and Jones, C., 1974, Climber's guide to the Rocky Mountains of Canada—North, 6th ed.: New York, American Alpine Club, and Banff, Alberta, Alpine Club of Canada, 289 p.

Rains, R.B., 1990, Cline Glacier and Shoe Leather Creek, Alberta—Morphology and hydrology: Edmonton, Alberta, University of Alberta, Department of Geography, 20 p.

Raymond, C.F., 1971a, Determination of the three-dimensional velocity field in a glacier: Journal of Glaciology, v. 10, no. 58, p. 39–53.

———1971b, Flow in a transverse section of Athabasca Glacier, Alberta, Canada: Journal of Glaciology, v. 10, no. 58, p. 55–84.

———1973, Inversion of flow measurements for stress and rheological parameters in a valley glacier: Journal of Glaciology, v. 12, no. 64, p. 19–44.

Reid, I.A., 1961, Triangulation survey of the Athabasca Glacier, July 1959: Ottawa, Department of Northern Affairs and National Resources, Water Resources Branch, 20 p. and 2 maps. [Internal report]

———1972, Glacier surveys by the Water Survey of Canada, *in* The role of snow and ice in hydrology, Proceedings of the Banff Symposia, September 1972: IAHS-AISH Publication No. 107, v. 2, p. 1133–1143.

Reid, I.A., and Charbonneau, J.O.G., 1972, Glacier surveys in Alberta: Ottawa, Department of the Environment, Inland Waters Directorate Report Series No. 22, 17 p. and maps.

———1975, Glacier surveys in Alberta—1971: Ottawa, Department of the Environment, Water Resources Branch, Inland Waters Directorate Report Series no. 43, 18 p. and maps.

———1979, Glaciers surveys in Alberta—1977: Ottawa, Environment Canada, Water Resources Branch, Inland Waters Directorate Report Series No. 65, 17 p. and 2 maps.

———1981, Glaciers surveys in Alberta—1979: Ottawa, Environment Canada, Water Resources Branch, Inland Waters Directorate Report Series No. 69, 19 p. (with maps)

Reid, I.A., Charbonneau, J.O.G., and Warner, L.A., 1978, Glacier surveys in Alberta—1975: Ottawa, Fisheries and Environment Canada, Water Resources Branch, Inland Waters Directorate Report Series No. 60, 17 p. and 4 maps.

Reid, I.A., and Paterson, W.S.B., 1973, Simple method of measuring the average amount of water produced annually by melting of ice on a glacier, *in* Symposium on the Hydrology of Glaciers, Cambridge, 7–13 September 1969, Association Internationale d'Hydrologie Scientifique Publication No. 95, p. 215–218.

Rigsby, G.P., 1958, Fabrics of glacier and laboratory deformed ice, *in* Symposium of Chamonix, September 16–24, 1958: Association Internationale d'Hydrologie Scientifique Publication No. 47, p. 351–358.

———1960, Crystal orientation in glacier and in experimentally deformed ice: Journal of Glaciology, v. 3, no. 27, p. 589–606.

Rogerson, R.J., 1985, Measured re-advance of a debris-covered glacier terminus in the President Range, Yoho National Park, British Columbia, Canada: Journal of Glaciology, v. 31, no. 107, p. 13–17.

Rogerson, R.J., and Batterson, M.J., 1982, Contemporary push moraine formation in the Yoho Valley, B.C., *in* Davidson-Arnott, Robin, Nickling, William, and Fahey, B.D., eds., Research in glacial, glacio-fluvial and glacio-lacustrine systems, Symposium on geomorphology, 6th, Guelph, 9–10 May 1980, Proceedings: University of Guelph, Department of Geography, Guelph, Ontario, p. 71–90.

Rossiter, J.R., 1977, Interpretation of radio interferometry depth sounding, with emphasis on random scattering from temperate glaciers and the lunar surface: Toronto, Ontario, University of Toronto, Department of Physics, Ph.D. thesis, 223 p.

Savage, J.C., and Paterson, W.S.B., 1963, Borehole measurements in the Athabasca Glacier: Journal of Geophysical Research, v. 68, no. 15, p. 4521–4536.

———1965, Additional borehold measurements in the Athabasca Glacier: Journal of Geophysical Research, v. 70, no. 14, p. 3511–3513.

Schafer, J.P., 1954, Scott Glacier notes, 1953: Canadian Alpine Journal, v. 37, p. 124–126.

Schaffer, M.T.S., 1908, Untrodden ways: Canadian Alpine Journal, v. 1, no. 2, p. 288–294.

Sedgwick, J.K., and Henoch, W.E.S., 1975, Peyto Glacier: Ottawa, Environment Canada, Inland Waters Directorate, Water Resources Branch, Glaciology Division, map and booklet, 30 p.

Sharp, R.P., and Epstein, Samuel, 1958, Oxygen-isotope ratios and glacier movement, *in* Symposium of Chamonix, September 16–24, 1958: Association Internationale d'Hydrologie Scientifique Publication No. 47, p. 359–369.

Sherzer, W.H., 1905, Glacial studies in the Canadian Rockies and Selkirks (Smithsonian Expedition of 1904) preliminary report: Smithsonian Miscellaneous Collections (Quarterly Issue), v. 47, no. 1567, Part 4, Smithsonian Institution, Washington, D.C., p. 453–496.

———1907, Glaciers of the Canadian Rockies and Selkirks (Smithsonian Expedition of 1904): Washington D.C., Smithsonian Institution, Smithsonian Contributions to Knowledge, v. 34, art. 4, no.1692, 135 p.

———1908, The nature and activity of Canadian glaciers: Canadian Alpine Journal, v. 1, no. 2, p. 249–263.

Shilts, Elizabeth, Fick, Steven, Murray, Andrew, and McLean, Janice, 1998, The glaciers of Canada: Canadian Geographic, v. 118, no. 7, p. 51–52 (8-page foldout, color map).

Slaymaker, H.O., 1972, Physiography and hydrology of six river basins, *in* Robinson, J.L., ed., Studies in Canadian geography—British Columbia: Toronto, Ontario, University of Toronto Press, p. 32–68.

Sloan, V.F., 1987, Relationships between glacier terminus melt processes and climatic conditions, Boundary Glacier, Alberta: 43rd Annual Meeting, Eastern Snow Conference, Hanover, New Hampshire, 5–6 June 1986, Proceedings, p. 222–227.

Smart, C.C., 1983, Hydrology of a glacierized alpine karst - Castleguard Mountain, Alberta: Hamilton, Ontario, McMaster University, Department of Geography, Ph.D. thesis, 343 p.

———1984, Glacier hydrology and the potential for subglacial karstification: Norsk Geografisk Tidsskrift, v. 38, no. 3–4, p. 157–161.

———1986, Some observations on subglacial ground-water flow: Journal of Glaciology, v. 32, no. 111, p. 232–234.

Smith, N.D., 1978, Sedimentation processes and patterns in a glacier-fed lake with low sediment input: Canadian Journal of Earth Sciences, v. 15, no. 5, p. 741–756.

———1981, The effect of changing sediment supply on sedimentation in a glacier-fed lake: Arctic and Alpine Research, v. 13, no. 1, p. 75–82.

Smith, N.D., and Syvitski, J.P.M., 1982, Sedimentation in a glacier-fed lake: The role of pelletization on deposition of fine-grained suspensates: Journal of Sedimentary Petrology, v. 52, no. 2, p. 503–514.

Smith, N.D., Vendl, M.A., and Kennedy, S.K., 1982, Comparison of sedimentation regimes in four glacier-fed lakes of western Alberta, *in* Davidson-Arnott, Robin, Nickling, William, and Fahey, B.D., eds., Research in glacial, glacio-fluvial and glacio-lacustrine systems, Symposium on geomorphology, 6th, Guelph, 9–10 May 1980, Proceedings: University of Guelph, Department of Geography, Guelph, Ontario, p. 203–238.

Stacey, J.S., 1960, A prototype hotpoint for thermal boring on the Athabasca Glacier: Journal of Glaciology, v. 3, no. 28, p. 783–786.

Stanley, A.D., 1965, Relation between secondary structures in Athabasca Glacier and laboratory deformed ice: Vancouver, B.C., University of British Columbia, Department of Geology, Ph.D. thesis, 214 p.

———1970, A pilot study for the inventory of the glaciers in the Rocky Mountains. Inventory of glaciers in the Waputik Mountains, *in* Perennial Ice and Snow Masses: UNESCO/IASH Technical Papers in Hydrology No. 1, International Association of Scientific Hydrology, UNESCO A. 2486, p. 36–46.

Stenning, A.J., Banfield, C.E., and Young, G.J., 1981, Synoptic controls over katabatic layer characteristics above a melting glacier: Journal of Climatology, v. 1, no. 4, p. 309–324.

Strangway, D.W., Simmons, Gene, LaTorraca, G., Watts, R., Bannister, L., Baker, R., Redman, J.D., and Rossiter, J.R., 1974, Radio-frequency interferometry—A new technique for studying glaciers: Journal of Glaciology, v. 13, no. 67, p. 123–132.

Stutfield, H.E.M., and Collie, J.N., 1903, Climbs in the Canadian Rockies: New York, Longmans Green & Co., 343 p.

Tangborn, W.V., 1980, Dolia lednikovogo stoka v formirovanii gidroenergetiches-kikh resursov reki Kolumbii [Contribution of glacier runoff to hydroelectric power generation on the Columbia River]: Materially Gliatsiologicheskikh Issledovanii, Khronika, Obsuzhdeniia, Mezhduvedomstvennyi Geofizicheskii Komitet, Sektsiia Gliatsiologii, Institute Geografii, Academy Nauk SSSR [Data of Glaciological Studies, Chronicle, Discussion, Section of Glaciology of the Soviet Geophysical Committee and Institute of Geography, Academy of Sciences of the U.S.S.R.], No. 39, Moskva [Moscow], Iiuni [July], in Russian, p. 62–67, in English, p. 140–143.

Thorington, J.M., 1927, The Lyell and Freshfield Glaciers, Canadian Rocky Mountains, 1926: Smithsonian Miscellaneous Collection, v. 78, no. 6, Publication No. 2911, p. 1–8.

———1932, Lyell and Freshfield Glaciers: Canadian Alpine Journal, v. 20, p. 138–140.

———1938, Notes on Saskatchewan and Freshfield Glaciers: American Alpine Journal, v. 3, no. 2, p. 219–220.

———1945, Notes on Freshfield and Lyell Glaciers: American Alpine Journal, v. 5, no. 3, p. 435–436.

Trombley, T.J., 1986, A radio-echosounding survey of Athabasca Glacier, Alberta, Canada: Durham, New Hampshire, University of New Hampshire, Department of Earth Science, M.Sc. thesis, 64 p.

UNESCO, 1970, Perennial ice and snow masses: A guide for compilation and assemblage of data for a world inventory: United Nations Educational, Scientific, and Cultural Organization and International Association of Scientific Hydrology (IASH), 19 p.

Valdeyev, A.E., 1986, Glacier mass balance estimations from the measurements made at the mean weighted altitude: International Symposium "Glacier Mass-balance, Fluctuations and Runoff," Alma-Ata, 30 September–5 October 1986, Proceedings: Moscow, Soviet Geophysical Committee, Academy of Sciences of the U.S.S.R., Data of Glaciological Studies No. 57, p. 110–111 and p. 228–229.

Vaux George, Jr., 1910, Observations on glaciers in 1909: Canadian Alpine Journal, v. 2, no. 2, p. 126–130.

Vaux, George, [Jr.,] and Vaux, W.S.[Jr.,] 1901, Observations made in 1900 on glaciers in British Columbia: Proceedings of the Academy of Natural Sciences of Philadelphia, v. 53, p. 213–215.

———1907a, Glacier observations: Canadian Alpine Journal, v. 1, no. 1, p. 138–148.

———1907b, Observations made in 1906 on glaciers in Alberta and British Columbia: Proceedings of the Academy of Natural Sciences of Philadelphia, v. 58, p. 568–579.

———1908, Observations made in 1907 on glaciers in Alberta and British Columbia: Proceedings of the Academy of Natural Sciences of Philadelphia, v. 59, p. 560–563.

Vaux, M.M., 1911, Observations on glaciers in 1910: Canadian Alpine Journal, v. 3, p. 127–130.

———1913, Observations on glaciers: Canadian Alpine Journal, v. 5, p. 59–61.

Vaux, M.M., and Vaux, George, Jr., 1911, The glaciers of the Canadian Rockies and Selkirks (2d ed.): Bryn Mawr, Pennsylvania, privately printed, 20 p.

Waddington, E.D., and Jones, D.P., 1977, A radio-echo ice thickness survey of the Columbia Icefield: Vancouver, B.C., University of British Columbia, Department of Geophysics and Astronomy, Unpublished report, 8 p.

Warner, L.A., Anderson, J.E., Kerber, R.E., and Robinson, C.P., 1972, 1972 survey of the Athabasca and Saskatchewan Glaciers: Calgary, Dept. of Environment, Water Survey of Canada, 34 p. [Internal report]

Watson, H.M., 1983, A dendrochronological study of two sites in Mount Robson Provincial Park: London, Ontario, University of Western Ontario, Department of Geography, B.A. thesis, 147 p.

Watt, A.O., and Maxwell, E.L., 1960, Measured electrical properties of snow and glacial ice: Washington, D.C., Journal of Research of the National Bureau of Standards, v. 64D, no. 4, p. 357–363.

West, K.E., 1972, $H_20^{18}/H_20^{16}$ variations in ice and snow of mountainous regions of Canada: Edmonton, Alberta, University of Alberta, Department of Physics, Ph.D. thesis, 123 p.

Wharton, R.A., Jr., and Vinyard, W.C., 1983, Distribution of snow and ice algae in western North America: Madroño, v. 30, no. 4, p. 201–209.

Wheeler, A.O., 1907, Observations of the Yoho Glacier: Canadian Alpine Journal, v. 1, no. 1, p. 149–156.

———1908, Motion of the Yoho Glacier: Canadian Alpine Journal, v. 1, no. 2, p. 271–275.

———1909, Motion of the Yoho Glacier: Canadian Alpine Journal, v. 2, no. 1, p. 97–99.

———1910, Motion of the Yoho Glacier: Canadian Alpine Journal, v. 2, no. 2, p. 121–125.

———1911, Motion of the Yoho Glacier: Canadian Alpine Journal, v. 3, p. 123–126.

———1913, Motion of the Yoho Glacier: Canadian Alpine Journal, v. 5, p. 53–58.

———1915a, Motion of the Yoho Glacier: 1912–1914: Canadian Alpine Journal, v. 6, p. 133–138.

———1915b, Robson Glacier: Canadian Alpine Journal, v. 6, p. 139–142.

———1917, Motion of the Yoho Glacier: 1914–1916: Canadian Alpine Journal, v. 8, p. 118–120.

———1920a, Motion of the Yoho Glacier: 1917, 1918 and 1919: Canadian Alpine Journal, v. 11, p. 182–185.

———1920b, Notes on the glaciers of the Main and Selkirk Ranges of the Canadian Rocky Mountains: Canadian Alpine Journal, v. 11, p. 121–146.

———1923, Motion of the Robson Glacier: Canadian Alpine Journal, v. 13, p. 158–159.

———1932, Glacial change in the Canadian Cordillera, the 1931 Expedition: Canadian Alpine Journal, v. 20, p. 120–137.

———1934, Records of glacial observations in the Canadian Cordillera, 1933 and 1934: Canadian Alpine Journal, v. 22, p. 172–187.

Wilcox, W.D., 1900, The Rockies of Canada: New York, G.P. Putnam's Sons, and London, The Knickerbocker Press, 309 p.

Xie, Zichu, and Zang, Jinhua, 1986, A study in the mass balance of the glaciers in China: International Symposium "Glacier Mass-balance, Fluctuations and Runoff," Alma-Ata, 30 September–5 October 1986, Proceedings: Moscow, Soviet Geophysical Committee, Academy of Sciences of the U.S.S.R., Data of Glaciological Studies No. 57, p. 105–110 and 223–227.

Yarnal, B.M., 1979, The sequential development of a rock glacier-like landform, Mount Assiniboine Provincial Park, British Columbia: Calgary, Alberta, University of Calgary, Department of Geography, M.Sc. thesis, 146 p.

Yarnal, Brent, 1984, Relationships between synoptic-scale atmospheric circulation and glacier mass balance in south-western Canada during the International Hydrological Decade, 1965–74: Journal of Glaciology, v. 30, no. 105, p. 188–198.

Young, G.J., 1974a, Glacier mass-balance and terrain shape—a methodological study: Montréal, Québec, McGill University, Department of Geography, Ph.D. thesis, 320 p.

———1974b, A stratified sampling design for snow surveys based on terrain shape: the Western Snow Conference, 42nd Annual Meeting, Anchorage, Alaska, Proceedings, p. 14–22.

———1976, An approach to glacier mass-balance analysis utilizing terrain characterization: Ottawa, Environment Canada, Water Resources Branch, Inland Waters Directorate Scientific Series No. 60, 34 p.

———1977a, Relations between mass-balance and meteorological variables on Peyto Glacier, Alberta, 1967–1974: Zeitschrift für Gletscherkunde und Glazialgeologie, 13, no. 1-2, p. 111–125.

———1977b, The seasonal and diurnal regime of a glacier-fed stream, *in* Swanson, R.H., and Logan, P.A., compilers, Alberta Watershed Research Program Symposium Proceedings, 31 August–2 September 1977: Edmonton, Alberta, Fisheries and Environment Canada, Forestry Service, Northern Forest Research Center, Information Report NOR–X–176, p. 111–126.

Young, G.J., 1980, Formirovanie pechnogo stoka v lednikovom basseine v Skalistykh gorakh Kanady [Streamflow formation in a glacierized watershed in the Rocky Mountains Canada]. Materialy Gliatsiologicheskikh Issledovanii, Khronika, Obsuzhdeniia, Mezhduvedomstvennyi Geofizicheskii Komitet, Sektsiia Gliatsiologii, Institut Geografii, Academy Nauk SSSR, Moskva [Moscow], Academy of Sciences of the U.S.S.R., Section of Glaciology of the Soviet Geophysical Committee and Institute of Geography, Discussion, Chronicle, Data of Glaciological Studies No. 39, in Russian, p. 55–62; in English, p. 134–139.

———1981, The mass balance of Peyto Glacier, Alberta, Canada, 1965 to 1978: Arctic and Alpine Research, v. 13, no. 3, August, p. 307–318.

———1982, Hydrological relationships in a glacierized mountain basin, *in* Glen, J.W., ed., Hydrological Aspects of Alpine and High Mountain Areas: Proceedings of the Exeter Symposium, 19–30 July 1982: IAHS-AISH Publication No. 138, p. 51–59.

Young, G.J., and Arnold, K.C., 1977, Orthophotomaps of glaciers—An evaluation of an automated method applied to Peyto Glacier, Alberta: Zeitschrift für Gletscherkunde und Glazialgeologie, v. 13, no. 1-2, p. 99–110.

Young, G.J., Glynn, J.E., Reid, I.A., and Sherstone, D.A., 1978, Mapping the Athabasca Glacier, Alberta, Canada, by orthophotography and by conventional methods: International Symposium on New Technology for Mapping, International Society for Photogrammetry, Commission 4, Ottawa, Ontario, 2–6 October 1978, Proceedings, p. 643–659.

Young, G.J., and Stanley, A.D., 1976a, Canadian glaciers in the International Hydrological Decade program, 1965–1974. No. 3: Ram River Glacier, Alberta—Summary of measurements: Ottawa, Fisheries and Environment Canada, Water Resources Branch, Inland Waters Directorate Scientific Series No. 70, 54 p.

———1976b, Canadian glaciers in the International Hydrological Decade program, 1965–1974. No. 4: Peyto Glacier, Alberta - summary of measurements: Ottawa, Fisheries and Environment Canada, Water Resources Branch, Inland Waters Directorate Scientific Series No. 71, 59 p.