Glaciers of North America–

GLACIERS OF CANADA

HISTORY OF GLACIER INVESTIGATIONS IN CANADA

By C. SIMON L. OMMANNEY

SATELLITE IMAGE ATLAS OF GLACIERS OF THE WORLD

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

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1386–J–1

The earliest recorded description of a Canadian glacier was in 1861. Since that time, various glaciological investigations have been conducted in the several glacierized regions of Canada (for example, Coast Mountains, Interior Ranges, *Rocky Mountains, and Arctic Islands), including mass balance, modeling, dendrochronology, climatology, ice chemistry and physics, ice-core analyses, glacier-surge mechanics, and airborne and satellite remote sensing*

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GLACIERS OF NORTH AMERICA–

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HISTORY OF GLACIER INVESTIGATIONS IN CANADA

By C. SIMON L. OMMANNEY[1]

Abstract

Because of extensive high mountain ranges (peaks nearly 6,000 meters above sea level in western Canada) and high latitude (latitude 83° North in the High Arctic Islands), Canada has a large number of glacierized regions; the area covered by glaciers increases from south to north along the border with Alaska in the west and from Labrador to Ellesmere Island in the east. Glaciers cover an estimated 150,000 square kilometers of the Arctic Islands, three times the glacier cover in western Canada (about 50,000 square kilometers), for an approximate total area of 200,000 square kilometers. The principal glacierized regions of Canada are the mountain groups of the Coast Mountains: St. Elias Mountains, Boundary Ranges, and Pacific Ranges; *Interior Ranges*; Rocky Mountains; and Arctic Islands: Baffin Island, Devon Island, Ellesmere Island, Axel Heiberg Island, Meighen Island, and Melville Island. The first field observations of Canadian glaciers were made in 1861. During the past 140 years, various types of glaciological measurements, from observations in the field to airborne and satellite remote sensing, have been made, for varying periods of time, of 176 individual glaciers, including 13 glaciers in Yukon Territory (St. Elias Mountains), 63 glaciers in the Coast Mountains, 10 glaciers in the *Interior Ranges*, 27 glaciers in the Rocky Mountains, 41 glaciers in the High Arctic, 10 glaciers in the Low Arctic, and 5 glaciers in Labrador (Torngat Mountains). Seven other glaciers have been studied but are outside these mountain ranges and are not discussed. Most of the studies of mass-balance, modeling, dendrochronology, climatology, ice chemistry and physics, ice-core analysis, glacier-surge mechanics, and airborne and satellite remote sensing were carried out during the past 50 years, stimulated by the need for increased knowledge of water resources in the western glacierized basins and to support scientific work during the International Geophysical Year (1945 to middle 1950's), increased knowledge of Arctic Canada, a response to security and sovereignty concerns (middle 1950's to the middle 1960's), and by the International Hydrological Decade (middle 1960's to the 1970's). During the 1990's governmental support of glacier research in Canada waned, but by the beginning of the 21st century, the Geological Survey of Canada initiated a National Glaciology Programme, including a Cryospheric Systems Research Initiative (CRYSYS), motivated by achieving a better scientific understanding of the potential impact of climate change on Canada's water resources and the Arctic region. With the increased availability of the higher spatial and spectral resolution in satellite imagery (including stereoscopic imagery), radar imagery (including InSAR), and laser altimetry, glaciologists will increasingly rely on satellite remote sensing to acquire some of the data needed to monitor changes in area and volume and glacier velocity.

Occurrence of Glaciers

The Canadian landmass, extending from long 53°W. to 141°W. and from lat 42°N. to 83°N., has an area of almost 10 million km^2. The mountains range up to a height of nearly 6,000 m above sea level and contain a variety of environments suitable for the development and maintenance of glaciers. Field, in his memorable study of mountain glaciers, described the glacier

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Manuscript approved for publication 7 March 2002.

[1] International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, England (formerly with the National Hydrology Research Institute [now the National Hydrology Research Centre], Environment Canada, Saskatoon, Saskatchewan S7N 3H5, Canada).

distribution and reported on much of the work done on them (Field, 1975c); work on the glaciers was last updated by Ommanney (1996). Small glaciers are found on both continental margins, in the Torngats of Labrador (Fahn, 1975), and in the central mountains of Vancouver Island (Ommanney, 1972a). Larger glacier masses are found in the Rocky Mountains (Denton, 1975a), the *Interior Ranges* (Coleman, 1921; Denton, 1975c), and the Coast Mountains (Denton, 1975b). The glaciers get progressively larger as one moves north along the "Panhandle" (Field, 1975a), the boundary between British Columbia and Alaska. The size continues to increase through the Juneau Icefield region up to the Yukon Territory (Ommanney, 1993) and the Icefield Ranges (Field, 1975b, 1990), which contain large glacier systems such as the Seward Glacier [11],[2] (Post and LaChapelle, 1971) (table 1, fig. 1). Some smaller outliers are found in the eastern Yukon Territory and western District of Mackenzie (Northwest Territories) (Horvath, 1975). The variety of the landscapes encountered can be seen in Dunbar and Greenaway (1956), Post and LaChapelle (1971), Slaney (1981), Prest (1983), and Mollard and Janes (1984).

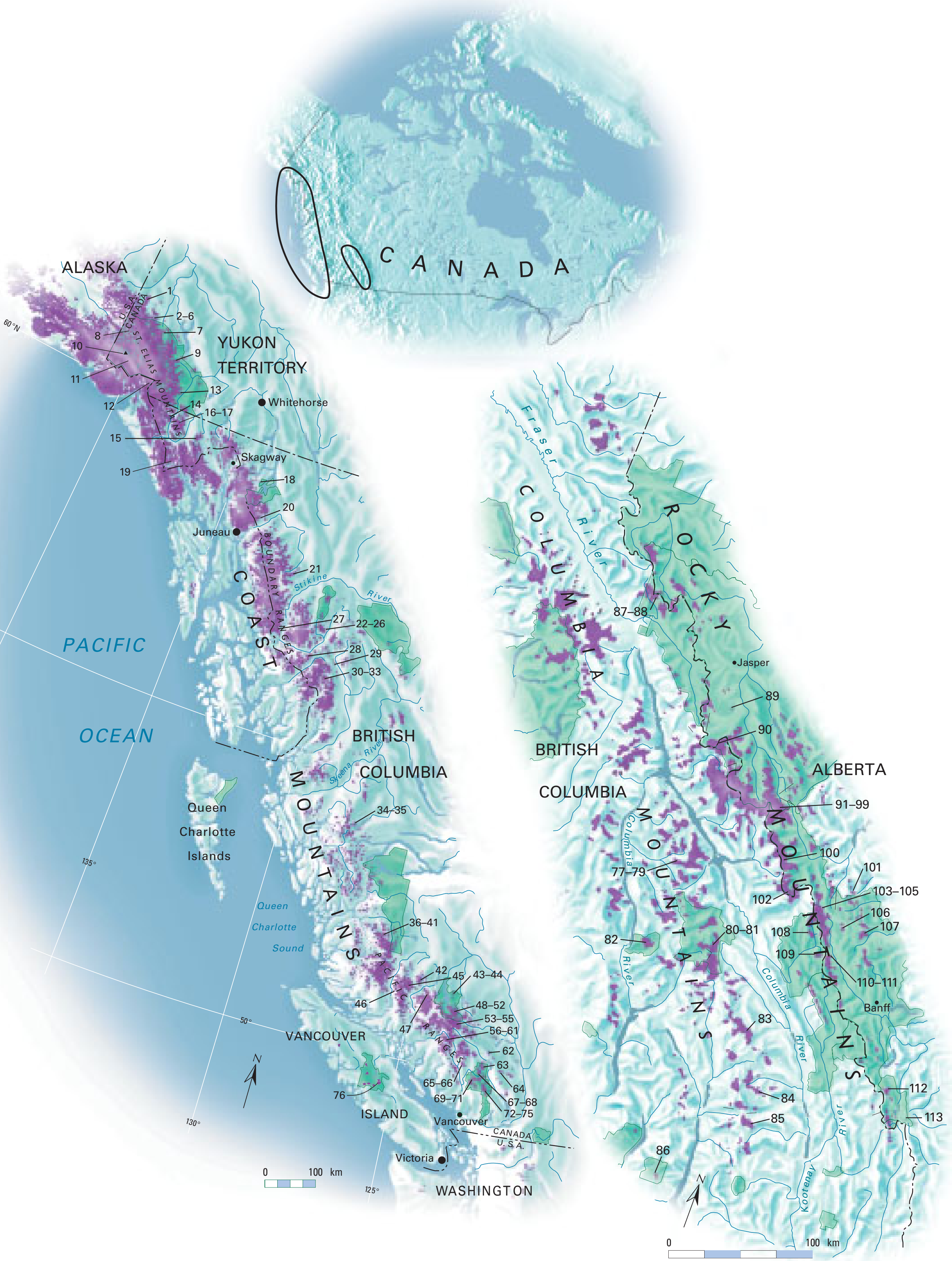
The mean height of the equilibrium line of the glaciers rises steadily as one crosses the mountains from west to east, from about 1,700 m in the Coast Mountains to more than 2,700 m in the Rockies, reflecting a continentality effect. Moving northward, the glaciers increase in size and reach to lower elevations, demonstrating a latitudinal effect due to the lowering of mean annual temperature as one moves toward the North Pole. This effect is best seen in the eastern Arctic, where the mean height of the equilibrium line declines from some 700 m on Baffin Island virtually to sea level at the Ward Hunt Ice Shelf [120] (table 2, fig. 2). Glaciers in the eastern Arctic are distributed along the mountain and fjord coast of Baffin Island (Ives, 1967c), with bigger concentrations of ice in the Barnes [164] and Penny [168] Ice Caps (Mercer, 1975a). Such concentrations become larger and more common farther north. Axel Heiberg Island, Ellesmere Island, and Devon Island are partially covered by large ice fields and ice caps several thousand square kilometers in size (Mercer, 1975b). The regional characteristics of glaciation levels, snowlines, and equilibrium lines throughout Canada have been described by Østrem (1966a, 1972, 1973b), Andrews and Miller (1972), Bradley (1975) and Miller and others (1975).

Figure 1 shows the distribution of glaciers in western Canada. The numbers in this figure refer to those in table 1 and identify the locations of specific glaciers mentioned in the text or for which some historical information is summarized in the table. The numbers are given in the text in square brackets after the glacier names to aid the reader in identifying their geographic location. Figure 2 and table 2 provides the same information for the glaciers of arctic and eastern Canada.

To aid in the management of its glacier resources, the Canadian government initiated a comprehensive inventory of all Canadian glaciers in the 1960's. The inventory was a contribution to the International Hydrological Decade (IHD) and also to the International Hydrological Programme (IHP) (Ommanney, 1980). However, no recent measurement of the total area of Canada's glaciers has been made. A summary of the best available information (Ommanney, 1971a) shows that about three-quarters of Canada's permanent ice masses, some 150,000 km^2, is found in the eastern Arctic, with the balance lying on the mainland, chiefly in the Yukon Territory and British Columbia (Ommanney, 1989) (table 3).

Figure 1.—*(opposite page) The glaciers of western Canada. Numbers on the map correlate to the numbered glaciers in table 1. The areas shown in darker green are national parks and other protected areas; the areas shown in purple are glaciers. Modified from map in Canadian Geographic (Shilts and others, 1998). Used with permission.*

[2] Numbers in brackets refer to tables 1 and 2 and to figures 1 and 2.


CANADA
ALASKA
U.S.A.
CANADA
60°N
ST. ELIAS MOUNTAINS
YUKON
TERRITORY
Whitehorse
Skagway
Juneau
BOUNDARY RANGES
COAST
MOUNTAINS
Stikine
River
PACIFIC
OCEAN
55°
140°W
135°
130°
125°
50°
BRITISH
COLUMBIA
Skeena River
Queen
Charlotte
Islands
Queen
Charlotte
Sound
PACIFIC RANGES
VANCOUVER
ISLAND
Vancouver
Victoria
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22–26
27
28
29
30–33
34–35
36–41
42
43–44
45
46
47
48–52
53–55
56–61
62
63
64
65–66
67–68
69–71
72–75
76
Fraser
River
COLUMBIA
ROCKY
MOUNTAINS
Jasper
BRITISH
COLUMBIA
ALBERTA
Columbia
River
Kootenay
River
Banff
87–88
89
90
91–99
100
101
102
103–105
106
107
108
109
110–111
77–79
80–81
82
83
84
85
86
112
113

TABLE 1.—*Summary of historical information on glaciers of western Canada (see also fig. 1)*

[x, variations; o, mass balance; *, variations and mass balance; z, other studies; s, other, some mass balance; m, other, some variations; ?, missing glacier area and location data; italicized place-names are variant names and names not listed in the CPCGN/CGNDB[3]]

YUKON TERRITORY	Latitude North	Longitude West	km^2		1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
1. Klutlan Glacier	61°30.0'	140°37.0'	1091.		....	....	....	....	....	....	....	.....zz...	.....z....	....	....	
2. Hazard Glacier	61°15.7'	140°21.9'	16.		....	....	....	....	....	....	....	....	.....zz..z	....	....	
3. Steele Glacier	61°14.6'	140°10.6'	99.		....	....	....	....	....	....	....	......zzzz	..zzzzz..z	.z........	....	
4. Trapridge Glacier (*Hyena*)	61°13.6'	140°20.0'	5.5		....	....	....	....	....	....	....	........zz	zzzzz.z...	zzzzzzzzzz	zzzzzzzzz.	
5. Backe Glacier (*Jackal*)	61°12.8'	140°17.9'	3.4		....	....	....	....	....	....	....	........z.	.x........	....	....	
6. Rusty Glacier (*Fox*)	61°12.4'	140°17.9'	4.9		....	....	....	....	....	....	....	.......zoo	zzzzzzz...	....	....	
7. Donjek Glacier	61°03.6'	139°42.8'	290.		....	....	....	....	....	....	....	....	....z....z	....	....	
8. Walsh Glacier	60°53.0'	140°45.0'			....	....	....	....	....	....	.xx.......	....xxx...	....	....	....	
9. Kaskawulsh Glacier	60°45.0'	139°06.0'	700.		....	....	....	....	x	....	....	.zzzzzzzzz	z..zz.....	....	....	
10. Mount Logan	60°34.0'	140°23.0'	?		....	....	....	....	....	....	....	........z.	....zzz.z.	zz....z.zz	....	
11. Seward Glacier	60°25.0'	140°30.0'	?		....	....	....	....	....	xx	....o.....	....zz....	.z........	....	....	
12. Hubbard Glacier	60°22.6'	139°22.5'	?		....	....	....	....	....	....	....	....	....	.z.z.z....	....	
13. Lowell Glacier	60°17.8'	138°17.2'	530.		....	....	....	....	....	....	....	....	xxxxx	xxxxx.....	....	
COAST MOUNTAINS	**Latitude North**	**Longitude West**	**km^2**		**1890**	**1900**	**1910**	**1920**	**1930**	**1940**	**1950**	**1960**	**1970**	**1980**	**1990**	**2000**
14. Tweedsmuir Glacier	59°52.0'	138°19.3'	497.		....	....	....	....	....	....	....	....	....xx....	....	....	
15. Nadahini Glacier	59°44.0'	136°41.0'	6.1		....	....	....	....	....	....	....	....x.x.x.	x.x.x.....	....	....	
16. *East Arm Glacier*	59°43.2'	137°35.6'	102.		....	....	....	....	....	....	....	....	....	.x.x......	....	
17. Tats Glacier	59°41.4'	137°46.2'	16.1		....	....	....	....	....	....	....	....	....	........oo	....	
18. Cathedral Glacier	59°20.3'	134° 06.3'	2.0		....	....	....	....	....	....	....	....	.ooo.o....	....	....	
19. Grand Pacific Glacier	59°07.5'	137°08.0'	565.		....	....	....	.....x....	....	......x...	x.......x.	....x.....	....x.....	....	....	
20. Tulsequah Glacier	58°50.0'	133°45.6'	~200.		....	....	....	....	..z.......	....	....	....	....	....	....	
21. Flood Glacier	57°10.7'	131°55.0'	11.		....	....	....	....	....	....	....	....	.........z	zzzzzz....	....	
22. Alexander Glacier	57°06.4'	130°49.1'	5.8		....	....	....	....	....	....	....	....	.........o	oooooo..oo	o.........	
23. Natavas Glacier	57°03.6'	130°49.6'	3.1		....	....	....	....	....	....	....	....	....	zo........	....	
24. Yuri Glacier	56°58.0'	130°42.2'	3.6		....	....	....	....	....	....	....	....	........oo	oooooo..oo	o.........	
25. Andrei Glacier	56°55.7'	130°55.6'	92.		....	....	....	....	....	....	....	....	........oo	oooooo..oo	o.........	
26. *Forrest Kerr Glacier*	56°54.1'	130°05.6'	99.		....	....	....	.......x..	.x..x.....	.....xxxx.	....	....	........oo	ooo.......	....	
27. Great Glacier	56°50.9'	131°52.0'	~175.		....	....	....	....	....	....	....	....	....	....	....	
28. *Ridge Icefield Glacier*	?	?	?		....	....	....	....	....	....	....	....	....	....	.z........	
29. *Tim Williams Glacier*	56°33.4'	130°00.0'	8.		....	....	....	....	....	....	......z...	....	....	.........z	....	
30. Leduc Glacier	56°14.0'	130°22.0'	12.3		....	....	....	....	....	....	....	.....z....	.	....	....	
31. Frank Mackie Glacier	56°19.5'	130°10.0'	153.		....	....	....	....	....	....	....	.....z....	....	....	....	
32. Berendon Glacier	56°14.8'	130°05.0'	33.4		....	....	....	....	....	....	....	.....z.ooo	oooooo....	....	....	
33. Salmon Glacier	56°08.6'	130°04.0'	35.		....	....	....	....	....	....	......zz.z	.....z.zzz	z.........	....	....	
34. New Moon Glacier	53°55.3'	127°46.5'	1.0		....	....	....	....	....	......x...	....x.....	.......x..	.x...x..x.	...x......	....	
35. UTEM Glacier	53°54.5'	127°46.7'	1.2		....	....	....	....	....	....	....	....	....	...x......	....	
36. Purgatory Glacier	52°09.0'	126°22.0'	13.9		....	x.........	....	....	....	.......x..	....x.....	....x.....	........x.	....x.....	....	
37. Atavist Glacier	52°09.0'	126°09.0'	5.5		....	x.........	....	....	....	....	.x..x.....	....x.....	........x.	....x.....	....	
38. Noeick Glacier	52°06.5'	126°16.7'	8.9		....	x.........	....	....	....	....	....x.....	....x.....	........x.	....	....	
39. Fyles Glacier	52°06.0'	126°13.6'	15.9		....	x.........	....	....	....	.......x..	....x.....	....x.....	...x....x.	....mmm...	....	
40. Ape Glacier	52°04.3'	126°12.2'	8.1		....	x.........	....	....	....	.......x..	.x..x.....	....x.....	...x....x.	....x.x...	....	
41. *Deer Lake Glacier*	52°04.0'	126°10.0'	4.6		....	....	....	....	....	....	....	....	...x......	....	....	
42. Bench Glacier	51°27.0'	124°56.0'	10.		....	....	....	....	....	....	....	....	....	.ooooo..oo	o.........	
43. *Tsoloss Glacier*	51°23.5'	123°52.0'	1.1		....	x.........	....	....	....	....	.x........	....	....	..x.......	....	
44. *Elkin Glacier*	51°22.5'	123°51.0'	1.5	...	....	....	....	....	....	....	.x........	....	....	..x.......	....	
45. Tiedemann Glacier	51°19.5'	125°00.0'	63.	...	....	....	....	....	....	....	....	....	....	.ooooo..oo	o.........	
46. Franklin Glacier	51°14.5'	125°28.0'	132.	...	....	....	....	.......x..	.x..x.....	.....xxxx.	....	....	....	....	....	
47. Cumberland Glacier	51°12.0'	124°23.3'	2.8	...	....	....	....	....	....	....	....	....	....	...z......	....	
48. Miserable Glacier	51°04.2'	123°52.0'	3.3	...	....	x.........	....	....	....	....	.x........	....	.....x....	....	....	

TABLE 1.—*Summary of historical information on glaciers of western Canada (see also fig. 1)*—Continued

[x, variations; o, mass balance; *, variations and mass balance; z, other studies; s, other, some mass balance; m, other, some variations; ?, missing glacier area and location data; italicized place-names are variant names and names not listed in the CPCGN/CGNDB[3]]

COAST MOUNTAINS	Latitude North	Longitude West	km²		1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
49. Pathetic Glacier	51°03.4'	123°47.5'	0.1	...	....	x.........	....	....	....	....	.x........	....	.....x....	....	....	
50. Friendly Glacier	51°03.0'	123°51.4'	4.4	...	....	x.........	....	....	....	....	.x........	x	.....x....	..x.......	....	
51. Hourglass Glacier	51°01.6'	123°46.0'	4.2	...	....	x.........	....	....	....	....	.x........	....	.....x....	....	....	
52. Tchaikazan Glacier	51°01.2'	123°47.3'	21.4	...	....	x.........	....	....	....	....	.x........	........x.	.....xx...	..x.......	....	
53. *Sykora Glacier*	50°52.7'	123°33.8'	25.	...	....	....	....	....	....	....	....	....	00000	000000....	....	
54. Bridge Glacier	50°49.4'	123°33.0'	83.5	...	....	....	....	....	....	....	....	....	00000	000000....	....	
55. *Zavisha Glacier*	50°48.4'	123°25.3'	6.5	...	....	....	....	....	....	....	....	....	00000	000000....	....	
56. Berm Glacier	50°33.0'	123°59.0'	1.1	...	....	....	....	....	....	.......xx.	.x........	....	x......x.x	....	....	
57. Havoc Glacier	50°30.3'	123°52.3'	9.5	...	...x......	....	....	....	....	.......x..	.x........	....x.....	x......x.x	....	....	
58. Wave Glacier	50°30.0'	123°59.0'	4.4	...	....	....	....	....	....	.......xx.	.x........	....x.....	x......x.x	....	....	
59. Surf Glacier	50°29.7'	123°58.1'	1.0	...	...x......	....	....	....	....	.......x..	x.........	....x.....	x......x.x	....	....	
60. Terrific Glacier	50°26.4'	123°57.8'	4.6	...	....	....	....	....	....	.......x..	.x........	....x.....	x......x.x	....	....	
61. Clendenning Glacier	50°25.2'	123°54.1'	26.5	...	...x......	....	....	....	....	.......x..	.x........	....x.....	x......x.x	....	....	
62. Place Glacier	50°25.3'	122°36.0'	3.8	...	....	....	....	....	....	....	....	00000	0000000000	0000000000	0000000000	
63. Wedgemount Glacier	50°09.2'	122°47.8'	2.6	...	....	x.........	....	x.........	....	.......x.x	.x........	....x....x	..xx.xzxxx	x* *xxx....	x...xx....	
64. *Caltha Lake Glacier*	50°08.7'	122°17.0'	0.1	...	....	....	....	....	....	....	.x........	x	....	x..x.x....	....	
65. Boomerang Glacier	50°07.2'	123°15.8'	4.0	...	....	....	....	....	....	....	....	....	..z.......	....	....	
66. *Brandy Bowl Glacier*	50°07.1'	123°14.7'	1.5	...	....	....	....	....	....	....	....	....	..z.......	....	....	
67. Horstman Glacier	50°05.8'	122°53.0'		...	....	....	....	....	....	....	....	....	....	....	....	
68. Overlord Glacier	50°01.2'	122°50.0'	2.6	...	....	x.........	....	........x.	....	....	.x........	....	..x.......	....	x.xx.x....	
69. Helm Glacier	49°57.8'	123°00.0'	3.1	...	....	....	..x.......	........x.	.....xxx..	xxxxx	x.x.x.x.x.	x.........	00000	0000000000	000000....	
70. Sphinx Glacier	49°55.0'	122°57.5'	4.7	...	....	....	.x........	....	.....xxx..	xxxxx	x.x.x.x.x.	x...x.x.x.	x.x...0000	000.......	....	
71. Sentinel Glacier	49°53.6'	122°58.9'	1.8	...	....	....	....	....	.....xxx..	xxxxx	x.x.x.x.x.	x...x0*0*0	*0*0000000	0000000000	....	
72. Thunderclap Glacier	45°51.0'	122°39.0'	2.7	...	....	....	....	....	.x........	....	.xx.......	......x..x	..x....x..	....	....	
73. Griffin Glacier	49°51.0'	122°38.0'	2.1	...	....	....	....	....	.x........	....	.xx.......	......x..x	..x....xx.	....	....	
74. Staircase Glacier	49°51.0'	122°37.0'	1.6	...	....	....	....	....	.x........	....	.xx.......	......x..x	..x....xx.	....	....	
75. Gl. de Fleur des Neiges	49°51.0'	122°36.0'	0.4	...	....	....	....	....	.x........	....	.xx.......	......x..x	..x....xx.	....	....	
76. Moving Glacier	49°33.0'	125°23.2'	1.2	...	....	....	....	....	.x........	....	....	..x.......	....	.x........	....	

INTERIOR RANGES	Latitude North	Longitude West	km²		1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
77. Silvertip Glacier	51°42.2'	117°54.2'	3.5	...	....	....	x.x.......	....	....	x	.x...x....	......x...	.....x.x..	....	....	
78. Haworth Glacier	51°41.6'	117°54.3'	4.1	...	....	....	x.x.......	....	....	x	.x...x....	......x...	.....x.x..	....	....	
79. Sir Sandford Glacier	51°40.3'	117°54.0'	10.4	...	....	....	x.x.......	....	....	x	.x...x....	.x....x...	.....x.x..	....	....	
80. Illecillewaet Glacier	51°14.2'	117°26.5'	6.4	xx.	x.......xx	xxxxxxxxxx	xxx.......	....	.x........	xxxxx	x.x.x.x.x.	x.........	....	....	....	
81. Asulkan Glacier	51°12.4'	117°27.3'	1.2	...	xx	xx.xxxxx.x	xxx.......	....	.x........	....	....	....	....	....	....	
82. Woolsey Glacier	51°07.5'	118°02.5'	3.9	...	....	....	....	....	....	....	....	00000	000000....	....	....	
83. Bugaboo Glacier	50°43.8'	116°46.5'	5.	...	....	....	....	....	....	....	....	....x.x.x.	x.x.x.....	....	....	
84. Commander Glacier	50°25.7'	116°32.5'	6.0	...	....	....	....	x.........	....	....	....x.....	x.........	....	....	....	
85. Toby Glacier	50°13.7'	116°32.0'	8.	...	....	....	.....x....	.x..x...xx	....	....	....	....	....	....	....	
86. Kokanee Glacier	49°45.0'	117°08.5'	3.1	...	....	....	....	...x......	....	xxxxx	x.x.x.x.x.	x...x.x.x.	x.x.......	....	....	

ROCKY MOUNTAINS	Latitude North	Longitude West	km²		1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
87. Robson Glacier	53°08.5'	119°06.0'	13.		....	........x.	.x.x......	..x.......	.x........	....	...x......	....	....	....	....	
88. *Small River Glacier*	53°06.0'	119°17.0'	5.8		....	....	....	....	....	....	....	....	....	....	...z.z....	
89. Angel Glacier	52°41.0'	118°04.0'	0.9		....	....	....	....	....	......xx...	z.........	....	....	....	....	
90. Scott Glacier	52°26.0'	118°05.0'	16.		....	....	....	....x.....	....	....	...x......	....	....	....	....	
91. *East Chaba Glacier*	52°12.5'	117°40.8'	1.7		....	....	....	.......x..	......x...	....	....	......x...	x.........	....	....	
92. Saskatachewan Glacier	52°12.5'	117°08.2'	30.	(1824–62)		....	..x.......	.....x....	....	xxxxx	x.xxx.x.x.	x.xxxxxxxx	xxxxxxxxxx	....	.mmmmmmmm.	
93. Athabasca Glacier	52°11.7'	117°15.0'	15.	(1843–44)		....	....	..x.......	....	xxxxx	x.xxx.x.xm	mmmmxzmmmm	xxxxxxxxxx	.x..xx....	.mmmmmmmm.	
94. Columbia Icefield	52°10.0'	117°20.0'	285.		....	....	....	....	....	....	....	....	.........z	zz........	....	
95. Columbia Glacier	52°09.5'	117°23.0'	16.	(1698–1739)		....	x	....x.....	....	........x.	...x......	......x...	x.x.......	....	....	

TABLE 1.—*Summary of historical information on glaciers of western Canada (see also fig. 1)*—Continued

[x, variations; o, mass balance; *, variations and mass balance; z, other studies; s, other, some mass balance; m, other, some variations; ?, missing glacier area and location data; italicized place-names are variant names and names not listed in the CPCGN/CGNDB[3]]

ROCKY MOUNTAINS	Latitude North	Longitude West	km²	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
96. *Boundary Glacier*	52°11.5'	117°11.4'	1.5	....	...x......	....	....	....	........x.	......x...	......x...	x.x.......	...xxx....	x	
97. Dome Glacier	52°12.1'	117°18.1'	5.92	(1846).	....	....	....	....	....	...x......	....	.......m..	.x..xx..zz	zxzzzzzzz.	
98. *Hilda Glacier*	52°11.0'	117°10.0'	1.35	....	....	....	....	....	....	....	....	........z.	....	........z.	
99. *Cline Glacier*	52°05.0'	116°41.0'	?	....	....	....	....	....	....	....	....	....	.......zzz	zz........	
100. Southeast Lyell Glacier	51°54.5'	117°01.6'	16.	(1858)...	....	x	......x...	x.........	....	...x......	....	.......m..	.x..xx..zz	zxzzzzzzz.	
101. Ram River Glacier	51°51.0'	116°11.5'	1.8	....	....	....	....	....	....	....	00000	000000....	....	....	
102. Freshfield Glacier	51°45.8'	116°54.2'	40.	....	..x.......	....	..x...x...	x...x..x..	xxx	x.x.x.....	....	....	....	....	
103. Peyto Glacier	51°40.6'	116°32.8'	13.	.......x..	....	....	....	...x..x..x	..x..xxxxx	x.x.x.x.x.	x.x.0*0000	000000000s	00s0s00000	..0000000.	
104. Bow Glacier	51°38.9'	116°30.4'	5.1	.......x..	....	....	..x.......	...x......	.....x....	..xx......	......x...	....	....	.......zzz	
105. Yoho Glacier	51°36.0'	116°32.5'	23.	.......x..	.x.xxxxxxx	x.xxx.xxxx	....	.x.x......	....	....	....	....	....	....	
106. Hector Glacier	51°35.7'	116°15.5'	2.5	....	....x.....	....	....	........x.	....	..x.......	.....x....	....	....	....	
107. Drummond Glacier	51°35.5'	116°02.0'	1.3	....	......x...	....	x.........	x........x	....	..x.......	..****xx..	....	....	....	
108. Emerald Glacier	51°30.0'	116°32.0'	1.9	....	....	....	....	....	....	....	....	xx	xxx.......	....	
109. *Cathedral Glacier*	51°24.3'	116°23.4'	0.9	....	....	....	....	....	....	....	....	........zx	..z.z.....	....	
110. Victoria Glacier	51°22.8'	116°17.2'	3.5	.......xx.	...x...x.x	x.x.......	....	.x........	xxxxx	x.x.......	......x...	......x...	....	....	
111. Wenkchemna Glacier	51°18.7'	116°14.2'	4.3	....	xxx.x.....	....	....	....	....	...x......	.....z.z.z	.......z.z	....	....	
112. *Robertson Glacier*	50°44.0'	115°20.0'	0.8	....	....	....	....	....	....	....	....	....	....	.....zz...	
113. *Rae Glacier*	50°37.4'	114°59.1'	?	....	....	....	....	....	....	....	....	....	....	...z......	

TABLE 2.—*Summary of historical information on glaciers of arctic and eastern Canada (see also fig. 2)*

[x, variations; o, mass balance; *, variations and mass balance; z, other studies; s, other, some mass balance; m, other, some variations; ?, missing glacier area data; italicized place-names are variant names and names not listed in the CPCGN/CGNDB[3]]

HIGH ARCTIC	Latitude North	Longitude West	km²	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
120. Ward Hunt Ice Shelf (Elles)	83°07.2'	73°30.3'	660.	....	....	....	....	....	....	...zz....z	0zzzz00000	0000000...	000000....	....	
121. *Ward Hunt Ice Rise* (Elles)	83°07.0'	74°10.0'	32.	....	....	....	....	....	....	00	0000000000	0000000...	000000....	....	
122. Milne Glacier (Elles)	82°24.0'	80°00.0'	900.	....	....	....	....	....	....	x	......x...	....	...x......	....	
123. Gilman Glacier (Elles)	82°05.8'	70°36.9'	480.	....	....	....	....	....	....	000	0000000000	....	..0.......	....	
124. *Muskox Glacier* (Elles)	82°05.0'	86°10.0'	?	....	....	....	....	....	....	....	....	....	......z...	....	
125. *Unnamed Ice Cap* (Elles)	81°57.3'	64°12.0'	7.5	....	....	....	....	....	....	....	......00..	0000000...	....	....	
126. Per Ardua Glacier (Elles)	81°31.0'	76°27.0'	4.3	....	....	....	....	....	....	....	000000	00........	....	....	
127. Otto Glacier (Elles)	81°20.0'	84°15.0'	1018.	....	....	....	....	....	....	....	...x..z...	....	....	....	
128. Hare Fiord Glacier (Elles)	81°08.5'	82°20.0'	?	....	....	....	....	....	....	........x.	....	........x.	....	....	
129. Webber Glacier (Elles)	80°55.0'	82°10.0'	123.	....	....	....	....	....	....	....	....	........z.	....	....	
130. Gnome Glacier (Elles)	80°54.5'	82°23.5'	3.1	....	....	....	....	....	....	....	....	........x.	....	....	
131. Dwarf Glacier (Elles)	80°54.0'	82°30.3'	4.3	....	....	....	....	....	....	....	....	........x.	....	....	
132. Midget Glacier (Elles)	80°53.7'	82°37.3'	3.0	....	....	....	....	....	....	....	....	........x.	....	....	
133. Arklio Glacier (Elles)	80°53.6'	82°44.0'	7.2	....	....	....	....	....	....	....	....	........x.	....	....	
134. Okpuddyshao Glacier (Elles)	80°53.1'	82°50.9'	5.6	....	....	....	....	....	....	....	....	........x.	....	....	
135. Nukapingwa Glacier (Elles)	80°52.9'	82°58.1'	4.8	....	....	....	....	....	....	....	....	........x.	....	....	
136. Van Royen Glacier (Elles)	80°53.2'	83°10.5'	111.	....	....	....	....	....	....	....	....	........x.	....	....z.....	
137. *Shirley Glacier* (Elles)	80°50.0'	83°25.0'	?	....	....	....	....	....	....	....	....	....	....	....z.....	
138. *Blackwelder Ice Cap* (Elles)	80°38.0'	85°00.0'	117.	....	....	....	....	....	....	....	....	....	....	....z.....	
139. Agassiz Ice Cap (Elles)	80°25.0'	75°00.0'	17326.	....	....	....	....	....	....	....	....	......ssss	ssssssssss	sssssssss.	

TABLE 2.—*Summary of historical information on glaciers of arctic and eastern Canada (see also fig. 2)*—Continued

[x, variations; o, mass balance; *, variations and mass balance; z, other studies; s, other, some mass balance; m, other, some variations; ?, missing glacier area data; italicized place-names are variant names and names not listed in the CPCGN/CGNDB[3]]

HIGH ARCTIC	Latitude North	Longitude West	km²	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
140. d'Iberville Glacier (Elles)	80°25.6'	77°33.0'	1609.	....	....	....	....	....	....	....	....	...zz.....	....	....	
141. John Evans Glacier (Elles)	79°38.5'	74°30.0'	220.	....	....	....	....	....	....	....	....	....	....	....ossss.	
142. *Quviagivaa Glacier* (Elles)	79°34.0'	83°15.0'	?	....	....	....	....	....	....	....	....	....	....	.ooo......	
143. Leffert Glacier (Elles)	78°41.3'	75°01.4'	593.	....	....	....	....	....	....	....	....	.........o	o.........	....	
144. *Unnamed Glacier* (Elles)	78°39.1'	74°55.0'	50.	....	....	....	....	....	....	....	....	.........o	o.........	....	
145. Prince of Wales Icefield (Elles)	78°15.0'	80°00.0'	?	....	....	....	....	....	....	....	....	..zzz......	....	....	
146. *Laika Glacier* (Coburg)	75°53.5'	79°05.2'	4.3	....	....	....	....	....	....	....	....	...oo....o	o.........	....	
147. *Laika Ice Cap* (Coburg)	75°53.0'	79°09.1'	10.	....	....	....	....	....	....	....	....	....ooo..o	o.........	....	
148. *Wolf Glacier* (Coburg)	75°54.2'	79°12.2'	2.0	....	....	....	....	....	....	....	....	.........o	o.........	....	
149. Baby Glacier (Axel)	79°26.4'	90°58.0'	0.6	....	....	....	....	....	....	.........o	oooooooooo	oooooooooo	ooo......o	oo........	
150. Crusoe Glacier (Axel)	79°25.7'	91°10.0'	44.	....	....	....	....	....	....	x	xxxxxxxxxxx	xxxxxxxxxx	xxx.......	....	
151. Müller Ice Cap (Axel)	79°54.0'	90°59.0'	6300.	....	....	....	....	....	....	.........z	zzzz......	......o...	....	....	
152. Thompson Glacier (Axel)	79°28.0'	90°30.0'	230.	....	....	....	....	....	....	x	xxxxxxxxxx	xxxxxxxxxx	xxx.......	z.........	
153. White Glacier (Axel)	79°26.7'	90°40.0'	39.	....	....	....	....	....	....	..........o	oooooooooo	oooooooooo	oooooooooo	ooooooooo.	
154. *Good Friday Bay Glacier* (Axel)	78°37.0'	91°10.0	641.	....	....	....	....	....	....	..x......x	....	....	....	....	
155. Meighen Ice Cap (Meighen)	79°57.2'	99°08.0'	90.	....	....	....	....	....	....	.........o	ooooosssoo	oo.ooooooo	.ooooooooo	o....o....	
156. *South Ice Cap* (Melville)	75°25.4'	115°01.1	66	....	....	....	....	....	....	....	...oooo.oo	oo.oo.....	.oo.......	.ooooo....	
157. *West Ice Cap* (Melville)	75°37.8'	114°45.0'	36.4	....	....	....	....	....	....	....	...oooo.oo	oo.o......	....	.ooooo....	
158. *East Ice Cap* (Melville)	75°39.3'	114°28.6'	16.0	....	....	....	....	....	....	....	...oooo.oo	oo.o......	....	.ooooo....	
159. Leopold Glacier (Melville)	75°49.0'	114°45.0'	27.7	....	....	....	....	....	....	....	...oooo.oo	oo.o......	....	.ooooo....	
160. Devon Ice Cap (Devon)	75°20.0'	82°30.0'	12825.	....	....	....	....	....	....	....	.ooooooooo	sssssosooo	oooooooooo	oooooo....	
161. Sverdrup Glacier (Devon)	75°40.6'	83°15.5'	672.	....	....	....	....	....	....	....	.ooo......	....	....	....	
LOW ARCTIC	Latitude North	Longitude West	km²	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
162. Aktineq Glacier (Bylot)	72°54.9'	78°51.8'		....	....	....	....	....	....	....	....	....	....	....	
163. Lewis Glacier (Baffin)	70°25.9'	74°46.0'	182.	....	....	....	....	....	....	....	..zooo....	....	....	....	
164. Barnes Ice Cap (Baffin)	70°10.0'	73°30.0'	6200.	....	....	....	....	....	....	s.........	..zooooooo	ssssssssss	sssss....z	zzzzzz.z..	
165. Decade Glacier (Baffin)	69°38.2'	69°49.5'	8.7	....	....	....	....	....	....	....	.....ooooo	oo.o......	....	....	
166. *Akudnirmuit Glacier* (Baffin)	67°34.6'	65°14.5'	0.6	....	....	....	....	....	....	....	....	.oo.......	....	....	
167. *Boas Glacier* (Baffin)	67°34.1'	65°15.6'	1.4	....	....	....	....	....	....	....	.........o	oooooo....	....	....	
168. Penny Ice Cap (Baffin)	67°10.0'	66°13.0'	6000.	....	....	....	....	....	....	...z......	..z.zz...z	....	.........z	zzzzzz....	
169. Turner Glacier (Baffin)	66°41.2'	65°14.1'	26.2	....	....	....	....	....	....	...z......	....	....	....	....	
170. Virginia Glacier (Baffin)	66°36.5'	62°18.5'		....	....	....	....	....	....	....	....	....	....	....	
171. Grinnell Glacier (Baffin)	62°32.4	66°51.4'	126.	....	....	....	....	....	....	..x.......	.....x....	....	.z........	....	
LABRADOR	Latitude North	Longitude West	km²	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
172. *Bryant's Glacier*	59°19.0	63°55.7	1.3	....	........x.	....	....	.x........	....	....	....	....	....	....	
173. Superguksoak Glacier	58°57.0	63°47.0	1.8	....	....	....	....	....	....	....	....	....	.oooo.....	....	
174. Abraham Glacier	58°56.2	63°31.9	0.8	....	....	....	....	....	....	....	....	....	.****.....	....	
175. Hidden Glacier	58°55.7	63°32.7	0.7	....	....	....	....	....	....	....	....	....	.oooo.....	....	
176. Minaret Glacier	58°53.1	63°41.2	0.9	....	....	....	....	....	....	....	....	....	.oooo.....	....	

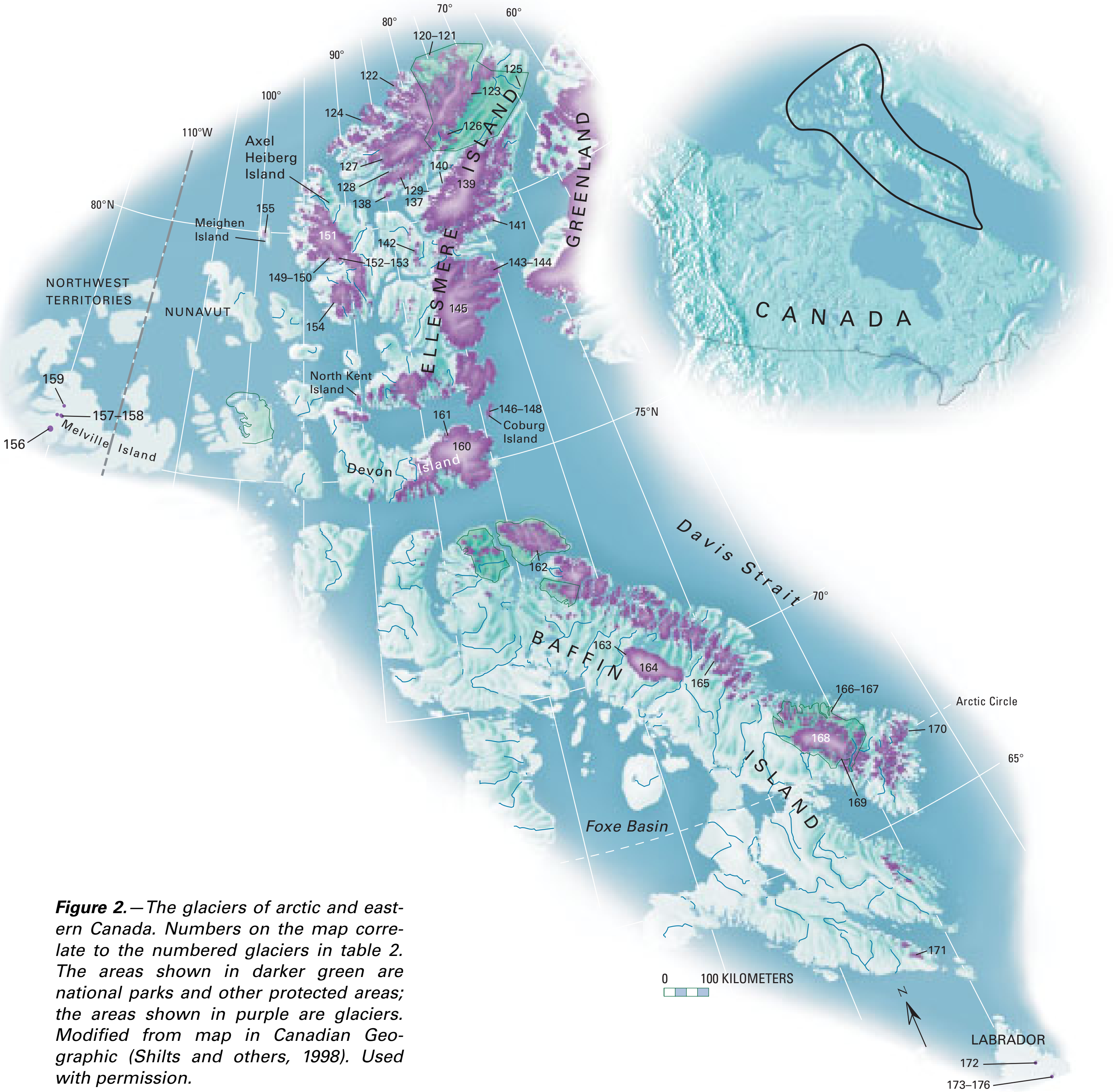


***Figure 2.**—The glaciers of arctic and eastern Canada. Numbers on the map correlate to the numbered glaciers in table 2. The areas shown in darker green are national parks and other protected areas; the areas shown in purple are glaciers. Modified from map in Canadian Geographic (Shilts and others, 1998). Used with permission.*

TABLE 3.—*The Glacierized Areas of Canada (km²) (Ommanney, 1971a)*

ARCTIC ISLANDS	
Ellesmere Island	80,000
ice shelves	500
Axel Heiberg Island	11,735
Devon Island	16,200
Coburg Island	225
Meighen Island	85
Melville Island	160
North Kent Island	152
Baffin Island	37,000
Bylot Island	5,000
Subtotal	151,057
MAINLAND	
Pacific drainage	37,659
Nelson River drainage	328
Great Slave Lake drainage	626
Yukon River drainage	10,564
Arctic Ocean drainage	840
Labrador	24
Subtotal	50,041
Total Glacierized Area	201,098

Observation of Glaciers

Historic (Prior to World War II)

Penetration of the western mountains by the Canadian voyageurs, by European traders, and by settlers took place only comparatively recently. Although some aboriginal legends refer to glaciers (Morey, 1971), the earliest recorded description of a Canadian glacier was probably that made by James Hector (1861), a geologist on the Palliser Expedition who visited Southeast Lyell Glacier [100] in 1858. Another early observation of note was that of the Great Glacier [27] by W.P. Blake (1867), a member of a scientific party on a Russian naval squadron ship, in 1863. Developments since then have largely been linked to technological innovations or to the stimulation provided by international initiatives.

One major influence on the settlement of southern Canada, and an element that is deeply etched in the Canadian psyche, has been the railroad. The crossing of the cordillera by the Canadian Pacific Railroad (CPR) was the first technological development that impacted the study of glaciers. The opening up of the west by the CPR and the linking of British Columbia with the rest of Canada gave everyone access to the Rocky Mountains and *Interior Ranges* (fig. 3), creating an opportunity for the first systematic glacier observations. New facilities such as Chateau Lake Louise and Glacier House provided bases from which the early amateur and professional scientists could work. Guides, imported from Switzerland, were made available to those wishing to climb or do glacier research. It was the CPR, responding to pressure from A.O. Wheeler, a prominent Canadian surveyor, and his

***Figure 3.**—Oblique aerial photograph of the Columbia Mountains,* Interior Ranges*, British Columbia, Canada, in late summer of 1970, showing the rugged topography and several mountain glaciers. Photograph by C. Simon L. Ommanney, National Hydrology Research Institute. [NTS Map: 082L16]*

influential friends, that provided the free passes that enabled the founders of the Alpine Club of Canada (ACC) to meet and establish that organization.

Glacier House was built by the CPR at Rogers Pass, in what is now Glacier National Park, because the grade was too steep to permit the inclusion of a restaurant car on the train. Passengers were required to disembark, and many took the opportunity of this enforced stop to take the trail to the Illecillewaet Glacier (or "Great Glacier") [80]. It is hardly surprising then that this, and the neighbouring Asulkan Glacier [81], became the object of the first investigations. Although the earliest observations in Glacier National Park were made by the Rev. Spotswood Green (1890), the subsequent systematic studies were made mainly by members of the Vaux family of Philadelphia (Vaux, G., Jr., and Vaux, W.S., Jr., 1900a, b, 1901, 1908; Vaux, W.S., Jr., 1907, 1909; Vaux, G., 1910; Vaux, M.M., 1911, 1913) (fig. 4). Their activities and contributions were reviewed by Edward Cavell (1983). Other studies of note in this area were those by A.O. Wheeler (1905, 1920; Wheeler and Parker, 1912) and Howard Palmer (1914). In the 1970's, the Canadian Exploration Group visited Palmer's field area and resurveyed the Silvertip, Haworth, and Sir Sandford Glaciers [77–79] (Marsh, 1976, 1978).

The Victoria Glacier [110], visible and easily accessible from Chateau Lake Louise, also received early attention. Studies here and on the Wenkchemna [111] and Yoho [105] Glaciers were conducted by W.H. Sherzer of the Smithsonian Institution (Sherzer, 1907, 1908; Gardner, 1977, 1978). The Yoho Glacier was also included in the set of observations undertaken by the Vaux family (Vaux, G., Jr., and Vaux, W.S., Jr., 1907a, b, 1908; Vaux, G., 1910; Vaux, M.M., 1911, 1913; Vaux, M.M., and Vaux, G., Jr., 1911). These studies were extended by A.O. Wheeler and members of the ACC who held a number of field camps near this glacier (Wheeler, 1911, 1913, 1932, 1934).

Table 1 summarizes the available information on glacier observations during this period. The early records for the Illecillewaet [80], Asulkan [81], and Yoho [105] Glaciers are evident, as is the comparative lack of similar studies in the Coast Mountains. Some of the apparent observations there [36–40, 43, 48–52, 57, 59, 61, 63, 68] reflect modern reconstructions of glacier snout positions using air-photo interpretation and dendrochronological techniques rather than field observations at the dates indicated.

The First World War caused a hiatus in the recording of glacier variations that continued until after the Second World War. However, a few observations were made in the interwar years by members of the ACC (Palmer, 1924; Munday, 1931; McCoubrey, 1938; Thorington, 1938), and snout positions for many other glaciers have been reconstructed.

An interesting development at this time was the 1931 aerial survey of glaciers in Labrador, completed under the auspices of the American Geographical Society (AGS) by Forbes and others (1938). Some ground observations of *Bryant's Glacier* [172][3] were made by Odell (1933), who compared the snout position with that recorded by Bryant and Forbes in 1908.

Compared to many more highly populated mountain areas, such as the Alps, the early record of Canadian glacier variations is fairly sparse. However, at least for the three glaciers discussed above (the Illecillewaet, Asulkan, and Yoho Glaciers), we do have fairly complete records of their retreat during an extended period of glacier recession.

[3] 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/]. The website is maintained by the Secretariat through Geomatics Canada, Natural Resources Canada, and combines the CPCGN server with the Canadian Geographical Names Data Base (CGNDB). Variant names and names not listed in the CPCGN/CGNDB are shown in italics.

Figure 4.—Photograph of the Illecillewaet Glacier ("Great Glacier"), Interior Ranges, *British Columbia, taken 19 August 1898. The successful crossing of the western mountains by the Canadian Pacific Railroad in the late 1880's gave access to the Rocky Mountains and* Interior Ranges *and made systematic glacier observations possible. The Vaux family was among the earliest to take an interest in the glaciers. According to George, Jr., and W.S. Vaux, Jr., the Illecillewaet Glacier was the most accessible and one of the most remarkable in the area. It was notable for the lack of debris at its foot and the rapidity of the ice fall. They concluded that photography offered the most satisfactory means of permanently recording the position of the ice from year to year. Photograph is a reproduction of Plate 5 from Vaux and Vaux (1900b). (Glacier 80 in table 1; see also section in this volume by Wheate and others on Mapping Glaciers in the* Interior Ranges *and Rocky Mountains with Landsat Data.)*

1945 to the Middle 1950's

The immediate postwar period saw a significant increase in the number of glacier studies. This was largely due to the commencement of an annual survey of specific glaciers in the cordillera. The survey was initiated by the Dominion Water and Power Bureau (DWPB), forerunner of the Water Survey of Canada (WSC), as part of its studies of the water resources of mountain rivers. In 1945, seven glaciers in Alberta—Angel [89], Athabasca [93], Freshfield [102], Peyto [103], Saskatchewan [92], Southeast Lyell [100], and Victoria [110] Glaciers—were investigated by the DWPB Calgary office. Eight glaciers in British Columbia were observed by the DWPB Vancouver office—Bugaboo [83], Franklin [46], Helm [69], Illecillewaet [80], Kokanee [86] (fig. 5), Nadahini [15] (fig. 6), Sentinel [71], and Sphinx [70] (fig. 7) Glaciers. The position of the glacier termini and changes in their areal extent were measured, and a set of plaques were placed on the ice surface to determine velocity. Some surveys were abandoned after a few years, but table 1 shows that many continued every year until 1950, when they became biennial. Detailed reports were prepared by the DWPB as internal documents, but some results were published (Lang, 1943; McFarlane, 1946; Meek, 1948a, b; Webb, 1948; McFarlane and others, 1950; Collier, 1958; Strilaeff, 1961). Summaries of the reports for Peyto Glacier and the Victoria Glacier have been published by Ommanney (1971b, 1972b).

During this period, photographs of many cordilleran glaciers appeared in mountaineering journals, and some specific photographic recording of glaciers was carried out (Field, 1949). Following on the WSC initiatives, the next significant development was by the American Geographical Society (AGS), which established the Juneau Icefield Research Project in 1948 in conjunction with the U.S. Office of Naval Research (ONR). This project concentrated on glaciers in Alaska but laid the groundwork for the subsequent Summer Institute of Glaciological and Arctic Sciences that, from its subsidiary base in Atlin, B.C., has contributed to our knowledge of Canadian glaciers in the area, particularly the Cathedral Glacier [18] (Field and Miller, 1950; Eagan, 1963; Miller, 1963; Marcus, 1964; Miller and Anderson, 1974). Another AGS expedition visited a number of glaciers in the Rockies in 1953. Glacier surface areas and variations for the Robson [87], Columbia [95], Southeast Lyell [100], Peyto [103], Freshfield [102], Athabasca [93], and Saskatchewan [92] Glaciers were documented using photographic and botanical techniques (Field and Heusser, 1954; Heusser, 1954, 1956, 1960). In the Yukon Territory, the Arctic Institute of North America (AINA)

Figure 5.—Photograph of the terminus of the Kokanee Glacier, Interior Ranges*, British Columbia, Canada, showing the transient snowline in September 1972. Photograph by I.A. Reid, Water Survey of Canada. (Glacier 86 in table 1) [NTS Map: 082F11]*

Figure 6.—Photograph of Nadahini Glacier in August 1974 at Photo Station No. 5, Coast Mountains, British Columbia. Studies of the glacier terminus and changes in its areal extent were begun in 1945 by the Dominion Water and Power Bureau, forerunner of the Water Survey of Canada. Studies continued in the 1960's and 1970's. Photograph by I.A. Reid, Water Survey of Canada. (Glacier 15 in table 1)

Figure 7.—Photograph of the terminus of Sphinx Glacier, Coast Mountains, British Columbia, Canada, in September 1968. Photograph by Oleg Mokievsky-Zubok, National Hydrology Research Institute. (Glacier 70 in table 1) [NTS Map: 092G15]

sponsored Project Snow Cornice. This airborne expedition established a semipermanent research station on Seward Glacier [11] (Wood, 1948, 1949; Baird and Salt, 1949; Sharp, 1950).

Advances in transportation technology made a significant impact on postwar field research in Canada. Previously inaccessible areas were opened up to scientists. Thus Baird, through the Arctic Institute of North America, was able to mount major expeditions on Baffin Island to study the Barnes Ice Cap [164] in 1950 (Baird and others, 1950; Baird, 1952a) and the Penny Ice Cap [168] in 1953 (Baird and others, 1953). These expeditions provided the first substantial information on glaciers in this region (Orvig, 1951, 1953, 1954; Baird, 1952b; Baird and others, 1953; Ward and Orvig, 1953; Ward, 1954, 1955; Ward and Baird, 1954). Other scientists also found it easier to work independently in such areas—for example, Mercer's (1956) study of Grinnell Glacier [171].

Meanwhile, in the High Arctic, a group sponsored by the United States government was attempting to understand the nature and origin of ice islands, such as Fletcher's Ice Island or T–3, by studies on Ward Hunt Ice Shelf [120] in 1953 and 1954 (Crary, 1956).

Mention was made earlier of the influence of international programs on Canadian glaciological studies. Although the International Geophysical Year (IGY) (1957–59) did not focus any particular emphasis on such studies, it did prompt some organizations to undertake new programs or to extend existing ones. Canadian participation in the IGY led to a University of Toronto Expedition (1956–57) to study Salmon Glacier [33] (Adkins, 1958, 1959; Jacobs, 1958; Haumann, 1960; Russell and others, 1960; Doell, 1963). On Ellesmere Island, the Defence Research Board (DRB) started a program on Gilman Glacier [123] and continued studies on the Ward Hunt Ice Shelf (Hattersley-Smith, 1954, 1959, 1961; Hattersley-Smith and others, 1961; Weber, 1961; Weber and others, 1961; Lister, 1962; Lyons and Ragle, 1962; Ragle and others, 1964; Lyons and others, 1972).

Middle 1950's to the Middle 1960's

In the period immediately following the IGY, concern in Canadian government circles about security and sovereignty in the Arctic, and a lack of knowledge about that region, translated into funding for major projects. The Geological Survey of Canada (GSC) mounted Operation Franklin to map the geology of the Queen Elizabeth Islands. A consortium of McGill University professors, in conjunction with George Jacobsen, an entrepreneur, obtained a major expedition grant from the National Research Council of Canada (NRCC) to launch the Jacobsen-McGill Arctic Research Expedition to Axel Heiberg Island under the direction of the Swiss glaciologist Fritz Müller. The Department of Mines and Technical Surveys organized Arctic logistics through the Polar Continental Shelf Project (PCSP), which was also charged with a multidisciplinary investigation of the continental shelf region, and appointed geologist Fred Roots as its first coordinator. The Arctic Institute of North America mounted an expedition to Devon Island, and the Department of National Defence continued and expanded its studies on Ellesmere Island. This Defence Research Board (DRB) expedition, led by Geoffrey Hattersley-Smith, and named Operation Hazen after the lake on which its base camp was located, later became Operation Tanquary when the camp was moved to the head of Tanquary Fiord (Hattersley-Smith, 1974). All these activities combined to raise glaciological research in Canada to a new level and helped establish Canada's reputation in the international scientific community during that period.

The McGill University expedition started with a small reconnaissance party in 1959; this was followed in 1960 and 1961 by large multidisciplinary parties working on Crusoe [150], Baby [149], White [153], and Thompson [152] Glaciers and on the Müller Ice Cap (renamed; previously Akaioa Ice Cap or informally *McGill Ice Cap*) [151] (Müller, 1961; Müller 1962a, b, 1963; Müller and others, 1963; Andrews, R.H.G., 1964; Havens, 1964; Havens and others, 1965; Redpath, 1965; Adams, 1966; Müller and Keeler, 1969) (fig. 8). A comprehensive list of publications arising out of this early work was included in a glacier inventory of Axel Heiberg Island (Ommanney, 1969).

Within the terms of reference establishing the PCSP, provision was made for the hiring of staff scientists to cover disciplines not contributed by the participating government departments. Stan Paterson joined the PCSP and started working on Meighen Ice Cap [155]. By the middle 1960's, his program on that ice cap had been expanded to include the Melville Island ice caps [156–159] and Devon Ice Cap [160], taking over in the latter case from the AINA, whose studies there were winding down.

The AINA program involved mass balance and meteorological studies on Devon Ice Cap and some detailed investigations of Sverdrup Glacier [161] (Apollonio, 1962; Keeler, 1964; Hyndman, 1965; Koerner, 1966; Vögtli, 1967; Holmgren, 1971).

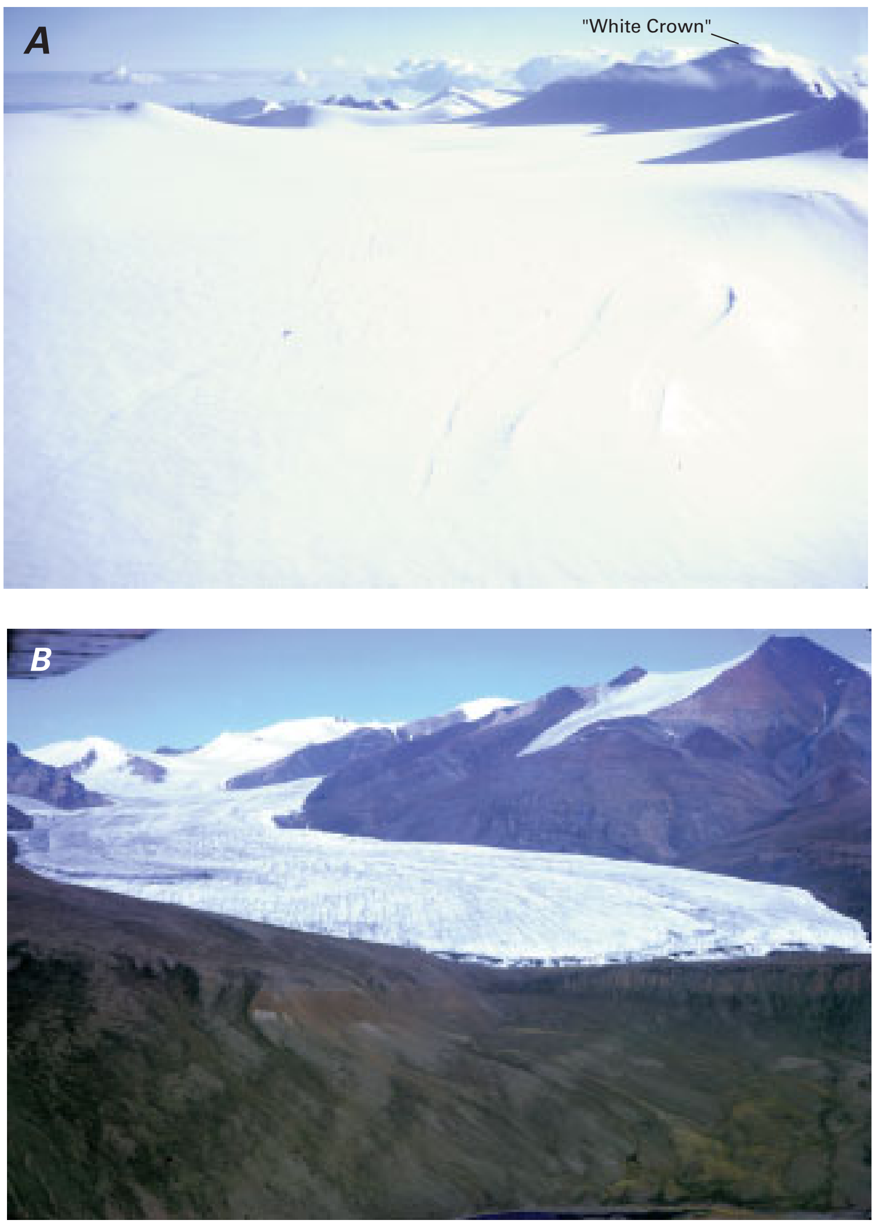


Figure 8.*—Photographs of the Müller Ice Cap* **A***, and Crusoe Glacier* **B***, on Axel Heiberg Island, Nunavut, High Arctic. In 1960 and 1961, large multidisciplinary parties of the Jacobsen-McGill Arctic Research Expedition carried out a number of glaciological studies, including measurements of mass balance and glacier variation under the direction of the Swiss glaciologist Fritz Müller on Müller Ice Cap, and Crusoe, White, Baby, and Thompson Glaciers on Axel Heiberg Island. Some studies continued in following years.* **A***, Photograph of Müller Ice Cap (Glacier 151 in table 2) and "White Crown" in 1962 by C. Simon L. Ommanney, McGill University.* **B***, Photograph of Crusoe Glacier in August 1962, looking to the northeast. Note that the termini abuts the terminal moraine, implying a mass balance in relative equilibrium. Photograph by C. Simon L. Ommanney, McGill University. (Glacier 150 in table 2)*

Operation Hazen, on Ellesmere Island, was a large multidisciplinary investigation, similar to the one underway on neighbouring Axel Heiberg Island. The glaciological part of the program was concentrated on Gilman Glacier [123], the Ward Hunt Ice Shelf [120] and *Ward Hunt Ice Rise* [121]. It resulted in reports on glacier surveying (Faig, 1966; Konecny and Faig, 1966; Dorrer, 1971), mass balance (Hattersley-Smith, 1960a, 1961; Hattersley-Smith and others, 1961; Sagar, 1964; Hattersley-Smith and Serson, 1970; Serson, 1979), temperatures (Hattersley-Smith, 1960b; Lyons and Ragle, 1962), radio-echo sounding (Evans and Robin, 1966; Hattersley-Smith, 1969b), and a popular account of the work done (Hattersley-Smith, 1974). A comprehensive bibliography covering this and other work on Ellesmere Island was published by Ommanney (1982).

Farther south, the Geographical Branch, Department of Mines and Technical Surveys, was continuing the work begun by the Baird (AINA) expedition on Barnes Ice Cap [164]. Geomorphologists were intrigued by this remnant of the last “Ice Age” and started a major investigation to map and study evidence of Wisconsinan glaciation in the area. Included were studies of the Barnes Ice Cap itself and the small Lewis Glacier [163] at its northern margin (Ives, 1966, 1967a, b; Løken, 1966; Løken and Andrews, 1966; Sagar, 1966; Anonymous, 1967) and regional variations of glaciers in northern Baffin Island and Bylot Island (Falconer, 1962). Some additional observations were also made on Penny Ice Cap [168] (Andrieux, 1970; Weber and Andrieux, 1970).

Many of the pilots who returned or emigrated to Canada after the war brought with them skills that were invaluable in the north. Most of the expeditions described above owed much to the use of small fixed-wing aircraft equipped with low-pressure balloon tires that were able to land on unprepared ground. The successful deployment of innumerable field camps was made possible by pilots who were willing to accede to the scientists’ often unreasonable demands.

There was also much activity on the mainland at this time. In 1961, the AGS, in conjunction with the AINA, established the Icefield Ranges Research Project (IRRP) (Wood, 1963; Ragle, 1964, 1973). This was similar in scope and intent to the McGill and DRB expeditions. It was centered on what is now Kluane National Park and included detailed glaciological and climatological studies (Taylor-Barge, 1969), particularly on the Kaskawulsh Glacier [9] and around Mount Logan (Holdsworth, 1965, 1969; Shimizu and Wakahama, 1965; Brecher, 1966; Clarke, 1967; MacPherson and Krouse, 1967; Dewart, 1968; Keeler, 1969; Collins, 1970; Loomis and others, 1970; Anderton, 1973; Cameron, 1976). It was an incarnation of the earlier Project Snow Cornice. Many glaciologists received their early training in the Icefield Ranges, and some, such as Garry Clarke and Gerald Holdsworth, have continued to work in the area. The results of the scientific investigations were published in four volumes by the AGS (Bushnell and Ragle, 1969, 1970, 1972; Bushnell and Marcus, 1974).

Elsewhere, in the Coast Mountains, a study in connection with a mining development was initiated on the Leduc, Frank Mackie, Berendon, and Salmon Glaciers [30–33] by Bill Mathews of the University of British Columbia (Mathews, 1964c). Of particular concern was the activity of the Berendon Glacier [32] (fig. 9) (Untersteiner and Nye, 1968; Fisher and Jones, 1971). A more detailed report on this work is included in two separate sections of this volume, Glaciers of the Coast Mountains and Glaciers of the St. Elias Mountains. Other work here has focused on the provenance of material within and on the glacier (Eyles and Rogerson, 1977a, b, c, 1978a, b; Rogerson and Eyles, 1979; Eyles and others, 1982). Research was also being carried out on a number of other glaciers in the Rocky Mountains (West and Maki, 1961), but most of this will be reviewed in the following section.

Figure 9.—*Photograph of the Berendon Glacier showing its prominent medial moraines, Coast Mountains, British Columbia, Canada, on 27 August 1974. Photograph by A.D. Stanley, National Hydrology Research Institute. (Glacier 32 in table 1) [NTS Map: 104B01]*

Middle 1960's to the 1990's

The most important next stimulus was provided by the International Hydrological Decade (IHD) program (1965–74), which led to a major expansion of glaciological investigations in Canada. The nature of some of these developments has been reviewed by various authors (Meier and Post, 1962; Løken, 1971; Ommanney, 1975; Roots, 1984; Ommanney and Young, 1988). In the Cordillera, five glaciers—Place [62], Sentinel [71], Woolsey [82], Peyto [103] and Ram River [101] Glaciers—were selected for an east-west transect, and Berendon Glacier [32] was added to provide a link in the north-south chain. The program was run by the Glacier Section of the Geographical Branch, Department of Mines and Technical Surveys, the forerunner of the Snow and Ice Division, later known as the Hydrology Division (Glaciology Subdivision) of the National Hydrology Research Institute (NHRI), Department of the Environment (Østrem, 1966b, 1973a, b; Mokievsky-Zubok, 1973a, b, 1974; Stanley, 1975; Zubok, 1975; Mokievsky-Zubok and Stanley, 1976a, b; Young and Stanley, 1976a, b; Fogarasi and Mokievsky-Zubok, 1978; Young, 1981; Mokievsky-Zubok and others, 1985). It followed a set of standardized measurements for mass balance and hydrological observations outlined in the manual by Østrem and Stanley (1966), which was subsequently revised (Østrem and Brugman, 1991) (fig. 10). Data were deposited with the World Glacier Monitoring Service (WGMS) in Zürich.

Decade Glacier on Baffin Island [165] was selected as a contribution to the north-south chain in the eastern Arctic (Østrem and others, 1967; Løken, 1972), which included the DRB studies on Per Ardua Glacier [126] and the McGill University studies on White [153] and Baby [149] Glaciers (Young, 1972). However, the effective network was much larger than the official "representative glacier basins" because existing research investigations continued or were expanded to include a larger hydrological component. Thus, in the Arctic, data continued to be collected and analyzed for the Ward Hunt Ice Shelf and *Ward Hunt Ice Rise* [120, 121] (Hattersley-Smith and Serson, 1970; Holdsworth, 1971; Williams and Hutter, 1983; Hattersley-Smith, 1985; Holdsworth, 1986b, 1987; MacAyeal and Holdsworth, 1986; Narod and others, 1988), Gilman Glacier [123], Meighen Ice Cap [155] (Arnold, 1965; Paterson, 1969; Alt, 1979), the Melville Island ice caps [156–159] (Spector, 1966; Paterson and Koerner, 1974), the Devon Ice Cap [160] (Koerner, 1970a, b, 1973, 1979, 1985, 1986; Koerner and others, 1973; Alt, 1978, 1985, 1987; Koerner and Russell, 1979) and

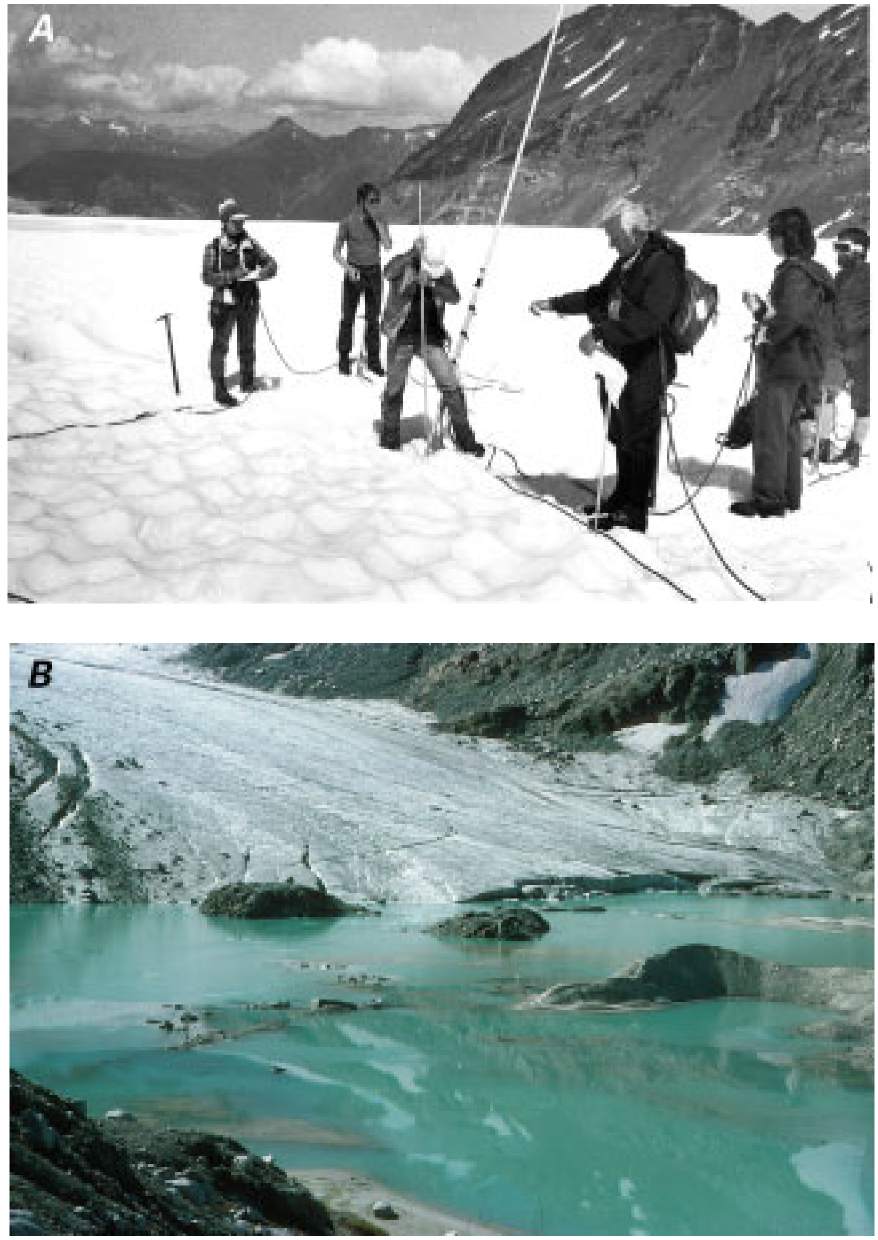


Figure 10.*—Photographs of the Place Glacier, Coast Mountains, British Columbia.* **A**, *Dr. Gunnar Østrem and members of the 1980 Field Glaciology Course making mass-balance measurements on Place Glacier. In 1965, as part of a major expansion of glaciological studies during the International Hydrological Decade, Place Glacier was selected to be part of an east-west transect of glaciers to be monitored in western Canada. The mass-balance measurements begun here in 1965 have continued to the present day.* **B**, *Terminus of the Place Glacier and its proglacial lake in October 1975. Photograph by Oleg Mokievsky-Zubok, National Hydrology Research Institute. (Glacier 62 in table 1) [NTS Map: 092J07]*

the Barnes Ice Cap [164] (Løken and Sagar, 1968; Parker, 1975). New studies included those on an unnamed ice cap near St. Patrick Bay [125] (Hattersley-Smith and Serson, 1973), which was continued by Bradley (Bradley and England, 1977, 1978a, b; Bradley and Serreze, 1987a, b; Serreze and Bradley, 1987) and ones on *Boas* [167] and *Akudnirmuit* [166] *Glaciers* by the University of Colorado (Andrews and Webber, 1969; Andrews and others, 1970; Andrews and Barry, 1972; Jacobs and others, 1973; Williams, 1974, 1975; Weaver, 1975).

Similarly, on the mainland, new studies began on Rusty (*Fox*) [6] (Crossley and Clarke, 1970; Clarke, 1971; Collins, S.G., 1972; Faber, 1973), Cathedral [18] (Jones, 1974; Guigné, 1975; Miller, 1975; Cialek, 1977) and Drummond [107] (Nelson and others, 1966; Brunger and others, 1967) Glaciers. Many of these did not continue throughout the IHD, and, of the representative basins, the investigations on Woolsey, Ram River, Berendon, Decade, and Per Ardua Glaciers were terminated during or at the end of the IHD, but various studies did continue on the other glaciers.

The availability of semipermanent facilities at most of these glaciers, and core staff to maintain a measurement program throughout the summer melt season, led to the development of many other complementary glaciological investigations. The case of Peyto Glacier [103] exemplifies this situation. Studies here, during and after the IHD, included the following: **mapping** (Sedgwick and Henoch, 1975; Henoch and Croizet, 1976; Young and Arnold, 1978; Glenday, 1991; Wallace, 1995), **dendrochronology** (Parker and Henoch, 1971; Reynolds, 1992), **depth sounding** (Goodman, 1970; Goodman and Terroux, 1973; Hobson and Jobin, 1975; (Holdsworth and others, in press), **instrumentation** (Young, 1976), **hydrochemistry** (Collins and Young, 1979, 1981; Binda, 1984; Collins and Power, 1985; Binda and others, 1985; Bradley, 1990), **hydrological modeling** (Derikx and Loijens, 1971; Henoch, 1971; Derikx, 1973, 1975; Loijens, 1974; Munro, 1976; Power and Young, 1979; Gottlieb, 1980; Young, 1982, 1990; Johnson and Power, 1985; Power, 1985; Johnson and David, 1987), **mass balance and techniques, including remote sensing** (Young, 1971, 1974, 1975, 1976, 1981; Pietroniro and Demuth, 1999) and **meteorology** (Goodison, 1971, 1972a, b; Föhn, 1973; Munro, 1976, 1989, 1990, 1991a, b; Munro and Davies, 1976, 1977, 1978; Young, 1978; Munro and Young, 1980, 1982; Stenning and others, 1981; Nakawo and Young, 1982; Cutler and Munro, 1996) (fig. 11). The need to place these single-site observations within the larger regional context was recognized, so a study was made on Yoho Glacier [105] (David, 1989) and the

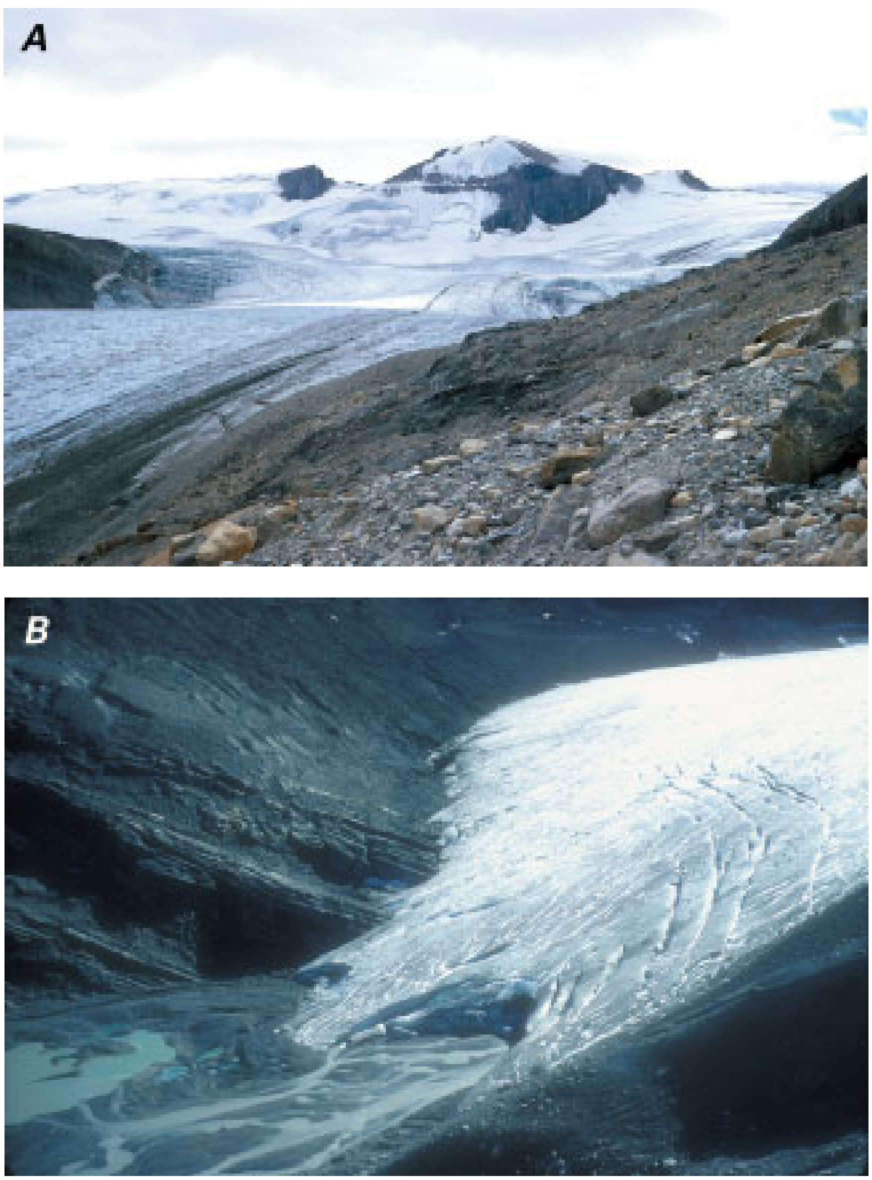


Figure 11.—**A**, *Photograph of Peyto Glacier, Rocky Mountains, Alberta, in late summer 1967. Peyto Glacier has been the site of numerous glacier studies since the early 1900's, including glacier variation, dendrochronology, hydrochemistry, meteorology, and mass-balance measurements and techniques. During the International Hydrological Decade, Peyto Glacier was one of the glaciers monitored in the east-west transect of western Canada. Mass-balance measurements begun here in 1964 are continuing. Photograph by C. Simon L. Ommanney, National Hydrology Research Institute. (Glacier 103 in table 1)* **B**, *Photograph of the terminal lobe of Peyto Glacier, Rocky Mountains, Alberta, on 25 September 1991. Photograph by Gerald Holdsworth, Arctic Institute of North America.*

Figure 12.—*Photographs of Bugaboo Glacier,* Interior Ranges*, British Columbia, Canada, in* **A***, August 1970, and* **B***, July 1970. Photographs by I.A. Reid, Water Survey of Canada. (Glacier 83 in table 1) [NTS Map: 082K10]*

Yoho Valley on the other side of the Continental Divide, as well as the intervening Waputik Icefield from which both glaciers flow.

Although the IHD studies within the Columbia River basin had been terminated, some studies were initiated in Glacier National Park for the Canadian Parks Service (Champoux and Ommanney, 1986a, b), on Bugaboo Glacier [83] (fig. 12) (Osborn, 1986; Osborn and Karlstrom, 1988), and elsewhere (Power, 1985; Rogerson, 1985; Luckman and others, 1987; Duchemin and Seguin, 1998).

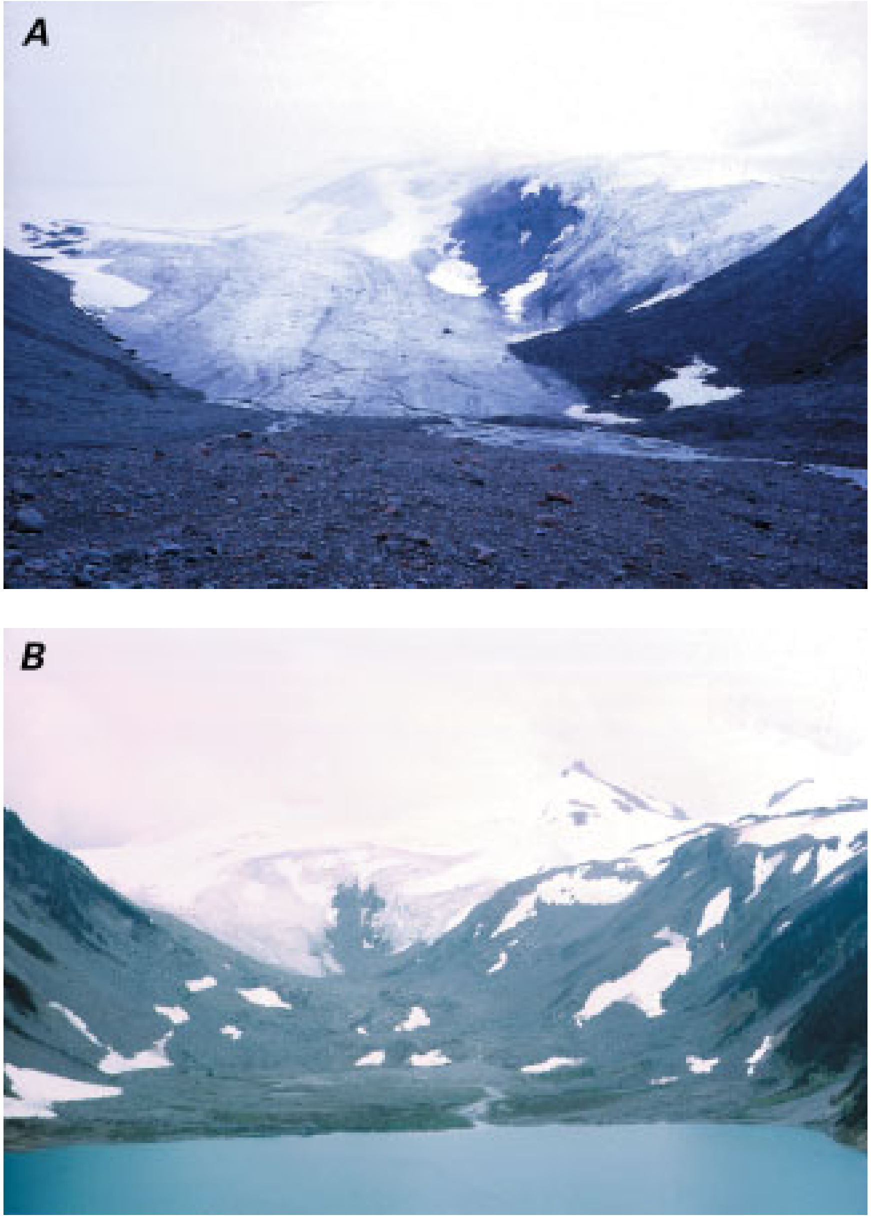


Figure 13.**—Photographs of Sentinel Glacier, Coast Mountains, British Columbia, Canada, showing the transient snowline in* **A, September 1968 and* **B***, 25 September 1973. Photographs by Oleg Mokievsky-Zubok, National Hydrology Research Institute. (Glacier 71 in table 1) [NTS Map: 092G15]*

In the Coast Mountains, continuous records were maintained on Sentinel [71] (fig. 13) and Place [62] Glaciers (Mokievsky-Zubok, 1987; Schmok, 1990), which served as bases for local studies (Yarnal, 1984b; Fogarasi and Mokievsky-Zubok, 1987; Brugman, 1991) and as benchmarks for comparison with shorter term mass-balance investigations elsewhere. The studies were closely related to the operational needs of the various governmental water-management agencies. Thus the program on the Bridge River glaciers, *Sykora Glacier* [53] (fig. 14), Bridge Glacier [54] (fig. 15), and *Zavisha Glacier* [55], aided in the management of the Downton Reservoir (Mokievsky-Zubok, 1980a; Mokievsky-Zubok, 1985). On the basis of data from Andrei [25], Alexander [22], *Forrest Kerr* [26], Natavas [23], and Yuri [24] Glaciers, the feasibility of a hydroelectric development in the Stikine and Iskut River basins was being assessed (Fogarasi, 1981; Mokievsky-Zubok, 1983b; Mokievsky-Zubok, 1992b). A similar study was started in the Homathko basin, on the Bench [42] and Tiedemann [45] (fig. 16) Glaciers (Mokievsky-Zubok, 1983a; Mokievsky-Zubok, 1992a). Data from all these studies were compiled in annual reports by NHRI and deposited with the WGMS. In the early 1990's, following a review of future hydroelectric needs for British Columbia, support for operational programs was withdrawn by BC Hydro.

Figure 14.—*Photograph of the terminus of the* Sykora Glacier, *Coast Mountains, British Columbia, Canada, on 19 August 1975. Photograph by Oleg Mokievsky-Zubok, National Hydrology Research Institute. (Glacier 53 in table 1)*

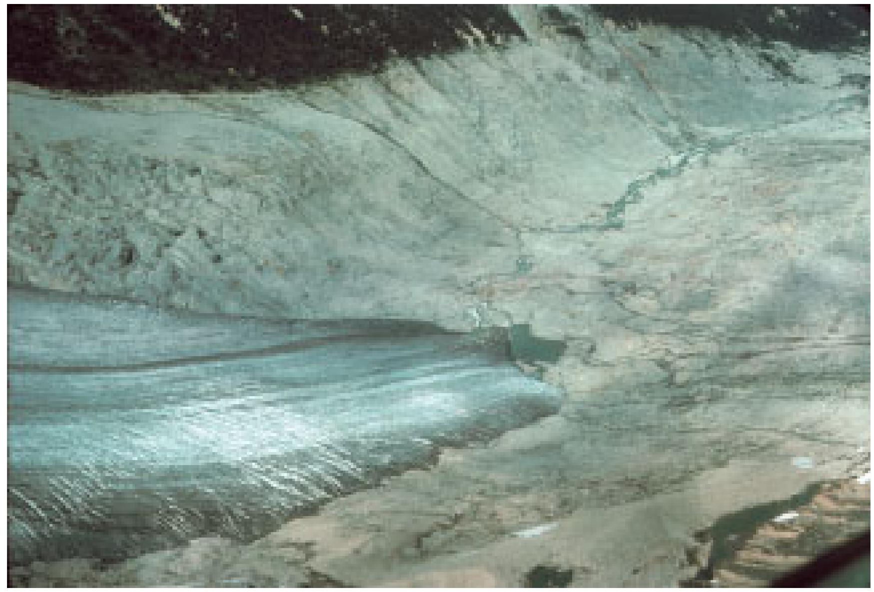


Figure 15.—*Photograph of the terminus of the Bridge Glacier, Coast Mountains, British Columbia, Canada, on 19 August 1975, showing icebergs which have calved into the proglacial lake. Photograph by Oleg Mokievsky-Zubok, National Hydrology Research Institute. (Glacier 54 in table 1) [NTS Map: 092J13]*

Figure 16.—*Photograph of the terminus of the Tiedemann Glacier, Coast Mountains, British Columbia, Canada, in August 1982, showing prominent trim lines on the valley wall, prominent medial moraines, and the morainic-debris-covered lower part of the glacier. The difference in elevation of the trimline and the present surface of the glacier in its lower part indicates significant reduction in glacier volume and a prolonged period of negative mass balance. Photograph by Oleg Mokievsky-Zubok, National Hydrology Research Institute. (Glacier 45 in table 1) [NTS Map: 092N06]*

Data from these transects and supplementary studies have been used in a number of regional analyses of the spatial distribution of glaciers, their variations, and the relationship between glacier mass balance and climate (Henoch, 1972; Yarnal, 1984a; Osborn and Luckman, 1988; Letréguilly, 1988; Letréguilly and Reynaud, 1989, 1990; Luckman and others, 1993; Demuth, in press).

The Juneau Icefield Research Project, partly working from a base in Atlin, British Columbia, continued to introduce students to glaciology and mountain environments. Some results from work on the Juneau Icefield and Cathedral Glacier [18] are available (Johnson, R.F., 1983; Marston, 1983; Hasenauer, 1984; Mauelshagen, 1984; Mauelshagen and Slupetzky, 1985; Yao Tandong, 1987; Rentsch and others, 1990; Marcus and others, 1992).

On Barnes Ice Cap [164] the mass-balance program soon changed to one emphasizing glacier physics (Jones, 1972; Hooke, 1973a, b, 1976a, b, 1981; Holdsworth, 1973a, b, 1975, 1977c; Barnett and Holdsworth, 1974; Hudleston, 1976, 1980; Classen, 1977; Hooke and others, 1979, 1980, 1983, 1987; Hooke and Hudleston, 1980, 1981; Hudleston and Hooke, 1980; Hooke and Clausen, 1982; Hudleston, 1983; Hooke and Hanson, 1986; Stolle, 1986, 1988; Hanson, 1987, 1990). The mass-balance program maintained by R. Hooke (Hooke and others, 1987) lapsed. New studies subsequently began here, using remote sensing to assess changes in the ice cap (Lodwick and Paine, 1985; Moisan and Dubois, 1993; Jacobs and others, 1997). Work was also done on the subglacial characteristics of Aktineq Glacier [162] on Bylot Island (Souchez and De Groote, 1985; Souchez and others, 1988; Tison and others, 1989; Zdanowicz and others, 1996). In the south, Grinnell Glacier [171] was revisited in connection with a sediment study (Dowdeswell, 1986) and became the subject of an educational project that included mapping, directed by Gunnar Østrem (Norwegian Water Resources and Energy Administration, 1991). Nearby, a climbing expedition measured the fluctuations of Virginia Glacier [170] (Cochran, 1978).

Interest in reconstructing past climates in the High Arctic led to deep ice-coring projects on Meighen Ice Cap [155], Devon Ice Cap [160] and Agassiz Ice Cap [139] (fig. 17). Although mass-balance investigations were an integral part of the initial surface observations, the focus subsequently changed to analysis of the core constituents and their interpretation. Reports have covered the following: **climate at different time scales** (Koerner and Paterson, 1974; Koerner, 1977a, 1989, 1992; Fisher and Koerner, 1981; Koerner and Fisher, 1981, 1985, 1990; Alt and others, 1985, 1992; Harvey, 1988; Reeh, 1991; Fisher, 1992); **snow and ice properties** (Koerner, 1968, 1973; Fisher and Koerner, 1986; Goto-Azuma and others, 1997); **englacial temperatures, precipitation and isotope analysis** (Paterson, 1968, 1976a; Krouse and others, 1977; Paterson and others, 1977; Paterson and Clarke, 1978; Fisher, 1979, 1991; Paterson and Waddington, 1984; Fisher and Koerner, 1988, 1994; Fisher and others, 1996); **core particles and gases** (Lichti-Federovich, 1975; Koerner and Taniguchi, 1976; Koerner, 1977b; Koerner and Fisher, 1982; McAndrews, 1984; Barrie and others, 1985; Raisbeck and Yiou, 1985; Bourgeois, 1986, 1990; Cresswell and Herd, 1991; Koerner and others, 1991, 1998; Gregor, 1992; Nriagu and others, 1994; Sturges and others, 1998); **glacier flow** (Doake and others, 1976; Paterson, 1976b, 1977, 1985; Koerner and Fisher, 1979; Waddington and others, 1986; Reeh and others, 1987; Reeh and Paterson, 1988); **thickness and topographic measurements** (Oswald, 1975; Koerner, 1977c; Walford and others, 1977; Koerner and others, 1987; Haythornthwaite, 1988); **basal conditions** (Koerner, 1983; Gemmell and others, 1986; Fisher, 1987); and the **interpretation of records** (Fisher and others, 1983, 1985; Koerner and others, 1988; Illangasekare and others, 1990; Pfeffer and others, 1990; Clarke and Waddington, 1991). Attention was later directed to the Penny Ice Cap [168] on Baffin Island, where cores were taken and analyses made (Holdsworth, 1984; Short and Holdsworth, 1985; Fisher and others, 1998; Grumet and others, 1998).

__Figure 17.__—Photograph of the electro-mechanical ice-core drill being lowered into the borehole on top of the Devon Ice Cap in April 1998. The drill was used in a partially fluid-filled borehole to minimize core fracturing. Lamp oil was used as a fluid and is filtered and re-used during drilling operations. On ice caps where the ice at the top of the flow line is often about 300-m thick, core fracturing usually begins at a depth of about 150 m and consists of microfractures that obscure the stratigraphy. Geological Survey of Canada personnel working in the shelter tent are as follows: D.A. Fisher is at the control box on the right; C. Zdanovicz has his hand on the torque springs on the left; and R. M. Koerner is in the left foreground. The torque springs prevent the outer sonde casing and the cable from turning in the borehole. Geological Survey of Canada photograph.

McGill University continued the Axel Heiberg Island investigations after the end of the Jacobsen-McGill phase in 1962. Following the move of Fritz Müller to the Geographisches Institut, Eidgenössische Technische Hochschule in Zürich, the work was largely directed from Switzerland. Many excellent research reports and papers were written by expedition members (Maag, 1969; Iken, 1972, 1974; Müller and Iken, 1973; Müller, 1976; Alean and Müller, 1977; Hambrey and Müller, 1978; Arnold, 1981; Braithwaite, 1981; Weiss, 1984; Blatter, 1987a, b; Blatter and Hutter, 1991). Recently the work has been continued by Trent University on Baby [149] (Adams and Ecclestone, 1991; Tolland and others, 1991; Dicks and others, 1992; Adams and others, 1998) and White [153] (Jung-Rothenhäusler and others, 1992; Adams and others, 1995; Cogley and others, 1996b; Robertson, 1997) Glaciers, with some continuing involvement by McGill University on Thompson Glacier [152] (Parent, 1991; Lehmann, 1992; Moisan and Pollard, 1992). Earlier results have been compiled and carefully analysed (Glenday, 1989; Cogley and others, 1995, 1996a)

Changing priorities and reduced resources eventually led to the abandonment of the Arctic glacier program of the Snow and Ice Division. Study of Per Ardua Glacier [126], which had been handed over to this group on the termination of the DRB Operation Tanquary, was given up, as was a new project on Leffert Glacier [143] (Holdsworth, 1978), and a shorter term study of d'Iberville Glacier [140] (Holdsworth, 1975, 1977b). However, support subsequently became available for continuation of studies on the Ward Hunt Ice Shelf and new studies along the northern Ellesmere Island coast (Jeffries, 1982, 1984, 1986a, b, 1991, 1992; Jeffries and Serson, 1983, 1986;

Jeffries and Krouse, 1985; Jeffries and Sackinger, 1990; Jeffries and others, 1988, 1991; Lemmen, 1988; Sackinger and others, 1985; Stewart, 1991). [See section in this volume on Ellesmere Island Ice Shelves and Ice Islands.] The University of Heidelberg later mounted a small multidisciplinary expedition to investigate the Webber, Gnome, Dwarf, Midget, Arklio, Van Royen, Okpuddyshao, and Nukapingwa Glaciers at the head of Oobloyah Bay [129–136] (Barsch and King, 1981; King, 1983) and a glacier tongue in the neighboring Hare Fiord [128] (Römmer and Hell, 1986; Hell and King, 1988). Meanwhile, studies of some other glaciers on Ellesmere Island (fig. 18) had been initiated: on *Quviagivaa Glacier* [142] (Wolfe, 1995; Wolfe and English, 1996); around *Blackwelder Ice Cap* [138], on *Shirley Glacier* [137] and a revisit to Van Royen Glacier [136] (Smith, 1997); at the head of Phillips Inlet on *Muskox Glacier* [124] (Evans and Fisher, 1987; Evans, 1989, 1993; Evans and England, 1992); and the University of Alberta commenced regular visits to John Evans Glacier [141] (Woodward, 1996; Arendt, 1997; Woodward and others, 1997).

In the middle 1960's, following the Glacier Mapping Symposium held in Ottawa and from recommendations made by the NRCC's Subcommittee on Glaciers, the WSC switched to a program of terrestrial photogrammetry that involved mapping the ablation areas of their glaciers every 2 years (Campbell and others, 1969a, b; Reid and Shastal, 1970; Reid and Charbonneau, 1972, 1975, 1979a, b; Reid, 1973; Reid and others, 1978). Terminus and plaque surveys of the Saskatchewan and Athabasca Glaciers [92–93] were continued in the intermediate years by the Calgary office of the WSC (Warner and others, 1972; Canada, 1976, 1982).

The accessibility of the Columbia Icefield [94] (Harmon and Robinson, 1981), particularly the Athabasca (Kucera, 1972) 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 included investigations of **glacier chemistry** (Sharp and Epstein, 1958; Epstein and Sharp, 1959; Hallet, 1976; Mayewski and others, 1979), **glacier flow** (Meier and others, 1954; Meier, 1958a, b, 1960; Rigsby, 1958, 1960; Paterson, 1960, 1961, 1962, 1964, 1970; Paterson and Savage, 1963a, b; Savage and Paterson, 1963, 1965; Clee and others, 1969; Raymond, 1971a, b, 1973), **depth measurement** (Kanasewich, 1963; Neave and Savage, 1970; Goodman, 1973, 1975; Rossiter and others, 1973; Trombley, 1986), **glacial history** (Luckman, 1986, 1988, 1993), **photogrammetry** (Reid, 1961; Konecny, 1966; Paterson, 1966; Reid and Paterson, 1973; Kite and Reid, 1977; Reynolds, and Young, 1997), **remote sensing** (Østrem, 1973b; Gratton and others, 1990, 1993; Vachon and others, 1996); **resistivity** (Keller and Frischknecht, 1960, 1961), **sediment transport and erosion** (Mathews, 1964a, b; Iverson, 1991) and **temperature** (Paterson, 1971, 1972). Nearby studies have included the **hydrology** of the *Small River Glacier* [88] (Smart, 1992, 1998) and **glacierized alpine karst** (Smart, 1984, 1986, 1988; Smart and Ford, 1983, 1986; Worthington, 1991), **erosion and hydrological characteristics** of Decade Glacier [165] (Østrem and others, 1967), *Hilda Glacier* [98] (Hammer and Smith, 1983; Gardner and Bajewsky, 1987; Bajewsky and Gardner, 1989), *Boundary Glacier* [96] (Gardner and Jones, 1985; Jones, 1987; Sloan, 1987; Mattson, 1990; Mattson and Gardner, 1991) and Dome Glacier [97] (Gardner, 1992). A welcome development was the construction of a new Icefields Interpretative Centre in the middle 1990's (Waskasoo Design Group Limited, 1991)

The fortunate conjunction of a climbing camp in the St. Elias Range and the surge of the Steele Glacier [3] (Roots, 1967) led to studies of its cause (Bayrock, 1967; Nielsen, 1969; Stanley, 1969), spawned an influential symposium which outlined directions for future research (Ambrose, 1969), and helped generate grants for further work (Jarvis and Clarke, 1974; Clarke and Jarvis, 1976). Garry Clarke has focused much of his research effort on the elucidation of the problem of **surging glaciers**. Extremely detailed studies have been carried out on the Trapridge (*Hyena*), Backe (*Jackal*), Rusty (*Fox*), and Donjek Glaciers [4–7] (Classen and Clarke, 1971; Johnson, 1971, 1972; Hoffmann and Clarke, 1973; Clarke and Goodman, 1975; Jarvis and Clarke, 1975; Clarke, 1976, 1991, 1996; Collins and Clarke, 1977; Collins, 1980; Narod and Clarke, 1980; Clarke and Collins, 1984; Clarke and others, 1984, 1986b; Maxwell, 1986; Clarke and Blake, 1991; Blake and Clarke, 1992; Stone and Clarke, 1993, 1998; Fischer and Clarke, 1994, 1997; Murray and Clarke, 1995; Waddington and Clarke, 1988;

Figure 18.*—Ice field adjoining ice cap, Victoria, and Albert Mountains, east coast Ellesmere Island, Queen Elizabeth Islands, Nunavut (80°18'N., 74°21'W.); view to the east; John Richardson Bay is at top right and Kane Basin and Greenland in the background. NAPL T400L–201. From figure 2 in Prest, 1983, p. 13.*

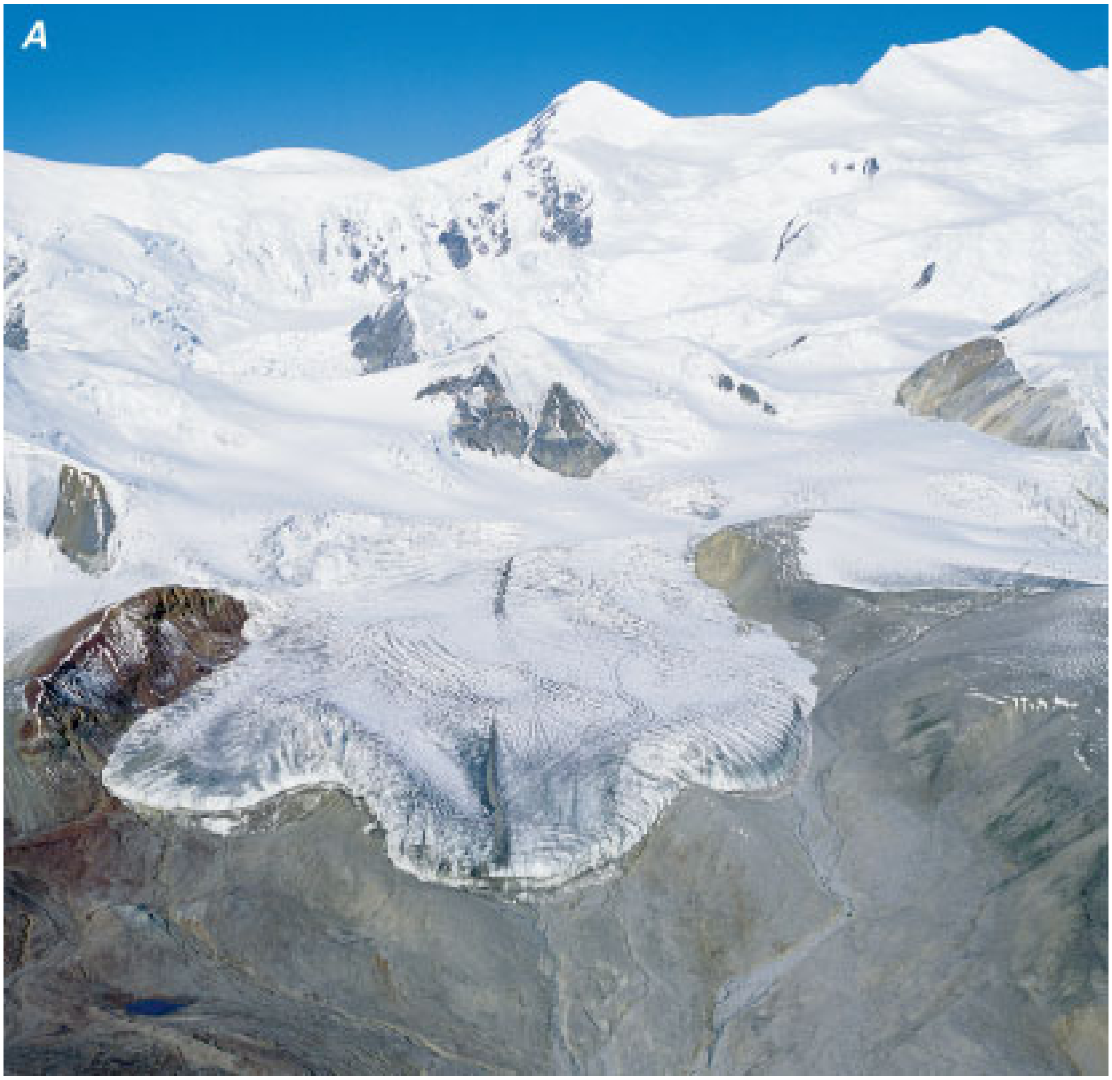


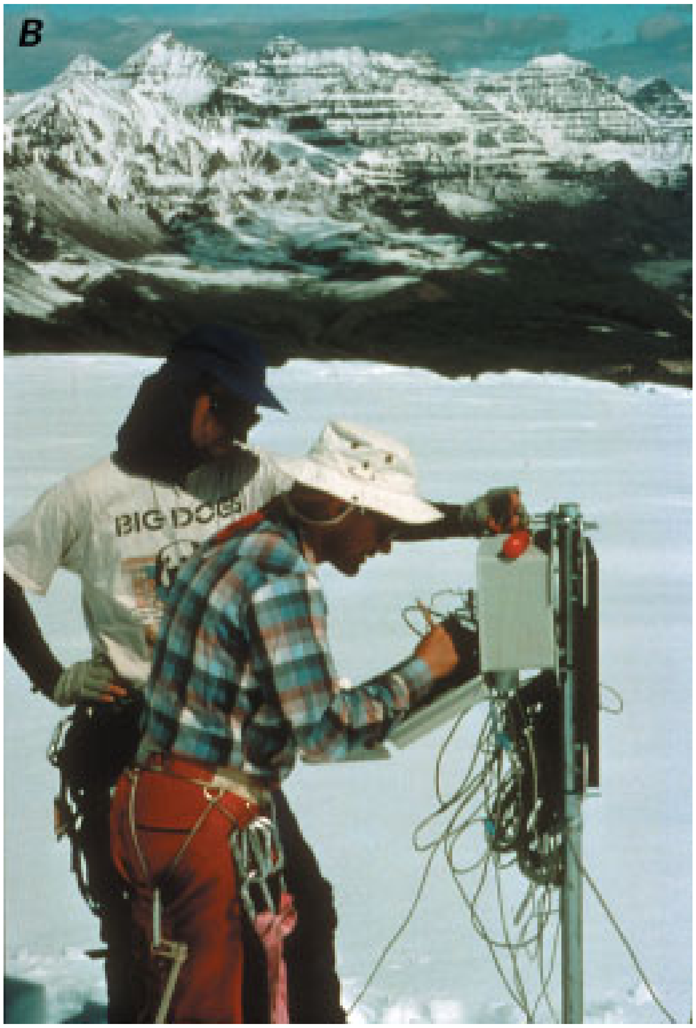
Figure 19.—**A**, *Oblique aerial photograph of Trapridge Glacier, Yukon, Canada, in August 1999. The peak in the background (top right) is Mount Wood. Photograph by Garry K.C. Clarke.* **B**, *(opposite page) Graduate students from the University of British Columbia connecting sensors to one of more than 20 data loggers operating year-round at Trapridge Glacier. Photograph by Garry K.C. Clarke, University of British Columbia. (Glacier 4 in table 1)*

Flowers and Clarke, 1999) (fig. 19). Other surging-glacier studies of have been made of the Tweedsmuir [14], Lowell [13] and Walsh Glaciers [8] (Post, 1966; Krimmel and Meier, 1975; Post and others, 1976), of Otto Glacier [127] (Hattersley-Smith, 1964, 1969a), Milne Glacier [122] (Jeffries, 1984), *Good Friday Bay Glacier* [154] (Müller, 1969), of the Barnes Ice Cap [164] (Holdsworth, 1973a, 1977c; Løken, 1969), and of the distribution of such features (Post, 1969). The most recent surge to attract substantial public attention was that of Hubbard Glacier [12] (Begley and White, 1986; Mayo, 1989; Trabant and others, 1991; Krimmel and Trabant, 1992).

Curiosity about the environmental effects of the large polynya known as the North Water, located at the head of Baffin Bay between Greenland and Ellesmere Island, prompted Fritz Müller to launch a major scientific program there. Although the focus was primarily on energy exchanges, sea ice, and atmospheric effects, mass-balance studies on Coburg Island, on *Wolf Glacier*, *Laika Glacier;* and *Laika Ice Cap* [146–148] (Berger and Müller, 1977; Blatter and Kappenberger, 1988), on Leffert Glacier, and on a neighboring unnamed glacier [143, 144] were started (Müller and others, 1974–80, 1977). A popular account of this work, and that on Axel Heiberg Island, was also published (Müller, 1981). Unfortunately, the unexpected death of Fritz Müller led to the premature termination of this project before all the analyses had been completed.

A later initiative by Karl Ricker, a private consultant, in conjunction with Bill Tupper of the British Columbia Institute of Technology, added

B



significantly to our knowledge of recent glacier variations in the Coast Mountains. Studies of glaciers (glacier numbers in table 1 shown in brackets for each mountain range) ranged from the St. Elias Mountains [16], through the Hazelton Mountains [34, 35], the Pacific Ranges [36–41], the Chilcotin Ranges [43, 44, 48–52], the Elaho Range [56–58], the Clendenning Range [59–61], and the Lillooet Ranges [64] to Garibaldi Provincial Park [63, 72–75] and Overlord Glacier [68] (Ricker, 1976, 1977, 1979, 1980, 1990; Tupper and Ricker, 1982; Ricker and others, 1983; Ricker and Jozsa, 1984; Ricker and Parke, 1984; Tupper and others, 1984, 1985, 1986; Ricker and Tupper, 1988, 1992, 1996). The extensive ice cover of parts of British Columbia means that geophysical surveys for mineral exploration are often conducted on and through glaciers; these have included *Ridge Icefield Glacier* [28] at McLymont Creek and Horstman Glacier [67] (J.P. Schmok, oral commun., 1991–93).

A valuable study was that begun by Robert Rogerson of Memorial University in 1981 on four glaciers in Labrador—Superguksoak, Abraham, Hidden, and Minaret Glaciers [173–176]. As small glaciers are expected to respond quite rapidly to changes in climate, and climatologists are predicting global warming as a result of the "greenhouse effect," the results, at the southeastern limits of glacier cover in Canada, would have been most interesting. Unfortunately, the program was concluded after only a few years (McCoy, 1983; Branson, 1984; Rogerson, 1986; Rogerson and others, 1986). However, Dan Smith of the University of Victoria started investigating the behavior of Moving Glacier [76] on Vancouver Island (Smith, 1994), which would be representative of the southwestern limits. While at the University of Saskatchewan, he had initiated a study of *Rae Glacier* [113] (Lawby and others, 1994), the most southerly of any glacier investigated in the Canadian Rocky Mountains.

In the Yukon Territory, Gerald Holdsworth, in conjunction with the AINA and their considerably reduced program in the Icefield Ranges, has been establishing the recent climate history of the southwest Yukon through the analysis of an ice core obtained from the 5,340-m-high plateau of Mount Logan [10] (fig. 20), (De la Barre, 1977; Holdsworth, 1977a, 1983, 1986a, 1990; Holdsworth and Jones, 1979; Holdsworth and others, 1984, 1989, 1991, 1992; Holdsworth and Peake, 1985; Pourchet and others, 1988; Monaghan and Holdsworth, 1990; Dibb and others, 1993; Holdsworth and Sawyer, 1993; Mayewski and others, 1993; Yang and others, 1995). Peter Johnson, together with staff and students from the University of Ottawa, has studied the glacier hydrology of the Grizzly Creek region and debris- and moraine-covered ice masses (Johnson, 1976, 1980a, b, 1981, 1983, 1984, 1985, 1991a, b, 1992, 1998; Lacasse, 1985; Johnson and David, 1987; Johnson and Lacasse, 1988; Kruszynski and Johnson, 1993).

Observations that cannot readily be subjected to either a systematic regional or chronological review are those on ice-dammed lakes and associated hazards. Their regional distribution on the mainland has been discussed by Post and Mayo (1971) and other general aspects reviewed by several authors (VanDine, 1985; Young, 1985; Evans, 1986; Shoemaker, 1991; Clague and Evans, 1994). The catastrophic drainage (jökulhlaup) of Summit Lake, dammed by Salmon Glacier [33], caused severe flooding downstream and washed out the access road to the Granduc Mine at Berendon Glacier [32] (Mathews, 1965, 1973; Gilbert, 1971; Fisher, 1973; Mathews and Clague, 1993). That of Ape Lake removed trees from a substantial area of forest downstream of Fyles Glacier [39] (Jones and others, 1985; Desloges and others, 1989; Desloges and Church, 1992). Other catastrophic events noted in British Columbia include those on Klattasine Creek associated with Cumberland Glacier [47] (Blown and Church, 1985; Clague and others, 1985) and on *Tim Williams Glacier* [29] (Evans and Clague, 1990). Detailed studies have been made on lakes associated with the surge-type Steele [3], Donjek [7] and Kaskawulsh [9] Glaciers (Collins and Clarke, 1977; Clarke and Mathews, 1981; Clarke, 1982; Liverman, 1987; Kasper and Johnson, 1991; Johnson and Kasper, 1992). To the south, the Tulsequah Glacier [20] flood was investigated by Marcus (1960). Hydropower feasibility investigations in the Stikine and Iskut River basins have included similar studies (Perchanok, 1980), particularly of the Flood Glacier [21] jökulhlaup (Mokievsky-Zubok, 1980b; Clarke and Waldron, 1984) (fig. 21). An interesting case study was that of the

Figure 20.—*Photograph of Mount Logan (5,959 m), St. Elias Mountains, Yukon Territory, Canada, from the ice-core drill site at Eclipse (3,017m) in June 1990. Photograph by Gerald Holdsworth, Arctic Institute of North America.*

Figure 21.—*Photograph of Flood Glacier, Coast Mountains, British Columbia, on 13 July 1979 showing the iceberg-filled lake dammed by the glacier. In August 1979, the lake drained catastrophically, causing severe flooding downstream. Photograph by Oleg Mokievsky-Zubok, National Hydrology Research Institute. (Glacier 21 in table 1)*

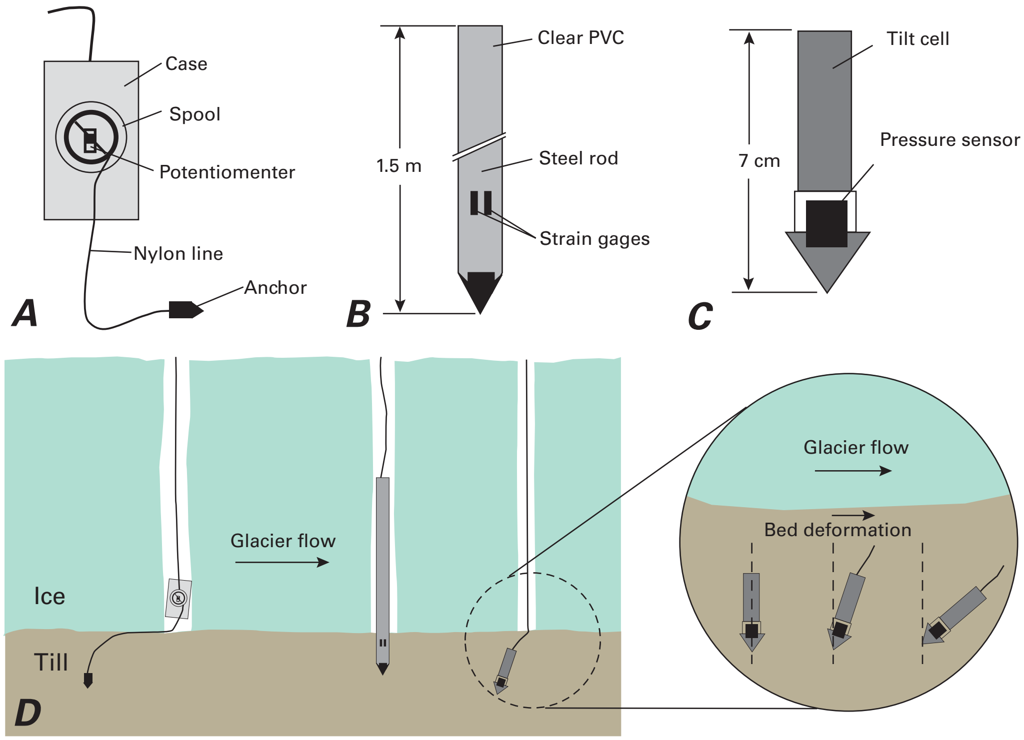


Figure 22.—*Bed instruments developed for studying the subglacial mechanical processes of Trapridge Glacier.* **A**, *Slidometer used to measure basal sliding rate.* **B**, *Ploughmeter used to measure the ploughing interaction between a glacier and a soft sedimentary bed.* **C**, *Tilt cell to measure the deformation of subglacial sediment.* **D**, *Schematic diagram (not to scale) showing the foregoing instruments installed near the ice-bed contact. Detail: Progressive tilting of a tilt cell in response to shear deformation of subglacial sediment. Diagram from Garry K.C. Clarke, University of British Columbia.*

Cathedral Glacier [109] jökulhlaup, whose debris flows periodically block the CPR railway and Trans-Canada Highway in Kicking Horse Pass (Jackson, 1979, 1980; Jackson and others, 1989). Such studies have not been limited to the mainland. Maag (1969) completed a comprehensive report on ice-dammed lakes and associated jökulhlaups in the expedition area of Axel Heiberg Island. Ricker (1962) has also reported on this area, and a later study was made by a McMaster University group along the margin of the Prince of Wales Icefield [145] on Ellesmere Island (McCann and Cogley, 1977; Blachut and McCann, 1981). Some environmental-impact studies have had a glaciological component that, carried out in connection with the proposed Alcan pipeline route in the Yukon, included a general study of glacier-dammed lakes in the St. Elias Mountains (Canada, 1977; Young, 1980). Studies on Tats Glacier [17] (J.P. Schmok, oral commun.,1990) were in connection with an impact assessment of the Windy Craggy development (Canada, 1990). In Alberta, a small glacier on Mount Cline [99] was assessed in response to a license application to mine the glacier for "pure" water and ice cubes (The Ice Age Co., 1989; Rains, 1990).

To complete this review, it is worth mentioning briefly that some of the field programs described above have prompted the development of new glaciological instruments and techniques. The geophysical group at the University of British Columbia, driven by the desire to measure Trapridge Glacier in even more detail, has been a leader in this area. Radars and ancillary equipment have been constructed (Narod and Clarke, 1983; Prager, 1983; Jones and others, 1989; Cross and Clarke, 1990), as well as devices for recording activity at the glacier bed (Blake and Clarke, 1991; Blake, 1992; Blake and others, 1992; Stone and others, 1993; Waddington and Clarke, 1995; Kavanaugh and Clarke, 1996) (fig. 22) and on the surface (Clarke and others, 1986a). One member of the group has gone on to develop instrumentation for use elsewhere (Blake and others, 1998). The current techniques used for mass-balance measurement in mainland Canada have been documented (Østrem and Brugman, 1991) and a conductivity measurement system automated for use in the Columbia River basin (Kite, 1994). A major contribution to the glaciological community has been Paterson's outstanding book on glacier physics (Paterson, 1994), now in its third edition.

The 21st Century

In the decade or so leading up to the end of the 20th century, there was a significant decline in governmental support of glacier research in Canada. At the end of the 20th century, systematic long-term mass-balance observations were being continued at Peyto Glacier [103] in the Rocky Mountains, Place Glacier [62] and Helm Glacier [69] in the Coast Mountains, and White Glacier [153] on Axel Heiberg Island, Canadian High Arctic, Nunavut (Haeberli and others, 1999), by the GSC under its new National Glaciology Programme. Three of the sites, one in the Rockies and two in the Coast Mountains, are low latitude and are unlikely to be representative of the full extent of these ranges. Old glacier sites may be revisited from time to time and additional glaciers added to the record as opportunities present themselves (for example, Bow [104] and *Robertson* [112] Glaciers (M. Sharp, oral commun., 2000). Airborne and satellite remote sensing and geographic information system (GIS) technology will be used increasingly in glaciological studies, such as the use of synthetic aperture radar (SAR) imagery in glacier-hydrology investigations of Place Glacier [62], Coast Mountains (Adam and others, 1997); Landsat Thematic Mapper (TM) and SAR imagery of Wapta Icefield and Peyto Glacier [103] (Brugman and others, 1996); airborne laser altimetry and interferometric SAR (InSAR) mapping of the Wapta Icefield (Demuth and others, 2001); areal and volumetric changes of the Prince of Wales Icefield and Devon Ice Cap using historical aerial photographs and Landsat 7 imagery (Burgess and others, 2001); studies of fluctuations of glacier termini on Axel Heiberg Island, using historical aerial photographs and satellite imagery (Cogley, 2001); and the Illecillewaet Icefield and Illecillewaet Glacier [80], *Interior Ranges* (see section on Mapping Glaciers in the *Interior Ranges* and Rocky Mountains with Landsat Data, by Roger D. Wheate, Robert W. Sidjak, and Garnet T. Whyte, in this volume). Improvements in spatial [reduction in size of picture elements (pixels)] and spectral (increase in the number and/or smaller band width) resolution of satellite sensors [for example Landsat 7 Enhanced Thematic Mapper (ETM+) (15-m pixels), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) (15-m pixels, stereoscopic capability; and 14 spectral bands on three sensors), and IKONOS (1-m pixels)] and the surface profile and elevation data to be acquired by ICESat (±1 m) after its planned launch in December 2002, will provide glaciologists with additional remote sensing datasets. The Global Land Ice Measurements from Space (GLIMS) is using ASTER and other satellite images to foster increased cooperation between regional centers.

The work in the Yukon Territory, by teams from the University of British Columbia and Ottawa University, will likely continue, but continued research may well be in doubt when the principal investigators retire. In the Arctic, the continuation of some of the smaller expeditions, on Axel Heiberg and Ellesmere Islands, is also in doubt. The Polar Continental Shelf Project provided the logistical support that has enabled scientists to work in remote areas of Nunavut for the last 40 years. Fortunately, the GSC's ice-coring project has been receiving sufficient support to continue acquiring data from existing core sites and even to obtain a new core from the Penny Ice Cap [168]. In 1998 and 1999, new ice cores to bedrock were obtained from Devon Island.

Looking to the future, it seems likely that water will return to the national agenda early in the 21st century. Recently there has been renewed public discussion in Canada about water exports. The gradual depletion of mountain reservoirs as the climate warms will alter not only the amount but also the timing of discharges. The switch from a glacial to a nival regime in some prairie rivers may adversely affect agriculture. The depletion of resources in central British Columbia potentially could lead to water-transfer disputes with the United States as flow in the Columbia River declines. If a warming climate creates more demand for energy, the hydroelectric-generating companies may be obliged to revisit some of their earlier proposals. All of these situations involve glaciers and may lead to the restoration of some previous studies and the initiation of new ones. However, as qualified and experienced scientists retire, a new generation of glaciologists will need to be trained.

Interest in past and present climates is expected to continue and even increase. Impact and adaptation studies funded by the Government of Canada's Climate Change Action Fund indicate renewed interest in water resources, including glacier hydrology. The Canadian CRYSYS (Cryospheric Systems Research Initiative), a Canadian contribution to the National Aeronautics and Space Administration Earth Observing System (EOS) Program, includes a glacier/ice cap theme as part of a government/university partnership. In the first decade of the 21st century, we will probably see a redrilling on the Agassiz Ice Cap [139]. Additional drilling programs are in the planning stage for Barnes Ice Cap, Baffin Island, and on Mt. Oxford, Ellesmere Island, Nunavat. After a long and patient wait we can also expect Trapridge Glacier [4] to surge and, thanks to all the preparatory work that has been done by Garry Clarke and his colleagues, to provide valuable new insights into the mechanism of surging glaciers, perhaps finally answering the question "why do some glaciers surge and what are the process(es) that cause some glaciers to surge?"

A promising recent development has been the establishment of a National Glaciology Programme (NGP) in the Terrain Sciences Division, Geological Survey of Canada (GSC), Natural Resources Canada. In 2001, a new ice core from a glacier on Mount Logan was obtained as part of this program. The NGP of the GSC also provides a national correspondent (Canada) to the World Glacier Monitoring Service, Zürich, Switzerland, who is responsible for the annual submission of glaciological data, including fluctuation of glaciers in Canada, and mass-balance data from the Place, Peyto, Helm, and White Glaciers. Glaciologists with the NGP (GSC) and the International Glaciological Society (Cambridge, England, U.K.) also provided information for the special issue of Canadian Geographic on Canada's glaciers (Anonymous, 1998), including a fold-out map on the Glaciers of Canada (Fick and others, 1998).

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