Glaciers of North America–

GLACIERS OF CANADA

MAPPING CANADA'S GLACIERS

By C. SIMON L. OMMANNEY

With a 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

SATELLITE IMAGE ATLAS OF GLACIERS OF THE WORLD

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

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Between the mid-1940's and the mid-1990's, seven 1:1,000,000-scale, forty-eight 1:500,000-scale (Glacier Atlas of Canada), and more than 110 miscellaneous scale (1:2,500- to 1:125,000-scale) maps of selected glaciers of Canada were completed by governmental and academic institutions; the types of maps include sketch, topographic, and stereo-orthophoto maps. Satellite images of glaciers and digital elevation models can be combined to produce maps (planimetric and topographic) and three-dimensional perspectives

CONTENTS

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Abstract

The extent and nature of the mapping of Canada's glaciers from the middle 1940's to the middle 1990's, covering terminus surveys and sketch maps to higher order, large-scale maps (Swiss-style publication quality) and stereo-orthophoto maps, are traced.

Introduction

In 1965, at the time of the first Symposium on Glacier Mapping, Canada was experiencing a remarkable flourishing of glacier-mapping activity. Papers at the symposium, by Blachut and Müller, and Konecny and Arnold (Gunning, 1966), reported on some of the developments at that time. The subsequent 20 years saw major developments in the large-scale mapping of Canada's glaciers, in which the Photogrammetric Research Section of the National Research Council of Canada (PRS-NRCC), the Department of Surveying Engineering of the University of New Brunswick, and the Glaciology Division of Environment Canada were the most significant contributors. A discussion of the maps produced by these agencies and others permits a general review of the growth and decline of this activity but does not necessarily reflect the overall history of glacier studies in Canada. In addition, there has been a replacement of the old system of mapping with a use of DEM and satellite images. Many of these maps appear in journal articles or reports and are in digital format.

Glacier Maps of Canada (1:1,000,000 Scale)

The decision to map Canada's glaciers at a scale of 1:1,000,000 arose

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TABLE 1.—*Glacier maps of Canada (1:1,000,000 scale)*

[Abbreviations used: DEMR, Department of Energy, Mines and Resources; DMTS, Department of Mines and Technical Surveys; GEOG, Geographical Branch; IWB, Inland Waters Branch; NTS, National Topographic Series]

Glacier map name	Number	Contours	Survey date	Production agency	Glacier representation
Southern British Columbia and Alberta	IWB 1000	none	date of NTS base map	GEOG, DMTS	Purple glaciers on white
NorthernBritishColumbiaandsoutheasternAlaska	IWB 1001	none	date of NTS base map	IWB, DEMR	Purple glaciers on white
Yukon Territory and District of Mackenzie	IWB 1002	none	date of NTS base map	IWB, DEMR	Purple glaciers on white
Southern Baffin Island and northern Labrador Peninsula	IWB 1006	none	date of NTS base map	IWB, DEMR	White glaciers on brown
Northern Baffin Island[1]	IWB 1005	none	date of NTS base map	IWB, DEMR	White glaciers on brown
Southern Queen Elizabeth Islands	IWB 1004	none	date of NTS base map	IWB, DEMR	White glaciers on brown
Northern Queen Elizabeth Islands	IWB 1003	none	date of NTS base map	IWB, DEMR	White glaciers on brown

[1] Included in map supplement to Journal of Glaciology, v. 9, no. 55, 1970.

from the need of the Geographical Branch, Department of Mines, to have small-scale maps available that were suitable for planning glaciological research and accurately depicting the geographic distribution of glaciers. A study was made in the middle 1960's on the representation of glaciers on topographic maps published at various scales, particularly how glacier information was generalized. Glaciers were delineated with heavy black-ink lines on the best available maps in 1965 and reduced to the common scale (Falconer and others, 1966). One surprise from the study was the conclusion that small-scale maps may depict glaciers better than large-scale maps (see fig. 2 in Falconer and others, 1966). The three maps of the western cordillera show glaciers in purple on a white background (a combination that was thought to give the best visual contrast, even for small glaciers), whereas on the four Arctic maps, glaciers are white on a brown background (Henoch and Stanley, 1968a, b, 1970; table 1). The maps have been used to complement the standard topographic maps (Henoch, 1969) primarily for plotting information such as glaciation levels, equilibrium lines, ice-cored moraines, transient snowlines, and glacier mass balance (Østrem, 1973; Miller and others, 1975); as base maps for the National Atlas of Canada (see Fremlin and Mindak, 1968); and for use in schools.

Glacier Atlas of Canada (1:500,000 Scale)

Much more detailed information on all glaciers was subsequently compiled through the Canadian glacier inventory. Until 1972, identification numbers and basin designations were published in individual sheets of the Glacier Atlas of Canada. Modified 1:250,000-scale National Topographic System (NTS) maps formed the basis for the four-color plates. Glaciers appear in a blue vignette within their hydrological basins, and the maps are bordered in brown (fig. 1). Ommanney (1980) described the program, and the maps published (Ommanney, 1989) are listed in table 2. The series was used in compiling the base map (1:2,000,000 scale) for the 5th edition of the National Atlas of Canada,[3] published at a scale of 1:7,500,000 on which glaciers are shown with a light purple vignette (Gosson, 1985), and subsequently for educational maps (Royal Canadian Geographical Society, 1998).

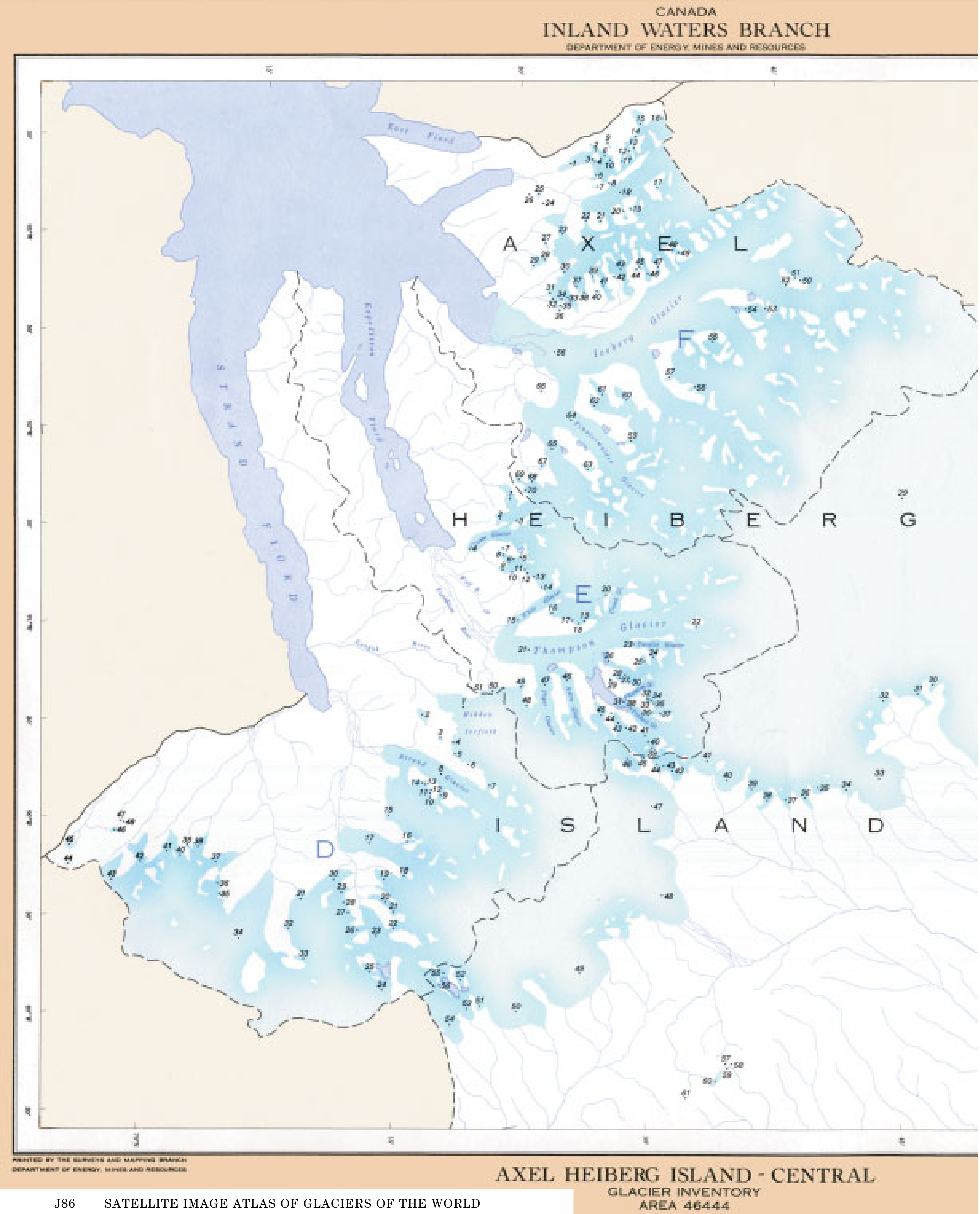
[3] The 6th edition of the National Atlas of Canada is available online at the following URL address: [http://atlas.gc.ca/].

TABLE 2.—*Glacier Atlas of Canada (1:500,000-scale Glacier Inventory Maps[1])*

[Abbreviations used: DEMR, Department of Energy, Mines and Resources; DOE, Department of the Environment; IWB, Inland Waters Branch; IWD, Inland Waters Directorate]

Plate no.	Name	Number	Date	Producer	Printer
ELLESMERE ISLAND					
1.1.1	Glacier Strait	IWD 1147	1972	DOE	DEMR
1.1.2	Starnes Fiord	IWD 1148	1972	DOE	DEMR
1.1.3	Sydkap Ice Cap	IWD 1149	1972	DOE	DEMR
1.1.4	Bjorne Peninsula	IWD 1150	1972	DOE	DEMR
1.2.1	Raanes and Svendsen Peninsulas	IWD 1151	1972	DOE	DEMR
1.2.2	Fosheim Peninsula	IWD 1152	1972	DOE	DEMR
DEVON ISLAND					
2.0	Devon Island	IWB 1146	1972	DOE	DEMR
2.1	Grinnell Peninsula	IWB 1144	1971	DOE	DEMR
2.2	Colin Archer Peninsula	IWB 1145	1971	DOE	DEMR
2.3	South West Devon Island	IWB 1138	1971	DOE	DEMR
2.4	Maxwell Bay	IWB 1136	1970	DOE	DEMR
2.5	Bear Bay	IWB 1140	1971	DOE	DEMR
2.6	Devon Ice Cap - South West	IWB 1143	1971	DOE	DEMR
2.7	Devon Ice Cap - North	IWB 1141	1971	DOE	DEMR
2.8	Devon Ice Cap - South East	IWB 1142	1971	DOE	DEMR
SVERDRUP ISLANDS					
4.0	Axel Heiberg Island	IWB 1129	1969	DEMR	DEMR
4.1	Southern Axel Heiberg Island	IWB 1106	1969	DEMR	DEMR
4.2	Central Axel Heiberg Island	IWB 1112	1969	DEMR	DEMR
4.3	Western Axel Heiberg Island	IWB 1115	1969	DEMR	DEMR
4.4	Northern and Eastern Axel Heiberg Island	IWB 1105	1969	DEMR	DEMR
BAFFIN AND BYLOT ISLAND					
5.0	Baffin Island	IWB 1100	1969	DEMR	DEMR
5.1	Bylot Island	IWB 1102	1969	DEMR	DEMR
5.2	Brodeur Peninsula	IWB 1104	1969	DEMR	DEMR
5.3	Borden Peninsula - West	IWB 1101	1969	DEMR	DEMR
5.4	Borden Peninsula - East	IWB 1103	1969	DEMR	DEMR
5.5	Milne Inlet	IWB 1109	1969	DEMR	DEMR
5.6	Tay Sound	IWB 1111	1969	DEMR	DEMR
5.7	Pond Inlet	IWB 1107	1969	DEMR	DEMR
5.8	Cambridge Fiord	IWB 1114	1969	DEMR	DEMR
5.9	Barnes Ice Cap	IWB 1116	1969	DEMR	DEMR
5.10	Gibbs Fiord	IWB 1117	1969	DEMR	DEMR
5.11	Sam Ford Fiord	IWB 1110	1969	DEMR	DEMR
5.12	Clyde Inlet	IWB 1113	1969	DEMR	DEMR
5.13	McBeth Fiord	IWB 1108	1969	DEMR	DEMR
5.14	Home Bay	IWB 1118	1969	DEMR	DEMR
5.15	Okoa Bay	IWB 1119	1969	DEMR	DEMR
5.16	Coronation Fiord	IWB 1121	1969	DEMR	DEMR
5.17	Padle Fiord	IWB 1126	1969	DEMR	DEMR
5.18	Hoare Bay	IWB 1123	1969	DEMR	DEMR
5.19	Kingnait Fiord	IWB 1122	1969	DEMR	DEMR
5.20	Penny Ice Cap	IWB 1120	1969	DEMR	DEMR
5.21	Popham Bay	IWB 1127	1969	DEMR	DEMR
5.22	Beekman Peninsula	IWB 1128	1969	DEMR	DEMR
5.23	Blunt Peninsula	IWB 1130	1969	DEMR	DEMR
5.24	Meta Incognita Peninsula	IWB 1124	1969	DEMR	DEMR
NELSON RIVER DRAINAGE BASIN					
7.0	Nelson River Drainage Basin	IWB 1135	1970	DEMR	DEMR
7.1	Oldman River	IWB 1132	1970	DEMR	DEMR
7.2	Bow River	IWB 1134	1970	DEMR	DEMR
7.3	Red Deer River	IWB 1133	1970	DEMR	DEMR
7.4	North Saskatchewan River	IWB 1131	1970	DEMR	DEMR
PACIFIC OCEAN DRAINAGE AREA					
8.8.1	Vancouver Island - South	IWB 113719	1971	DOE	DEMR
8.8.2	Vancouver Island - North	IWB 113919	1971	DOE	DEMR

[1] The first map in each complete series (numbered X.0) is a small-scale index map showing the distribution of subsequent maps.


CANADA
INLAND WATERS BRANCH
DEPARTMENT OF ENERGY, MINES AND RESOURCES
A X E L
H E I B E R G
I S L A N D
D
E
F
East Fiord
Strand Fiord
Expedition Fiord
Iceberg Glacier
Thompson Glacier
Strand Glacier
PRINTED BY THE SURVEYS AND MAPPING BRANCH
DEPARTMENT OF ENERGY, MINES AND RESOURCES
AXEL HEIBERG ISLAND - CENTRAL
GLACIER INVENTORY
AREA 46444

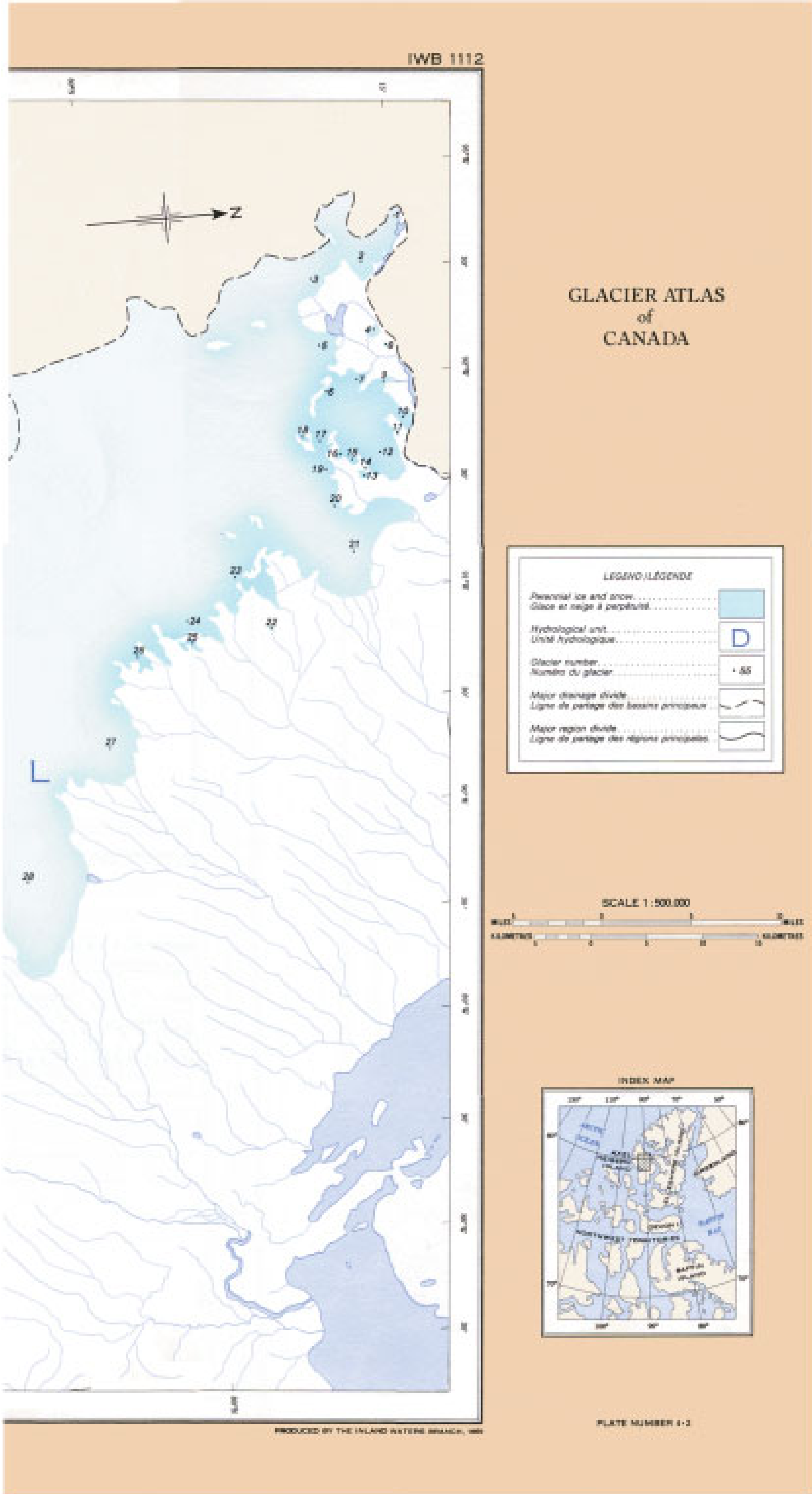


Figure 1.—*Part of Glacier Atlas of Canada, Plate No. 4.2, Map No. IWB 1112, Central Axel Heiberg Island, Nunavut, that includes the White Glacier (Glacier 46444E–15) and Thompson Glacier (Glacier 46444E–21). Map published in 1969 by the Inland Waters Branch, Department of Energy, Mines and Resources; scale 1:500,000 (see table 2 for other maps in the Glacier Atlas of Canada series).*

Water Survey of Canada

In 1945, the Dominion Water and Power Bureau, forerunner of the Water Survey of Canada (WSC), began annual surveys of 15 glaciers in western Canada to determine the effects of glacier variation on river runoff. The lower limits and activity of the glacier termini were measured from fixed points, and the movement and height change of the glacier surface were determined along a transverse profile of plaques in the ablation area. Glacier photographs and sketches of the relative changes were included in the annual reports of the district engineers, and some results were reported by Collier (1958). In 1950, the surveys became biennial and some surveys were terminated.

In 1959, the WSC carried out an aerial photogrammetric survey of Athabasca Glacier[4]; this was followed in 1962 by the University of New Brunswick terrestrial survey undertaken by Konecny (1964). The WSC decided that the latter technique was the most cost-effective and adopted it for future surveys of the Athabasca and Saskatchewan Glaciers in Alberta (1963 to 1979) and the Bugaboo, Kokanee, Sentinel, Sphinx, and *Nadahini*[4] Glaciers in British Columbia (1964 to 1978). Paterson (1966) assessed its accuracy and Reid (1973) discussed the procedures used. Maps were plotted at scales of 1:10,000 to 1:2,500 with topographic contours at 5 to 10 m on the ice, depending on glacier size (table 3). The biennial volumetric changes were also calculated and the maps and results published (Reid and Charbonneau, 1980, 1981). The map styles vary but generally use solid blue for ice, blue stipple for snow with blue-line contours on the glaciers; brown or gray contours are used outside the margins of the glacier. Only the exposed ice in the ablation area is mapped, however. Surveys of all these glaciers were terminated by 1980 (Reid, 1973; Reid and Charbonneau, 1980, 1981).

TABLE 3.—*Water Survey of Canada Glacier Map Series*

[DEMR, Department of Energy, Mines and Resources; DFE, Department of Fisheries and the Environment; DNANR, Department of Northern Affairs and National Resources; DOE, Department of the Environment; IWB, Inland Waters Branch; IWD, Inland Waters Directorate; UNB, University of New Brunswick; USGS, United States Geological Survey; WRB, Water Resources Branch]

Glacier map name	Number	Scale	Contours	Survey date(s)	Production agency	Glacier representation[1]
Athabasca Glacier		1:4,800		1 Aug 1959	WRB, DNANR	
Athabasca Glacier		1:4,800		1962	WRB, DNANR	
Athabasca Glacier	1–6	1:10,000	25/50/100 ft	26 Jul 1965	IWB, DEMR	C
Athabasca Glacier	2–6	1:10,000	25/50/100 ft	25 Jul 1967	IWB, DEMR	A
Athabasca Glacier	3–6	1:10,000	10/20/30 ft	25 Jul 1969	IWB, DEMR	A
Athabasca Glacier	4–6	1:10,000	5 and 10 m	12 and 16 Aug 1971	IWD, DOE	A
Athabasca Glacier[2]	5-6	1:10,000	5 and 10 m	3 Aug 1973	IWD, DOE	B, not all moraines shown
Athabasca Glacier	6–6	1:10,000	5 and 10 m	27 Aug 1975	IWD, DFE	A
Athabasca Glacier	7–6	1:10,000	5 and 10 m	13 Aug 1977	IWD, DFE	B, not all moraines shown
Athabasca Glacier	8–6	1:10,000	5 and 10 m	10 Aug 1979	IWD, DFE	A
Bugaboo Glacier	1–5	1:2,500	50 ft	9 Jul 1964	WRB, DNANR	C
Bugaboo Glacier	2–5	1:2,500	50 ft	4 Aug 1966	IWB, DEMR	C
Bugaboo Glacier	3A–5	1:2,500	50/100 ft	1 Aug 1968	IWB, DEMR	B
Bugaboo Glacier	3B–5	1:2,500	10/25 m	1 Aug 1968	IWB, DEMR	B
Bugaboo Glacier	4–5	1:2,500	10/25 m	18 Aug 1970	IWD, DOE	B
Bugaboo Glacier	5–5	1:2,500	10/25 m	29 Aug 1972	IWD, DOE	B
Bugaboo Glacier	6–5	1:2,500	10/25 m	24 Aug 1974	IWD, DOE	B
Bugaboo Glacier	7–5	1:2,500	10 m	21 Aug 1976	IWD, DFE	A
Bugaboo Glacier	8–5	1:2,500	10 m	19 Aug 1978	IWD, DOE	A

[4] 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.

TABLE 3.—*Water Survey of Canada Glacier Map Series*—Continued

[DEMR, Department of Energy, Mines and Resources; DFE, Department of Fisheries and the Environment; DNANR, Department of Northern Affairs and National Resources; DOE, Department of the Environment; IWB, Inland Waters Branch; IWD, Inland Waters Directorate; UNB, University of New Brunswick; USGS, United States Geological Survey; WRB, Water Resources Branch]

Glacier map name	Number	Scale	Contours	Survey date(s)	Production agency	Glacier representation[1]
Kokanee Glacier	1–4	1:2,500	20 ft	17 Aug 1964	WRB, DNANR	C
Kokanee Glacier	2–4	1:2,500	20 ft	7 and 8 Aug 1966	IWB, DEMR	C
Kokanee Glacier	3A–4	1:2,500	20/50 ft	5 and 6 Aug 1968	IWB, DEMR	B
Kokanee Glacier	3B–4	1:2,500	5 and 10 m	5 and 6 Aug 1968	IWB, DEMR	A
Kokanee Glacier	4–4	1:2,500	5 and 10 m	23 and 26 Aug 1970	IWD, DOE	A
Kokanee Glacier	5–4	1:2,500	5 and 10 m	24 and 25 Aug 1972	IWD, DOE	A
Kokanee Glacier[3]	8–4	1:2,500	5 m	17 Aug 1978	IWD, DOE	A
Nadahini Glacier	1–3	1:2,500	20 ft	26 Jul 1964	WRB, DNANR	C
Nadahini Glacier	2–3	1:5,000	20 ft	16 Aug 1966	IWB, DEMR	C
Nadahini Glacier	3A–3	1:5,000	20 and 50 ft	16 Aug 1968	IWB, DEMR	A
Nadahini Glacier	3B–3	1:5,000	5 and 10 m	16 Aug 1968	IWB, DEMR	A
Nadahini Glacier	4–3	1:5,000	5 and 10 m	3 Sep 1970	IWD, DOE	A
Nadahini Glacier	5–3	1:5,000	5 and 10 m	12 Aug 1972	IWD, DOE	A
Nadahini Glacier	6–3	1:5,000	5 and 10 m	16 and 17 Aug 1974	IWD, DOE	A
Nadahini Glacier	7–3	1:5,000	5 and 10 m	12 Aug 1976	IWD, DOE	A
Nadahini Glacier	8–3	1:5,000	5 and 10 m	10 Aug 1978	IWD, DOE	A
Saskatchewan Glacier[4]		1:24,000	50 ft	1954 and 1963	USGS, UNB, IWB	Blue/red overprint of 2 years
Saskatchewan Glacier[4]		1:20,000	10 ft	29 Jul 1963	IWB, DEMR, UNB	Black print, moraine stipple
Saskatchewan Glacier	1–7	1:10,000	20 ft	27 Jul 1965	IWB, DEMR	C
Saskatchewan Glacier	2–7	1:10,000	20 ft	26 Jul 1967	IWB, DEMR	A
Saskatchewan Glacier	3–7	1:10,000	10/50 ft	30 Jul 1969	IWB, DEMR	A
Saskatchewan Glacier	4–7	1:10,000	5 and 50 m	9 and 10 Aug 1971	IWD, DOE	B
Saskatchewan Glacier	5–7	1:10,000	5 and 50 m	1, 9, 10 Aug 1973	IWD, DOE	B
Saskatchewan Glacier	6–7	1:10,000	10/50 m	28 Aug 1975	IWD, DFE	B
Saskatchewan Glacier	7–7	1:10,000	10/50 m	14 Aug 1977	IWD, DFE	B
Saskatchewan Glacier	8–7	1:10,000	5 and 50 m	9 and 10 Aug 1979	IWD, DFE	B
Sentinel Glacier	1–1	1:2,500	20 ft	3 Sep 1964	WRB, DNANR	C
Sentinel Glacier	2–1	1:2,500	20 ft	21 Aug 1966	IWB, DEMR	C
Sentinel Glacier	3A–1	1:2,500	20 ft	24 Aug 1968	IWB, DEMR	A
Sentinel Glacier	3B–1	1:2,500	5 m	24 Aug 1968	IWB, DEMR	A
Sentinel Glacier	4–1	1:2,500	5 m	11 and 12 Sep 1970	IWD, DOE	A
Sentinel Glacier	5–1	1:2,500	5 m	20 Aug 1972	IWD, DOE	A
Sentinel Glacier[3]	8–1	1:2,500	5 m	15 Aug 1978	IWD, DOE	A
Sphinx Glacier	1–2	1:5,000	50 ft	3 Sep 1964	WRB, DNANR	C
Sphinx Glacier	2-2	1:5,000	25 ft	22 Aug 1966	IWB, DEMR	C
Sphinx Glacier	3A–2	1:5,000	25 ft	26 Aug 1968	IWB, DEMR	A
Sphinx Glacier	3B–2	1:5,000	10 m	26 Aug 1968	IWB, DEMR	A
Sphinx Glacier	4–2	1:5,000	10 m	9 and 10 Sep 1970	IWD, DOE	A
Sphinx Glacier	5–2	1:5,000	10 m	18 and 19 Aug 1972	IWD, DOE	A
Sphinx Glacier[5]	7–2	1:5,000	10 m	17 Aug 1976	IWD, DFE	A
Sphinx Glacier	8–2	1:5,000	10 m	13 Aug 1978	IWD, DOE	A

[1] A, Glaciers shown in a screened solid blue, off-ice areas in a solid buff color, contours on land and ice are gray with form lines used in the accumulation areas where adequate control is lacking. Seasonal snow cover and accumulation areas are shown in a blue stipple; old snout positions shown with a dotted line and the respective date. Symbols are used for measurement stakes and ablation mounds. B, Same as A but includes moraines depicted using a black stipple. C, Glaciers shown in a screened solid blue, off-ice areas are uncolored, contours on land are brown and on ice are blue with form lines used in the accumulation areas where adequate control is lacking. Seasonal snow cover and accumulation areas are shown in a blue stipple. Symbols are used for measurement stakes and ablation mounds. D, Glaciers shown in a screened solid blue, off-ice areas in a solid buff color, contours on land and ice are brown with form lines used in the accumulation areas where adequate control is lacking. Seasonal snow cover and accumulation areas are shown in a blue stipple, old snout positions shown with a dotted line and the respective date. Symbols are used for measurement stakes and ablation mounds. From 1976, the glacier maps were published in a bilingual format.

[2] Map included in supplement to 1970–1975 Permanent Service on the Fluctuation of Glaciers (PSFG) report (Müller, 1977).

[3] No maps made for 1974 and 1976 because of snow cover.

[4] Map included in supplement to Proceedings of Glacier Mapping Symposium (Gunning, 1966).

[5] No map made for 1974 because of snow cover.

Salmon Glacier

The PRS-NRCC has probably had a greater impact on glacier mapping in Canada than any other agency. Initially involved with the University of Toronto International Geophysical Year (IGY) Expedition, they developed and applied aerial photogrammetric techniques appropriate for mapping the lower part of Salmon Glacier (1:25,000/20 m),[5] British Columbia, and its terminus (1:12,500/20 m).[5] The color maps (five discrete colors) were published in conjunction with a detailed report on the survey by Haumann (1960). The photogrammetric base was used for assessing volumetric changes between 1949 and 1957. Details of these and subsequent maps discussed in the following paragraphs are shown in table 4.

TABLE 4.—*Miscellaneous glacier maps of Canada*

[Abbreviations: AINA, Arctic Institute of North America; ASE, Army Survey Establishment; BCIT, British Columbia Institute of Technology; DEMR , Department of Energy, Mines and Resources; DMTS, Department of Mines and Technical Surveys; DOE, Department of the Environment; DRB, Defence Research Board, Department of National Defence, Ottawa; EC, Environment Canada; ETH-Zürich, Eidgenössische Technische Hochschule, Zürich, Switzerland; FEC, Fisheries and Environment Canada; FGER, Foundation for Glacier and Environmental Research, Glaciological and Arctic Sciences Institute, Juneau, Alaska; Gestalt, Gestalt International Limited, Vancouver, B.C.; GD, Glaciology Division; IPTUK, Institut für Photogrammetrie und Topographie der Universität Karlsruhe, Germany; IWB, Inland Waters Branch; IWD, Inland Waters Directorate; McGill, McGill University, Montréal, Québec; NGS, National Geographic Society, Washington D.C., U.S.A.; NHRI, National Hydrology Research Institute; NRCC, Photogrammetric Section, Division of Physics, National Research Council of Canada; NVE, Norges Vassdrags-og Energiverk, Oslo, Norway; Parks, Parks Canada; SMB, Surveys and Mapping Branch, Department of Energy, Mines and Resources; TUH, Technical University of Hannover, German; UNB, University of New Brunswick; U of T, University of Toronto; AP, aerial photogrammetry; BP, bedrock portrayal; BW, black and white; MC, multi-colored; RS, relief shading; TP, terrestrial photogrammetry; mor., moraine; cont., contours; glac., glacier; struct., structural; crev., crevasses; unpub., unpublished; spot elev., spot elevations]

Glacier map name	Number	Scale	Contours	Survey date(s)	Production agency	Glacier representation
Athabasca Glacier						Orthophoto map
Baby Glacier		1:5,000	5 m	2 Aug 1960	McGill, NRCC, ASE	2-color, AP, mor. stipple
Berendon Glacier	IWB 1009	1:10,000	10/20 m	22 Aug 1968	IWB, DMTS	4-color, AP, blue/brown cont.
Glacier at Cathedral Peak		1:5,000	5 m	13 Aug 1975	FGER (1976), TUH	3-color, TP, RS, mor. stipple
Cathedral Massif Glacier and forefield		1:5,000	10 m	13 Aug 1975	Mauelshagen and Slupetzky (1985)	MC, AP, blue/brown cont.
Cathedral Massif, Atlin Provincial Park		1:20,000	100 ft		Cialek (1977)	
Centennial Range	M.C.R. 7	1:125,000	500 ft	from 1:250,000 maps	DEMR	4-color, AP, RS
Columbia Icefield	IWD 1011	1:50,000	20 m		NHRI, Parks, DOE	MC, RS, BP, AP + text
Crusoe Glacier Tongue[1]		1:5,000	5 m	2 Aug 1960	NRCC, McGill, DMTS	2-color, RS, blue glac., AP
Decade Glacier		1:10,000	10 m		IWB, DMTS	BW, AP, unpublished ozalid
d'Iberville Glacier		1:50,000	none		GD, EC	BW
Fox Glacier	115F/01	1:10,000	10 m		ASE, DMTS	AP, unpublished ozalid
Part of Grinnell Glacier		1:20,000	10/20 m		NVE (1991)	3-color, green glac., AP
Hare Fiord Glacier		1:20,000	20 m	1958 and 1978	Römmer and Hell (1986)	2-color, MC, blue glac., AP
Lowell Glacier		1:50,000	20 m	17 Aug 1974	IWD, DOE	3-color, RS on glac., AP
Meighen Ice Cap[1]	69H/560B	1:25,000	5 m	5 Aug 1960	DMTS	MC, AP, subglacier contours
Meighen Island N 1/2[1]	69G-H/560B	1:50,000	10 m	5 Aug 1959	DMTS	MC, AP, subglacier contours
Meighen Island S 1/2[1]	69 G-H	1:50,000	10 m	5 Aug 1959	DMTS	MC, AP, subglacier contours
Mount Logan		1:10,000	20 m	11 Aug 1972	IWD, FEC	2-color, AP, RS, BP
Mount Logan		1:10,000	20 m	1992	NHRI	BW, line map
Mount Logan		1:10,000	20 m	1993	AINA	2-color relief
The Massif of Mount Hubbard, Mount Alverstone, and Mount Kennedy		1:31,680	100 ft	1965	NGS© (1968), UNB, SMB	2-color (blue and gray), AP, RS, BP
Oobloyah Bay, Ellesmere Island		1:25,000	25 m	1959 and 1960	IPTUK	Orthophoto map

[5] Scale of map and contour interval on the glacier.

TABLE 4.—*Miscellaneous glacier maps of Canada*—Continued

Glacier map name	Number	Scale	Contours	Survey date(s)	Production agency	Glacier representation
Otto Fiord Glacier 1959[1, 2]		1:50,000	10 m	17 Aug 1959	DRB, UNB	BW, AP
Otto Fiord Glacier 1964[1, 2]		1:50,000	10 m	16 Aug 1964	DRB, UNB	BW, AP
Per Ardua Glacier[1]		1:20,000	10 m	17 Aug 1964	DRB, UNB	BW, AP
Per Ardua Glacier toe[1]		1:5,000	5 m	Jul 1964	DRB, UNB	BW, TP
Peyto Glacier Basin[3]		1:10,000	none	20 Aug 1966	NHRI, DOE, Gestalt	Stereo-orthophoto map, AP
Peyto Glacier	IWD 1008	1:10,000	10 m	20 and 22 Aug 1966	IWB, DEMR	MC, AP, BP, RS, 1st ed.
Peyto Glacier[3]	IWD 1010	1:10,000	10 m	20 and 22 Aug 1966	NHRI, DOE, DEMR	MC, AP, RS, BP, 2nd ed.
Peyto Glacier[4]		1:10,000	10 m	1984	NHRI	BW, line map
Place Glacier	92J/07E	1:10,000	10 m	7 Sep 1965	IWB, DMTS	3-color, AP, crevasses shown
Ram River Glacier	82N/16E	1:10,000	10 m	20 Aug 1966	IWB, DMTS	4-color, AP, RS, struct. shading
Rusty Glacier		1:10,000	10 m		ASE	
Salmon Glacier		1:25,000	20 m	Aug 1957	U of T, NRCC, ASE	MC, AP, mor. stipple, crev.
Salmon Glacier terminus		1:12,500	20 m	Aug 1957	U of T, NRCC, ASE	MC, AP, mor. stipple, crev.
Sentinel Glacier	92G/15W	1:10,000	10 m	7 Sep 1964	IWB, DMTS	4-color, AP, crevasses shown
Steele Glacier		1:25,000	20 m	Jul 1951	IWB, DMTS	BW, AP, unpub. ozalid, 2 sheets
Steele Glacier		1:25,000	20 m	Aug 1967	IWB, DMTS	BW, AP, unpub. ozalid, 2 sheets
Steele Glacier		1:50,000	50 m	Jul 1951	IWB, DMTS	BW, AP, unpub. ozalid, 1 sheet
Thompson Glacier Region		1:50,000	25 m	28 Jul, 13 Aug 1959	McGill, NRCC, ASE	MC, AP, RS, BP
Thompson Glacier Snout		1:5,000	5 m	2 Aug 1960	McGill, NRCC	2-color, AP, mor. stipple, crev.
Thompson Glacier Snout		1:5,000	10 m		McGill, NRCC	Orthophoto map
Thompson Glacier Snout		1:5,000	5 m		McGill, NRCC	Orthophoto map
Thompson Glacier		1:5,000	10 m	Aug 1977	ETH-Zürich	Orthophoto map
Trapridge Glacier		1:10,000	10 m		Nadir Mapping Corp.	
Tweedsmuir Glacier		1:50,000	20 m	1951	IWB, DOE	3-color, TP
Tweedsmuir Glacier		1:50,000	20 m	31 Aug 1974	IWB, DOE	TP, unpublished ozalid
Wedgemount Glacier		1:5,000	10 m	1973	Karl Ricker, BCIT	AP, BW, fluctuations shown
White Glacier[3]		1:2,500	spot elev.	17 and 26 Jun 1969	McGill	BW, TP, comparison plotting
White Glacier		1:5,000	5 m	2 Aug 1960	McGill, NRCC	MC, AP, RS, mor. stipple crev.
White Glacier[1]		1:10,000	10 m	2 Aug 1960	NRCC, McGill, DMTS	3-color, RS, blue glac., AP
Woolsey Glacier	82M/01E	1:10,000	10 m	20 Aug 1966	IWB, DMTS	MC, RS, AP

[1] Included in map supplement to Proceedings of Glacier Mapping Symposium (Gunning, 1966).
[2] Renamed Otto Glacier.
[3] Included in map supplement to the Permanent Service on the Fluctuation of Glaciers (PSFG) report 1970-1975 (Müller, 1977).
[4] Holdsworth and others (in press).

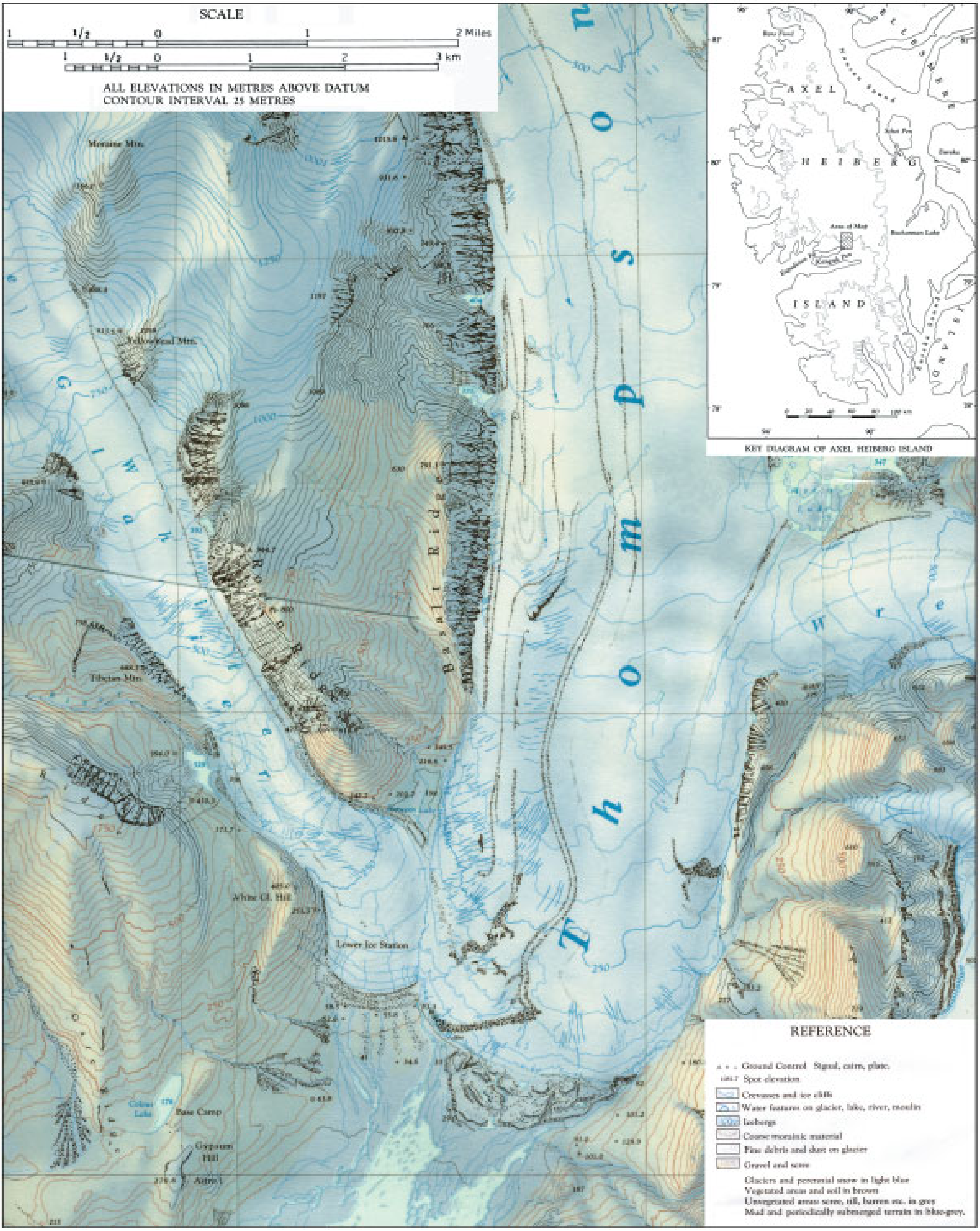

SCALE
2 Miles
3 km
ALL ELEVATIONS IN METRES ABOVE DATUM
CONTOUR INTERVAL 25 METRES
KEY DIAGRAM OF AXEL HEIBERG ISLAND
AXEL
HEIBERG
ISLAND
Area of Map
Thompson
White Glacier
Moraine Mtn.
Tibetan Mtn.
Basalt Ridge
White Gl. Hill
Lower Ice Station
Base Camp
Gypsum Hill
REFERENCE
Ground Control Signal, cairn, plate.
Spot elevation
Crevasses and ice cliffs
Water features on glacier, lake, river, moulin
Icebergs
Coarse morainic material
Fine debris and dust on glacier
Gravel and scree
Glaciers and perennial snow in light blue
Vegetated areas and soil in brown
Unvegetated areas scree, till, barren etc. in grey
Mud and periodically submerged terrain in blue-grey.

Figure 2.—*(opposite page) Part of Thompson Glacier Region map, Axel Heiberg Island, Nunavut; scale 1:50,000; contour interval 25 m. The map was the first glacier map in Canada to use eight colors, portray bedrock outcrops, and use relief shading.*

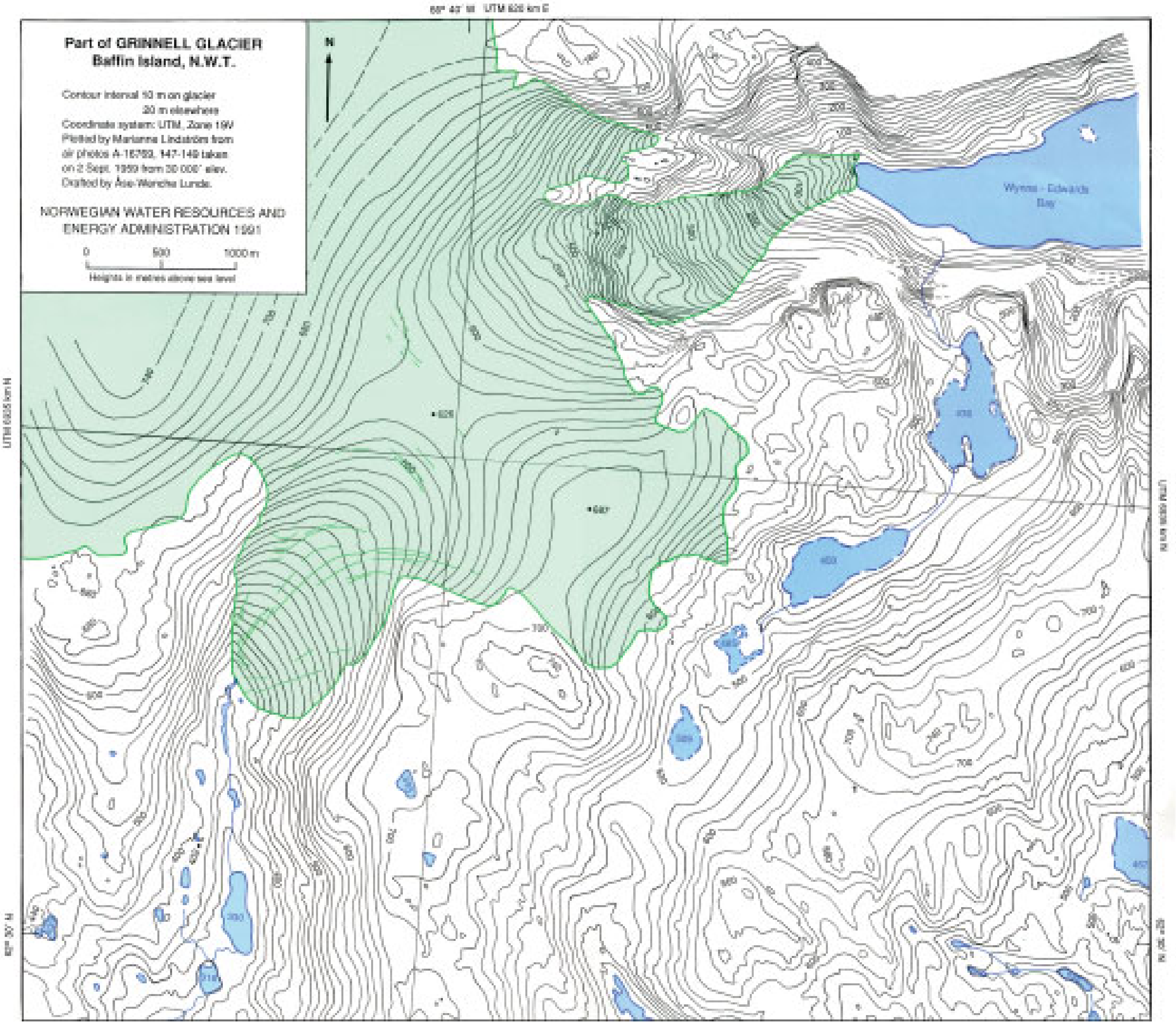
Glacier Maps of the High Arctic

After PRS-NRCC concluded the Salmon Glacier project, it became involved with the Jacobsen-McGill University Arctic Research Expedition to Axel Heiberg Island, Nunavut. This collaboration led to a remarkable set of maps, compiled using aerial photogrammetric methods; most of the maps were included in the report by Müller and others (1963). The Thompson Glacier Region map (1:50,000/25 m)[5] (fig. 2) was the first of its kind in Canada to combine eight colors, bedrock portrayal, and shading to create a strong visual impression of the landscape (McKortel, 1963). Large-scale glacier maps were made of Crusoe Glacier Tongue, Baby Glacier, and the Thompson Glacier terminus (1:5,000/5 m)[5] (fig. 3). All of White Glacier, the focus of the expedition's glaciological work, was mapped and printed in two colors (1:10,000/10 m),[5] and its terminus only (1:5,000/5 m)[5] in six colors (Haumann, 1963; McKortel, 1963). The maps were used as a base for much of the scientific work of the expedition (Blachut, 1963a, b; Blachut and Müller, 1966). An overview was provided by a smaller scale map of the expedition area (1:100,000/100 m).[5] In a subsequent experiment in the use of terrestrial photogrammetry for mass-balance determination, Arnold (1977, 1981) mapped the lowest 2 km of the White Glacier (1:2,500/5 m).[5]

To the west, the Surveys and Mapping Branch, Department of Energy, Mines and Resources, and the Polar Continental Shelf Project mapped Meighen Island (1:50,000/10 m)[5] and its ice cap (1:25,000/5 m),[5] using aerial photography taken 1 year apart (see fig. 9*B* in Glaciers of the High Arctic Islands in this volume), and compared the changes. An aspect not seen on any other Canadian glacier maps is that both the surficial and subglacial topography are contoured. The maps are multicolored and have been described by Arnold (1966).

On Ellesmere Island, the surging Otto Glacier was mapped twice by the Defence Research Board (1:50,000/10 m)[5] and the results reported by Konecny (1966). The terminus of d'Iberville Glacier was mapped (1:50,000 scale), but not contoured, in a project aimed at measuring displacement values of a tidewater glacier (G. Holdsworth, 1977; unpub. data). The changes in the ice shelves along the northern coast, surveyed and mapped by Jeffries and Serson (1986), did not result in a published topographic map (see subchapter on Ellesmere Island Ice Shelves and Ice Islands in this volume). In Hare Fiord, part of the ice tongue position in 1958 has been plotted against the 1978 position (Römmer and Hell, 1986).

Figure 3.—*The compound termini of the White Glacier, Axel Heiberg Island, Nunavut, High Arctic, Canada, in August 1964. The confluence of the two glaciers is marked by the medial moraine. View looking north-northeast across the outwash plain and source of the Expedition River. A low terminal moraine in front of White Glacier is visible in the center of the photograph. Photograph by C. Simon L. Ommanney, National Hydrology Research Institute. Maps of the area are shown in figures 1 and 2. A summary of historical information for White Glacier (153) and Thompson Glacier (152) is given in table 2 in the subchapter History of Glacier Investigations in Canada, by C. Simon L. Ommanney, this volume] [NTS map: 059H06].*



In southern Baffin Island, collaboration between Gunnar Østrem and the college in Iqaluit led to the mapping and publication of part of the Grinnell Glacier by Norges Vassdrags- og Energiverk (NVE) (1991) (fig. 4).

Figure 4.—**A**, *Map of part of the Grinnell Glacier, Baffin Island, Nunavut; reduced from original scale of 1:20,000; contour intervals 10 and 20 m. Published by Norges Vassdrags- og Energiverk (NVE) in 1991. The map is printed in three colors (black, blue, green), with the glacier and associated glaciological features (crevasses) shown in green. NVE pioneered the use of green to depict glaciers, instead of the conventional blue, reserving blue for hydrological features.* **B**, *see opposite page.*

IHD Glacier Maps

Canadian participation in the International Hydrological Decade (IHD) included mass- balance investigations on several glaciers in western Canada and the north for which metric maps at a scale of 1:10,000 with 10-m contours were required. Those of the Berendon, Place, and Sentinel Glaciers were printed in four process colors; in addition, the maps of Ram River and Woolsey Glaciers, both in National Parks, were embellished with shaded relief. The Peyto Glacier map is discussed later. The map of Decade Glacier, Baffin Island (1:10,000/10 m)[5] was not printed. Two maps were made of Per

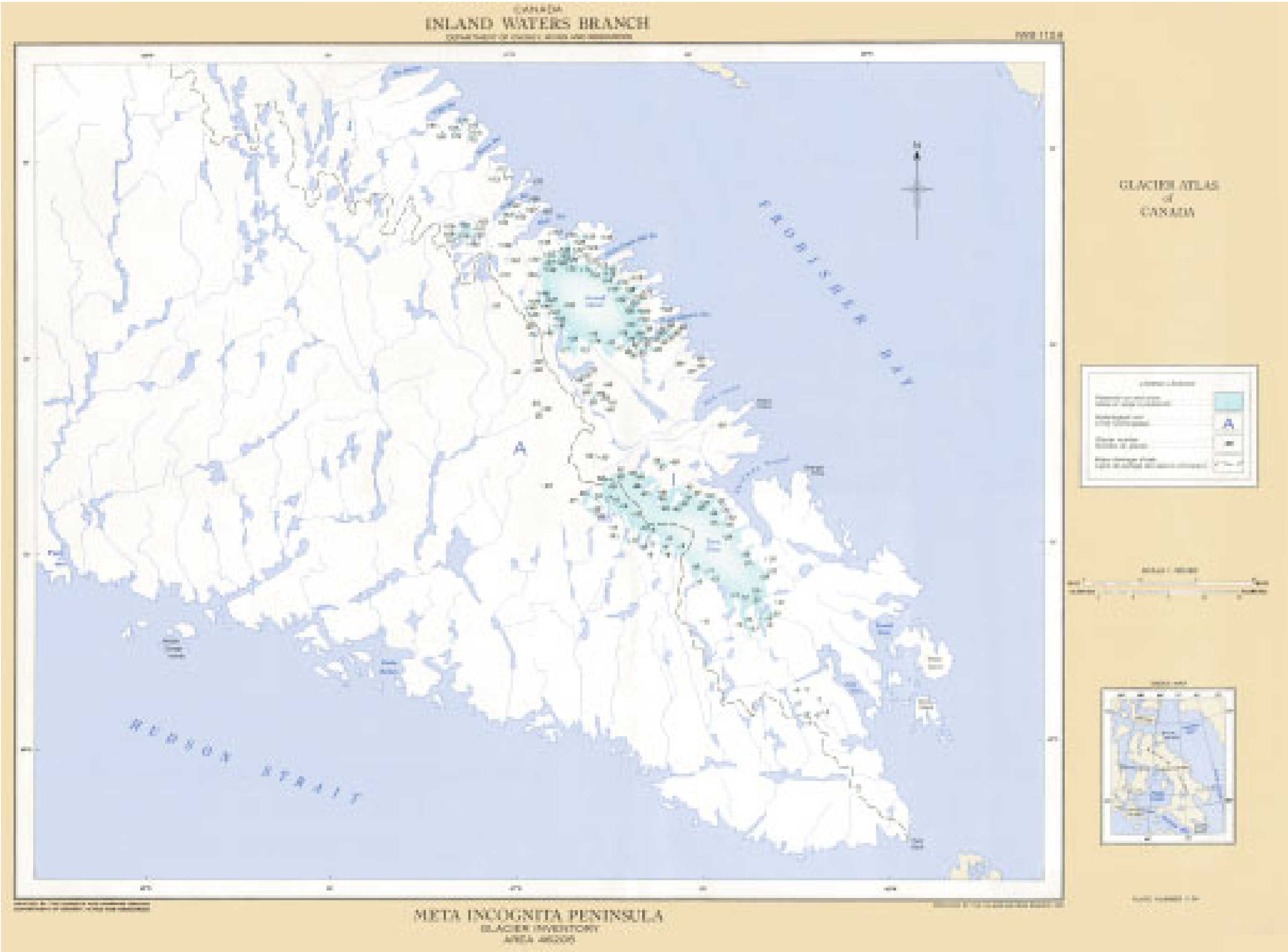


***Figure 4B**—Glacier Inventory Map (Area 46205) of the Meta Incognita Peninsula, showing the location of the Grinnell Glacier. Plate Number 5–24, Map No. IWB 1124, of the Glacier Atlas of Canada, 1969 (reduced from original scale).*

Ardua Glacier, Ellesmere Island, by Konecny (1966): the entire glacier (1:20,000/10 m)[5] and its tongue (1:5,000/5 m).[5] Maps of the Barnes Ice Cap were prepared by the Surveys and Mapping Branch as 1:50,000-scale NTS maps. Some were Arctic Provisional Maps with black contours, blue hydrography, and 25-ft contours; others were standard NTS maps with the ice shown in a blue vignette and dashed- brown 50-ft contours.

The original intent was to remap all IHD glaciers after the 10-year program was concluded to compare the accumulated mass balance with photogrammetrically determined volumetric change. This was not done, nor are there any plans to do so now. However, all glaciers in an east-west transect from Ram River Glacier to Sentinel Glacier were photographed almost simultaneously (22 to 24 August 1966). Some of the detailed glacier maps mentioned above and in tables 3 and 4 were compiled from this aerial photography. One of the objectives of the aerial photography was to map simultaneously the elevation of the transient snowline along the east-west transect (Østrem, 1973).

Miscellaneous Maps of Western Canada

Many individual glaciological projects require accurate maps for plotting results and determining changes in the glaciers. This was recognized quite early when the American Geographical Society (AGS) (1960) embarked on a project to map nine glaciers in North America, one of which was the *Little Jarvis Glacier* in the St. Elias Mountains, in a project that has been described in Brandenberger and Bull (1966). The AGS also sponsored termini mapping in Alaska by Bill Field that included the Grand Pacific Glacier, a Canadian glacier at the head of Glacier Bay (Field, 1966). Subsequent work in this region has resulted in a more general map of this glacierized area (Molenaar, 1990).

Steele Glacier, which surged during the Yukon Centennial Expedition of 1967, was mapped from 1951 aerial photography (1:50,000/25 m; 1:25,000/20 m)[5] and 1967 photography so that its velocity vectors could be plotted (Stanley, 1969). A four-color map of the Centennial Range (MCR-7, 1:125,000/500 ft),[5] that followed this expedition, had details of glaciological features normally omitted from NTS maps. Other surging glaciers in the Yukon and northern British Columbia have attracted considerable attention. The Army Survey Establishment compiled a map of Rusty Glacier (1:10,000/10 m).[5] In 1983, Nadir Mapping Corporation prepared a map of Trapridge Glacier (1:10,000/10 m)[5] for Garry K.C. Clarke, University of British Columbia.

Two maps of Tweedsmuir Glacier (1:50,000/20 m),[5] before- and after-surge, were produced under the direction of Gerald Holdsworth from 1951 aerial and 1974 terrestrial photography; the former was published in three colors. Finally, a three-color map of Lowell Glacier (1:50,000/20 m)[5] with moraine shading was prepared from 1974 photography in anticipation of a surge (see fig. 11 in Quantitative Measurements of Tweedsmuir Glacier and Lowell Glacier Imagery in the section about Glaciers of the St. Elias Mountains in this volume).

The Foundation for Glacier and Environmental Research (FGER), in collaboration with the Technical University of Hannover, Germany, has included mapping with its other studies of Cathedral Glacier near Atlin (1:5,000/5 m)[5] (Cialek, 1977; FGER, 1976; Mauelshagen, 1984; Mauelshagen and Slupetzky, 1985; Slupetzky and others, 1988).

A map of the northwest col of Mount Logan with hachured bedrock and relief shading (1:10,000/20 m)[5] was compiled in 1976 (Holdsworth and others, 1976) in connection with an ice core deep-drilling project there by Gerald Holdsworth of the Glaciology Division. It was subsequently modified in 1992 to include an area targeted for drilling in 2001 (Holdsworth and others, 1992). Two maps of the Mount Logan massif (1:75,000/40 m and 1:100,000/40 m)[5] were produced by Holdsworth and Sawyer (1993).

A joint project between the British Columbia Institute of Technology and Karl Ricker (1977) resulted in a map of Wedgemount Glacier (1:5,000/10 m).[5]

One of the finest North American examples of the cartographer's art is The Massif of Mount Hubbard, Mount Alverstone, and Mount Kennedy map (1:31,680/100 ft),[5] produced by the National Geographic Society with field surveys by the University of New Brunswick (Washburn and others, 1965; Washburn, 1971a, b). The two-color map with hachured bedrock and relief shading is a visual delight (fig. 5).

Peyto Glacier and Columbia Icefield

In 1970, a map of Peyto Glacier, Alberta, was published in nine colors using the French technique of bedrock portrayal (Sedgwick and Henoch, 1970) (1:10,000/10 m).[5] Subsequently, it was decided to experiment with the enhancement of this map to create a three-dimensional visual effect using the Swiss technique of hachured bedrock portrayal and shaded relief (Henoch and Croizet, 1976). The resultant map, published in 1975 at the same scale as the original edition, was printed in eight colors and accompanied by an explanatory booklet with the ensemble designed to cater to the scientist, teacher, and the general public.

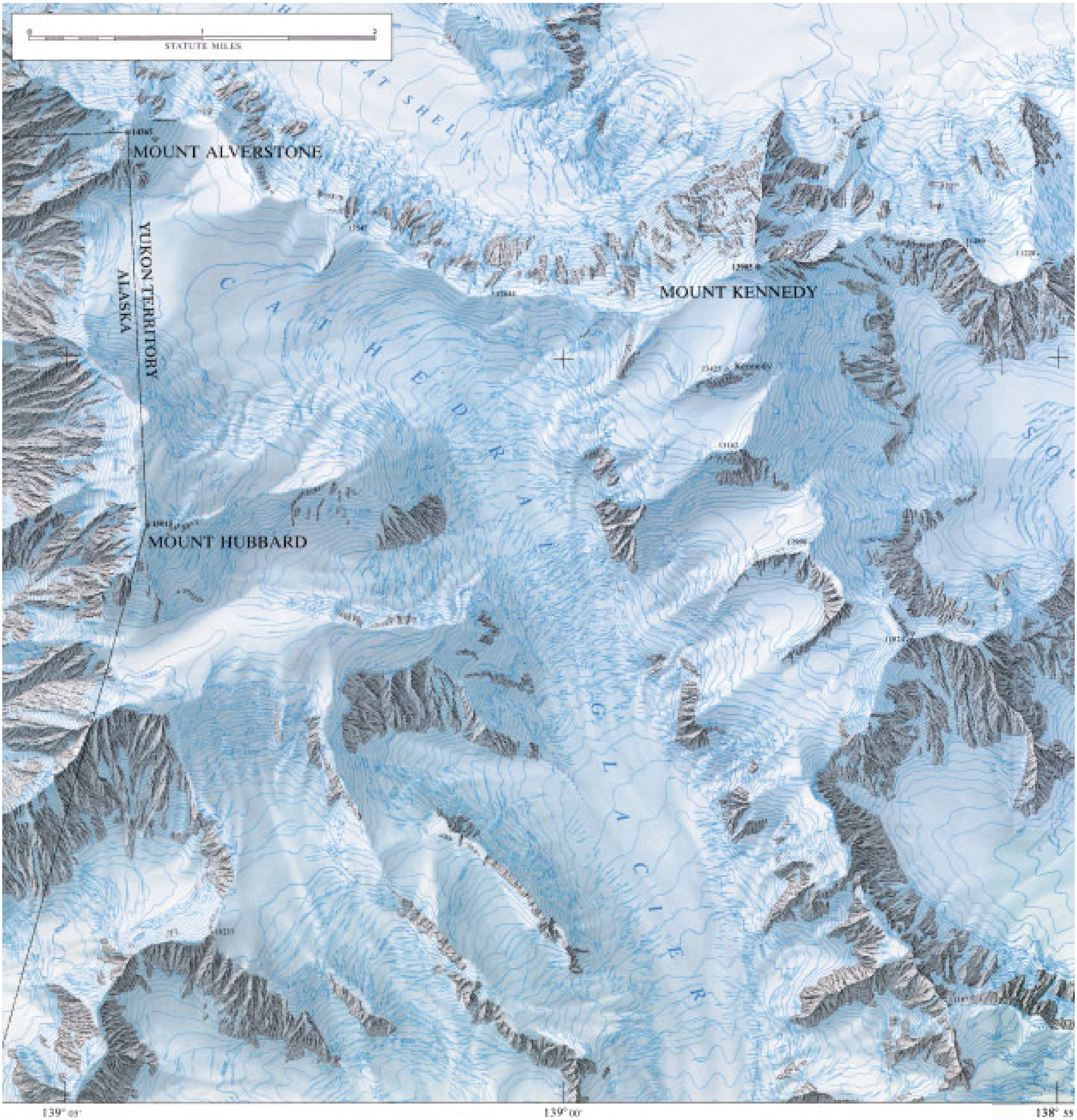


Figure 5.—Part of the Massif of Mount Hubbard, Mount Alverstone, and Mount Kennedy map, Yukon Territory, showing the highly glacierized terrain, including the source of the Hubbard and Lowell Glaciers. Map project directed by Bradford Washburn, Honorary Director, Boston Museum of Science. Published and copyrighted by the National Geographic Society (NGS), Washington, D.C., in 1968. Used with permission of Bradford Washburn and NGS. Reduced from original scale.

Following the success of the Peyto Glacier map, it was decided to experiment with a larger glaciological unit and a smaller scale, though continuing to apply the same cartographic techniques. The Columbia Icefield was selected as a joint project with Parks Canada in 1976. In 1981, a ten-color map with hachured bedrock portrayal, shaded relief, and interpretive information on the reverse side was published (1:50,000/20 m).[5]

Orthophoto Maps

Blachut and Müller concluded in 1965 that the orthophoto map would probably find extensive use in glaciological work (Blachut and Müller, 1966). Canadian experience has shown a trend toward this, although few of the resultant maps have been published or distributed widely. Once again PRS-NRCC has been a pioneer, producing stereo-orthophoto maps of Axel Heiberg Island glaciers in collaboration with Environment Canada and the Technical Universities of Vienna and Zürich: White Glacier (1:10,000/20 m),[5] Thompson Glacier and White Glacier termini (Institute of Cartography, 1998) (1:5,000/10 m)[5] (fig. 6), Crusoe Glacier terminus and Baby Glacier (1:5,000/10 m).[5] To the east, a map of Oobloyah Bay (1:25,000/25 m)[5] was prepared as a base map for the Heidelberg-Ellesmere Island Expedition 1978 (Hell, 1981).

In western Canada, the British Columbia Institute of Technology compiled a map of Wedgemount Glacier (1:10,000/20 m).[5] A stereo-orthophoto map of Peyto Glacier (1:10,000 scale) was prepared as part of a pilot study for the Forest Management Institute, Environment Canada, by Gestalt International, Ltd. Contours were not plotted on the map, but the elevation data were analyzed from the digital terrain model, which was a byproduct of the stereophotogrammetric-compilation process (Young and Arnold, 1978). The Gestalt system was further tested in the construction of three maps of the Columbia Icefield (1:25,000 scale) by the Surveys and Mapping Branch for the Glaciology Division using 1977 photography (Athabasca Glacier, Saskatchewan Glacier, Athabasca and Saskatchewan Glaciers). A larger scale map of Athabasca Glacier (1:5,000 scale), based on 1980 photography, was produced for the latter agency by Orthoshop of Calgary as part of a study of photogrammetric applications to mass-balance measurements.

Satellite Mapping

While the immediate future technology for glacier mapping in 1965 was the orthophoto map derived from aerial photographs, the current and future technology is based on satellite images and other remote-sensing devices (for example, satellite laser altimetry). Significant improvements in resolution (1-m pixel resolution of Ikonos) combined with stereo and all-weather capabilities [Synthetic Aperture Radar (SAR)] make this technology increasingly viable. The Surveys and Mapping Branch used Landsat images to revise their 1:250,000-scale NTS maps. Experiments have been carried out on the viability of using existing images to update glaciological information (Howarth and Ommanney, 1983), and some attempts were made to map with this technology (Sidjak and Wheate, 1999). The full range of potential applications has been documented in this volume and other volumes in the U.S. Geological Survey Professional Paper 1386, Satellite Image Atlas of Glaciers of the World.

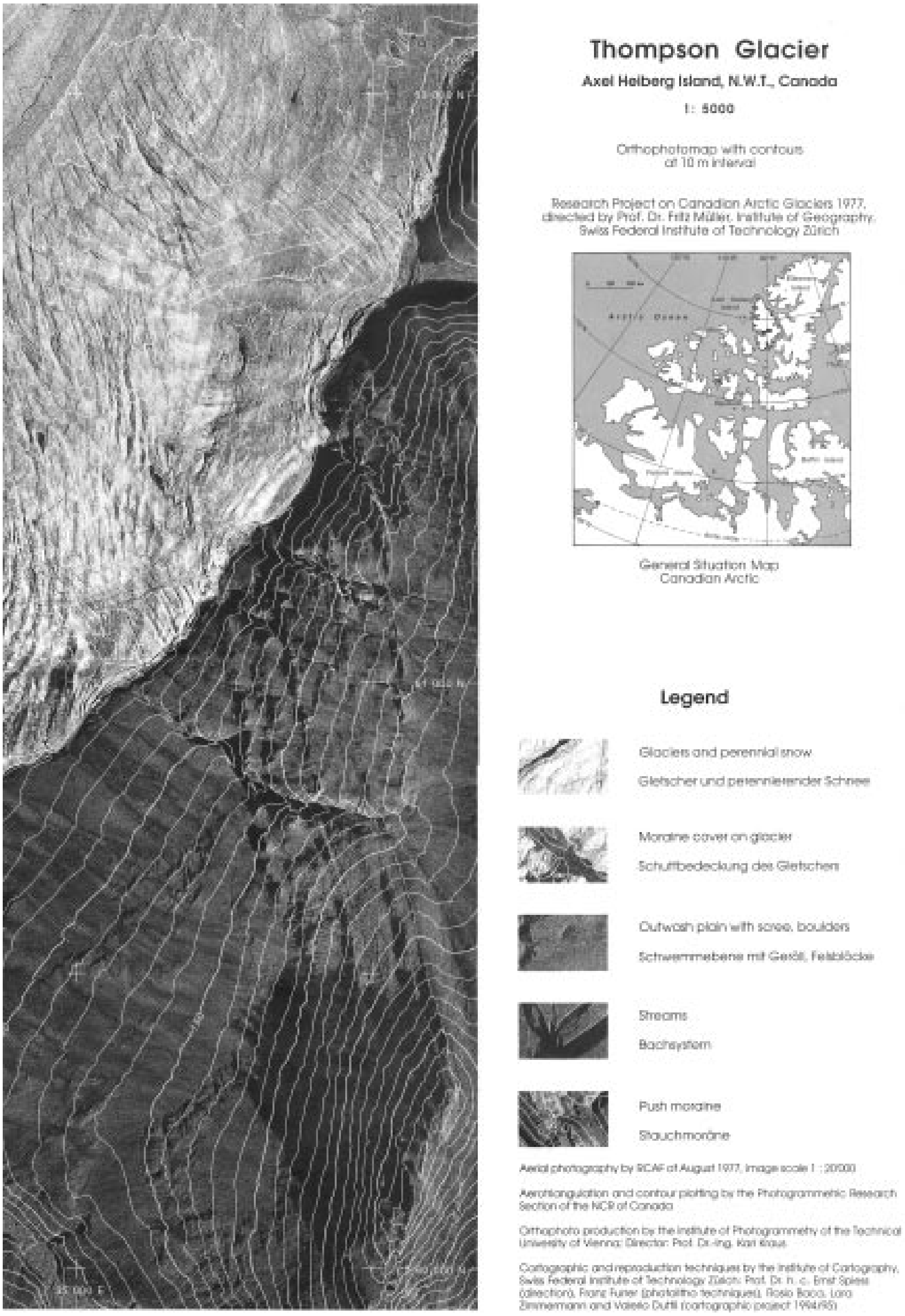


Figure 6.—*Orthophoto map of the Thompson Glacier termini, Axel Heiberg Island, Nunavut; reduced from the original scale of 1:5,000; contour interval 10 m. Map based on 1977 aerial photography by the Royal Canadian Air Force. Compiled in 1994/95 by the Institute of Cartography, Swiss Federal Institute of Technology, Zürich (Institute of Cartography, 1998).*

Mapping Glaciers in the *Interior Ranges* and Rocky Mountains with Landsat Data

By Roger D. Wheate, Robert W. Sidjak, *and* Garnet T. Whyte

Abstract

The areal extent and glacier facies of glaciers in Canada can be mapped effectively and monitored using satellite imagery especially where accessibility, size of ice mass, and large number of glaciers are limitations to conventional surveying methods. Glacier delineation, glacier facies, and surface details are enhanced by the use of specialized digital-imaging and analytical techniques, notably principal components analysis, the TM 4/5 ratio, and a normalized difference snow index (NDSI). The two examples illustrated here depict the glacier facies of the Illecillewaet Glacier, Columbia Mountains, *Interior Ranges*, British Columbia, and the retreat of the Monkman Glacier/Parsnip Glacier, Peace River, British Columbia, over a period of approximately 10 years. Retreat of glaciers in western Canada is clearly detectable using Landsat imagery with its good spatial resolution and decades of data acquisition, beginning with the launch of ERTS-1 (Landsat-1) on 23 July 1972. Three-dimensional perspectives can be produced by combining satellite images and digital elevation models.

Introduction

Glacier retreat represents a substantial change that is occurring in the Coast Mountains, *Interior Ranges*, and Rocky Mountains in western Canada. Topographic maps are revised at irregular intervals, but changes in areal extent of many Canadian glaciers and glacier facies may be significant on an annual basis. Glaciers in these mountains appear on 1:50,000- and 1:250,000-scale National Topographic System (NTS) and other map sheets. However, many of these sheets are based on glacier extent in the 1970's and 1980's and, thus, are generally outdated. Despite considerable cloud cover, it is usually possible to obtain cloud-free satellite images of western Canada during most years.

British Columbia Provincial Mapping

Glacier margins in digital format at the 1:250,000 scale for the Province of British Columbia (BC) were created in 1996 and are available to the public. The entire province has also been mapped at a scale of 1:20,000, using stereo aerial photogrammetric methods, as part of the Terrain Resource Inventory Management (TRIM) Program, which was completed between 1985 and 1996. Digital thematic datasets (layers) include glacier margins, but the accuracy of the glacier outlines may not always be reliable because of (1) masking by residual snowpack and (2) lack of experience in glacier mapping by cartographers whose primary experience is in forest-cover mapping. These two sources of error produced maps of glaciers that were initially incorrect and only become more so because of subsequent glacier changes in the more than 15 years since the mapping program began.

A second generation of mapping designed to update the changes since 1985, known as TRIM II, was begun in 1998 and is still in progress. Within the TRIM II program, orthophotographs have been produced for each 1:20,000-scale digital map quadrangle, each of which covers 12 min. longitude by 6 min. latitude (approximately 13 km x 11 km); there are 100 1:20,000-scale quadrangles in each 1:250,000-scale NTS sheet. However, an initial evaluation of some of these new data indicate that the use of early-summer aerial photography precludes the precise determination of glacier margins (concealment by snowpack). Hence, glacier-extent maps and precise location of ice-front positions for western Canada do not exist unless the glaciers were the subjects of special studies, such as Luckman and others (1987) (see also tables 1 and 4), which may now also be as dated as the first TRIM data.

The TRIM programs included the production of a digital elevation model (DEM), which contains sampled points from digital aerial stereophotogrammetry at approximately 50–70 m intervals along north-south transects, producing a 20-m contour interval. In many cases, the frequency of points decreases on glaciers because of the inability to determine elevation location under conditions of no contrast (for example, on a snow-covered glacier). Therefore, elevational inaccuracies are common in the accumulation areas of glaciers. Uncertainty in the accuracy of the DEM also complicates the calculation of the position of the equilibrium line altitude (ELA). Lodwick and Paine (1985) experimented with deriving elevation data directly from Landsat MSS data for the Barnes Ice Cap by applying principal components analysis (PCA) and utilizing the information contained in the lower components. However, their encouraging results have not been pursued with the higher resolution and spectral range of either Landsat Thematic Mapper (TM) or Enhanced Thematic Mapper (ETM+) data.

Satellite Image Data

Satellite imagery offers the dual advantages of repetitive coverage and multispectral remote sensing for updating glacier maps. The first increases the likelihood of obtaining cloud-free and snow-free scenes in mountainous areas at the latitude of western Canada and proximity to the coast, a region which typically experiences both frequent cloud cover and remnant snowpack most of the year. Ideally, satellite images are best obtained at the end-of-the-melt season, in late August to early September, to minimize snow cover, while avoiding shadows cast by the lower Sun angles in the autumn. Landsat TM data have so far offered the best combination of spatial resolution and spectral selection compared to other available sensors, such as the Système Probitoire d'Observation de la Terre (SPOT) and the Indian Remote Sensing (IRS) satellites, especially the inclusion of mid-infrared (IR) wavelength bands. The potential role of these bands [TM bands 5 (1.55µm–1.75µm) and 7 (2.08µm–2.35µm)] is based on the lower reflectance of snow and ice, in comparison to the higher reflectance and often complete saturation in the visible wavelengths. Landsat data have been shown to be effective in the mapping of the areal extent of glacier facies, including ice, wet snow, and snow (Williams, 1987; Williams and others, 1991). The 30-m picture-element (pixel) resolution has proven to be adequate here for monitoring glaciers with an area of 10 km^2 and greater, and for changes over periods of 4–5 years, as was also determined by Bayr and others (1994) in the Austrian Alps and for longer time periods in Iceland (Williams, 1986; Hall and others, 1992; Williams and others, 1997).

Digital-Image Processing for Glacier Mapping

Challenges facing the automated mapping of glacier areas include discrimination of the glacier facies, identification of debris-covered ice, topographically and cloud-shadowed areas, and water bodies marginal to the glaciers. Although glacier margins can be readily discerned visually using an optimum color composite of TM bands 3 (0.63µm–0.69µm), 4 (0.76µm–0.90µm), and 5 [or one in each part of the visible (0.4µm–0.7µm), near-IR (0.7µm–1.5µm), and mid-IR (1.5µm–8.0µm) wavelengths], the following image spectral bands and processes have been shown to greatly increase delineation of glacier facies and margins (Sidjak and Wheate, 1999).

PCA has been employed to reduce data redundancy due to correlation between TM bands and to enhance contrast in features of interest. The second principal component (PC2) is usually influenced by the mid-IR bands 5 and 7 and cleanly isolates glacier from nonglacier surfaces, unless the surface is covered with morainic material. PC4 displays more detail on the glacier surface than any of the TM bands; this has been suggested to be related to snow grain size (Brugman and others, 1996). The second component (PC2) can also be used to generate a mask to eliminate nonglacier surfaces in further analysis.

Pixel saturation is recognized as a typical problem over glacierized and snow-covered scene areas, particularly in the visible bands [Landsat TM bands 1 (0.45μm–0.52μm), 2 (0.52μm–0.60μm), and 3 (Hall and others, 1988)]. PCA reduces this problem by identifying most of the scene-brightness variance, and thus the saturation, within the first principal component (PC1). Subsequent principal components, especially the second, third, and fourth, usually depict strong, unsaturated contrast over the glacier areas, enhancing surface features and facies. Further image processing has involved the normalized difference snow index (NDSI) (Riggs and others, 1994) where NDSI = (TM2–TM5)/(TM2+TM5). The TM4/TM5 ratio has also been cited by Hall and others (1987) as effective for discriminating the ice-and-snow facies, particularly in areas of shadow.

Illecillewaet Névé and Illecillewaet Glacier

Illecillewaet Glacier (lat 51°14'N., long 117°27'W.) is the best known glacier in Glacier National Park, Columbia Mountains, east of the town of Revelstoke, B.C., and directly accessible from the Trans-Canada Highway. In the early 20th century, it formed the backdrop to a mountain lodge and was a popular climbing attraction. Champoux and Ommanney (1986) studied

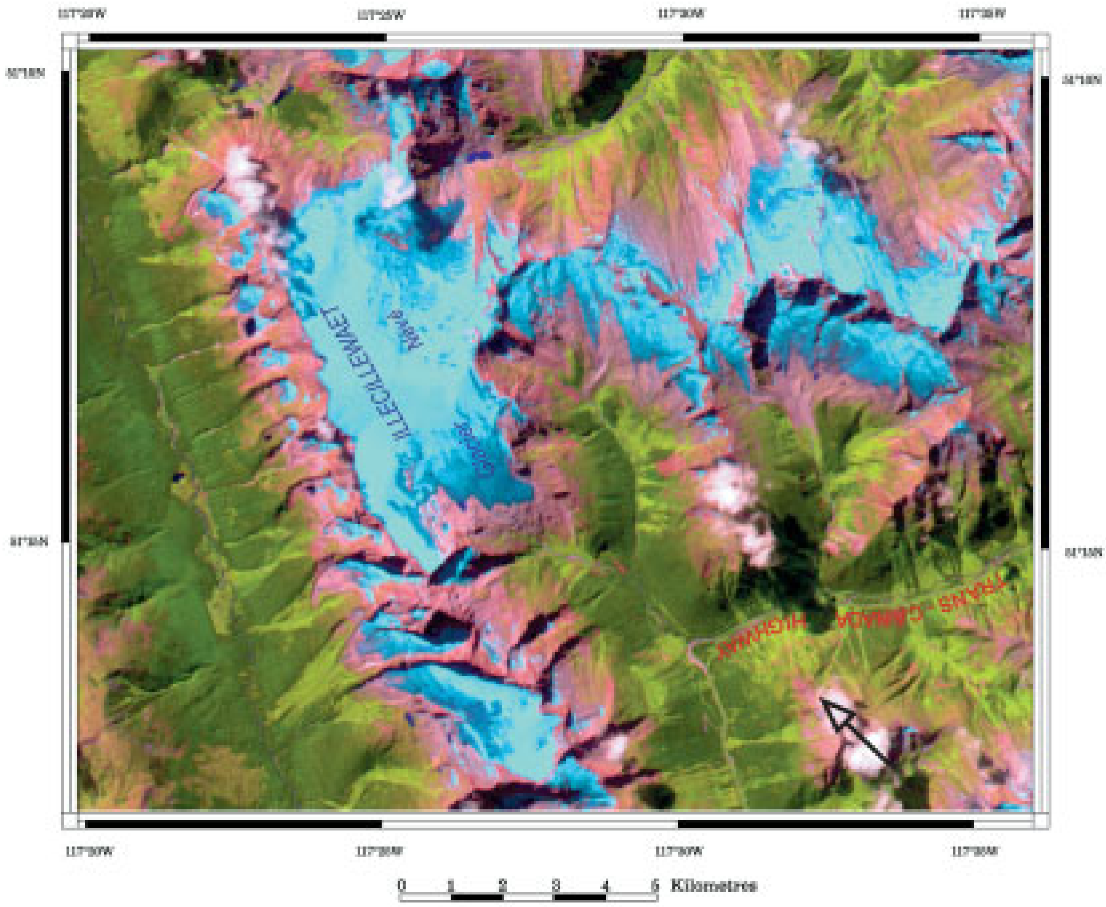
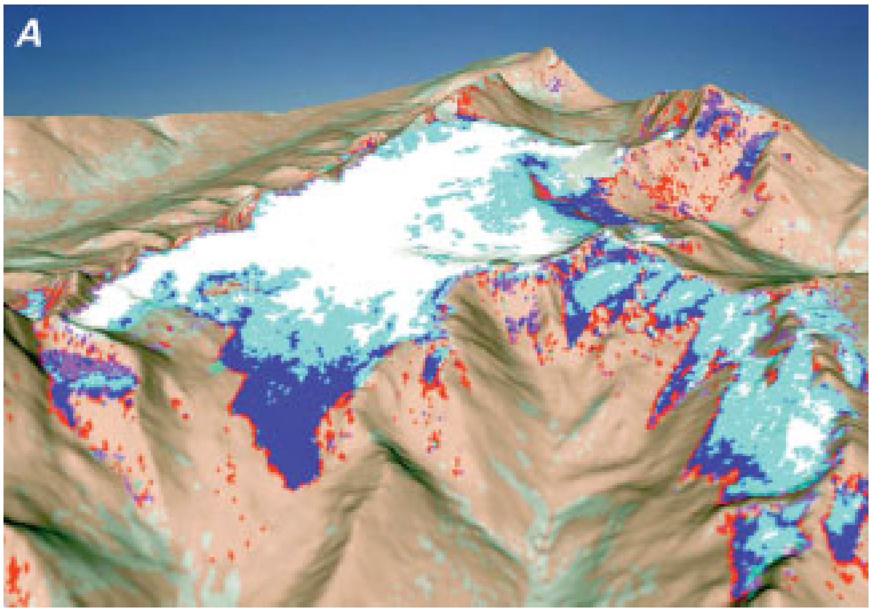


***Figure 7.**—Landsat 5 TM false-color composite image of the Illecillewaet Névé and Illecillewaet Glacier. The band combination is optimum for defining glacier extent. The image is oriented with south at the top. The Trans-Canada Highway is visible in the northwest corner of the image. The arrow indicates the perspective of the view shown in figure 8. Landsat 5 image (50440240094230T0; bands 3, 4, 5; 18 August 1994; Path 44, Row 24) from RADARSAT International, British Columbia.*

Figure 8.—**A**, *Perspective view of the Illecillewaet Glacier seen from the Trans-Canada Highway looking toward the southeast. The view is created by combining the Landsat image shown in figure 7 with the Province of British Columbia DEM. The following glacier facies are shown: accumulation area (snow): white; firn/wet snow: medium blue; bare ice (ablation area): dark blue; debris-covered ice: red; shadowed glacier: purple; meltwater lakes: green. Nonglacier surfaces are shown in gray (forested) and pink/salmon (nonforested).* **B**, *Photograph of the terminus of the Illecillewaet Glacier looking northwest from a position southeast of the Trans-Canada Highway, west of Rogers Pass, Glacier National Park, British Columbia, in August 1995. Photograph by Robert W. Sidjak, University of Northern British Columbia.*



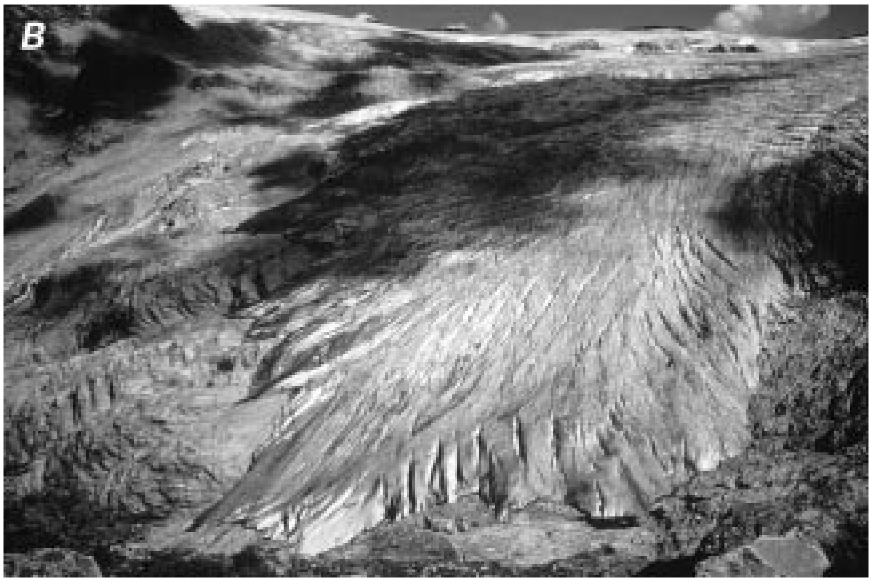


TABLE 5.—*Selected glaciological parameters of the Illecillewaet Névé and Illecillewaet Glacier*

	Illecillewaet Névé	Illecillewaet Glacier
Accumulation area	13.04 km^2	4.92 km^2
Ablation area	8.35 km^2	3.91 km^2
Total area	21.39 km^2	8.83 km^2
Accumulation-area ratio	0.61	0.56

the evolution of Illecillewaet Glacier using historic data, aerial photography and satellite imagery. This study uses the above Landsat combination (TM4/TM5 ratio) of spectral bands to classify the following glacier facies and give the best estimate of transient snowline and equilibrium line location: snow (accumulation area), bare ice (ablation area), from which the accumulation-area ratio (AAR) can be calculated (see table 5); water, shadowed glacier, and debris-covered ice (recognized as a significant challenge in glacier-inventory mapping by Whalley and Martin, 1986). The Landsat 5 TM false-color composite image (50440240094230T0; bands 3, 4, 5; 18 August 1994; Path 44, Row 24) is shown in figure 7. The computer-classified image is draped on the B.C. provincial DEM in figure 8*A*, as viewed from the northwest, a similar direction from the ground photograph (fig. 8*B*). Snow (accumulation area) is shown in white, bare ice in dark blue, and firn/wet snow in medium blue. There are a few scattered clouds on the south end of the icefield (white on figure 7).

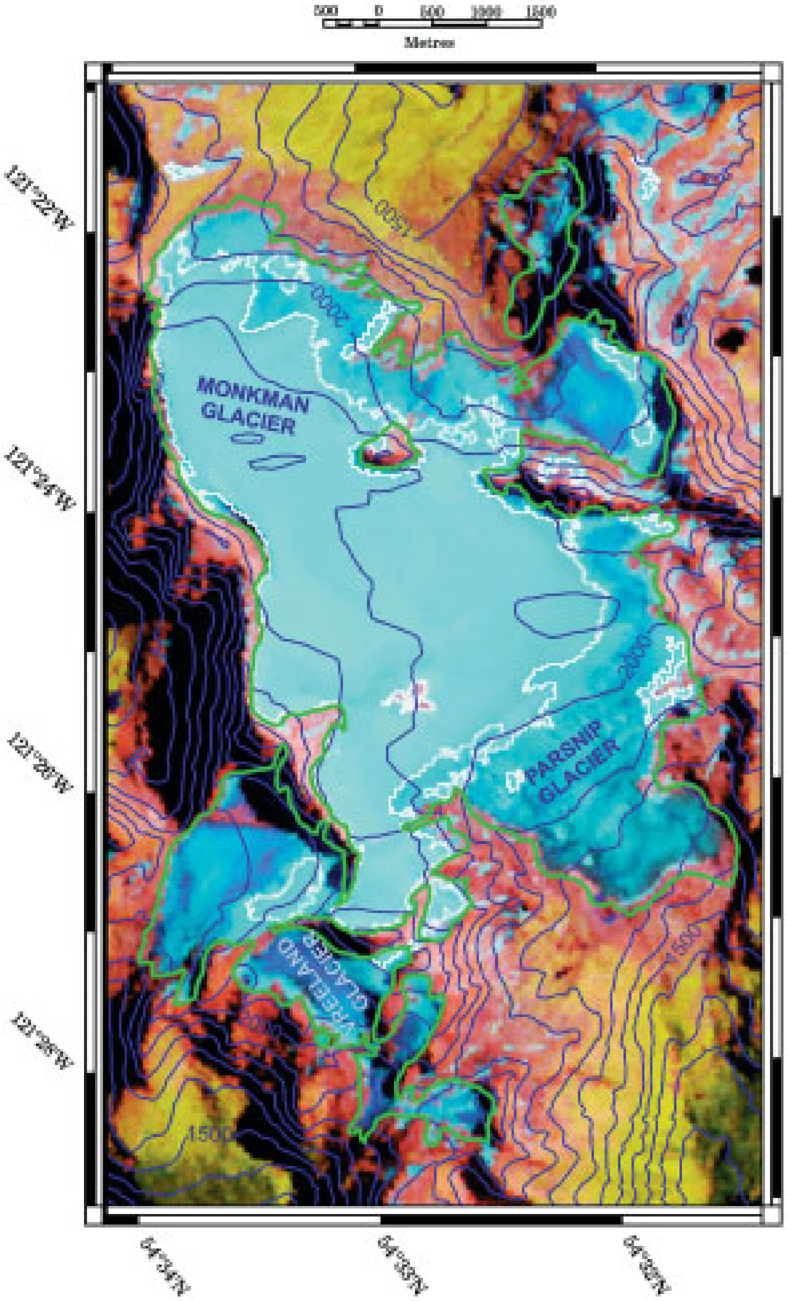


Figure 9.—*Landsat 5 TM false-color composite image of the Monkman Glacier/Parsnip Glacier. The image is oriented with southeast at the top. The superimposed contours are taken from the Province of British Columbia DEM; the contour interval is 100 m. The ablation area/accumulation area boundary is shown in white; the 1986 margin of the glaciers, derived from the Terrain Resource Inventory Management (TRIM) Program, is shown in green. Landsat 5 image (50480220097266T0; bands 3, 4, 5; 23 September 1997; Path 48, Row 22) from RADARSAT International, Richmond, British Columbia.*

Monkman Glacier/Parsnip Glacier

The Monkman Glacier/Parsnip Glacier (lat 54°30'N., long 121°30'W.) is the largest of a group of glaciers in the front ranges of the Rocky Mountains, about 100 km northwest of the city of Prince George, B.C. (see discussion of Hart Ranges in the Glaciers of the Canadian Rockies section); access to this area is very difficult except by helicopter. Comparison of image data from 23 September 1997 with the B.C. TRIM contour maps from the middle 1980's shows a decrease in glacier area from 24.8 to 23.2 km^2 and ice-front retreat ranging between about 100–200 m. Figure 9 shows a Landsat 5 TM false-color composite image (50480220097266T0; bands 3, 4, 5; 23 September 1997; Path 48, Row 22) overlain with 100-m DEM contours and includes the equilibrium line in white. The green line from the TRIM contour maps indicates the approximate areal extent of the glacier in 1986. Smaller ice patches that are not visible in dark shadow indicate some complications of using satellite images for glacier mapping and emphasize the need for derived products such as

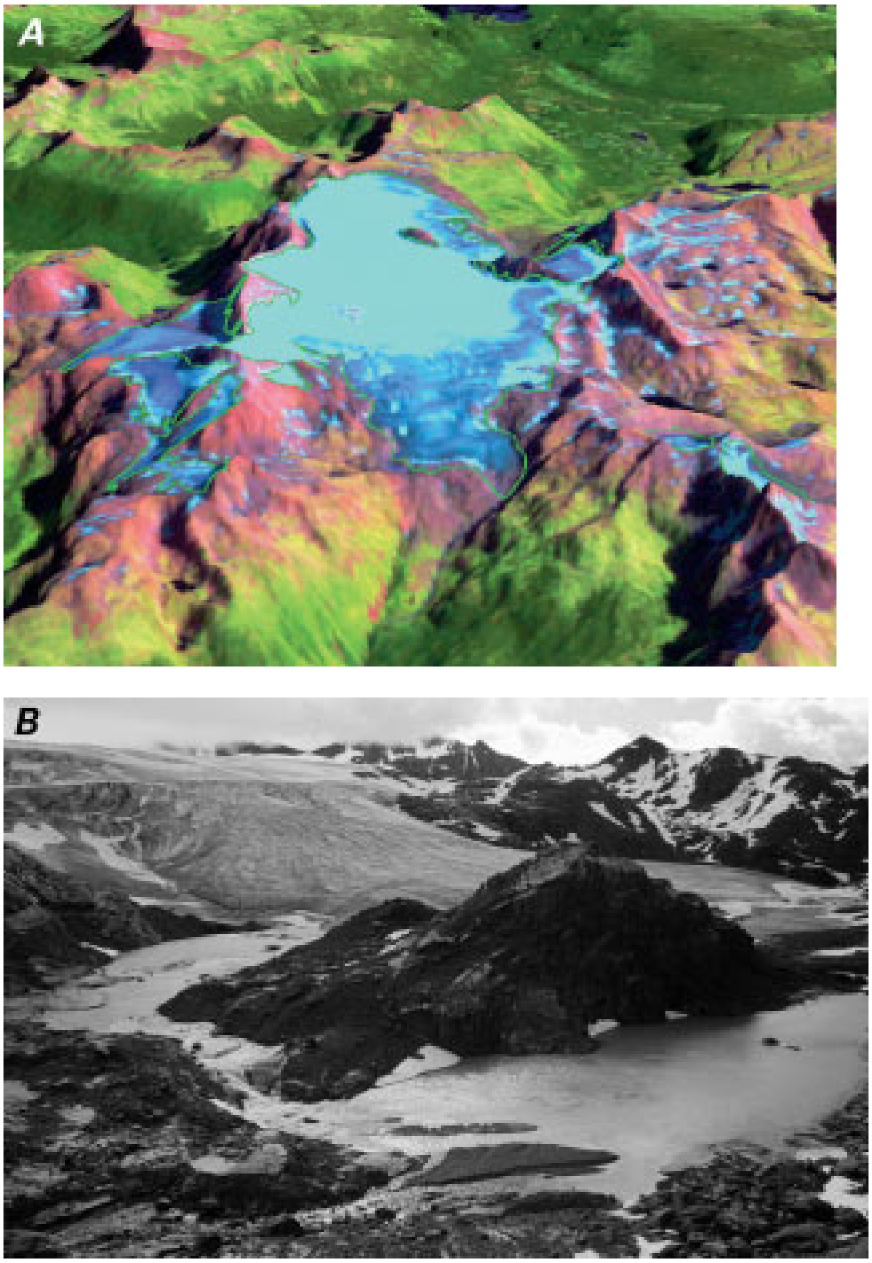


Figure 10.—**A**, *Perspective view of the Monkman Glacier/Parsnip Glacier looking toward the east. The areal extent (margins of the glaciers) in 1986, taken from the Terrain Resource Inventory Management (TRIM) Program, is shown as a green line. The view is created by draping the Landsat image shown in figure 9 with the Province of British Columbia DEM.* **B**, *Photograph of Parsnip Glacier and its proglacial lake looking toward the southeast from a terminal moraine on 26 July 2000. Photograph by Roger D. Wheate, University of Northern British Columbia.*

principal components and ratios to compensate for topographic shadows. Figure 10*A* depicts the same image (without contours), draped over the provincial DEM. Figure 10*B* is a ground photograph of the Parsnip Glacier.

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National Topographic Series

While individual glaciological investigators were producing the specialized maps necessary for their work, the quality, scale, and coverage of the federal and provincial mapping was improving. There is now complete coverage of Canada at the scale of 1:250,000. Of the maps involved, 157 of them contain some depiction of glaciers, and there are possibly another 28 sheets that cover regions where one might expect to find glacier-related features such as glacierets, snow patches, and rock glaciers that may have been overlooked. The mapping of Canada at the 1:50,000 scale still remains to be completed. Unfortunately for the glaciologist, the isolated, unpopulated, ice-covered regions of the country have the lowest priority. The exception is Kluane National Park, St. Elias Mountains, Yukon Territory, which is covered with nonstandard map sheets in black and white with low-quality relief shading that are useful for glaciological applications (see section on Quantitative Measurements of Tweedsmuir Glacier and Lowell Glacier Imagery in the subchapter Glaciers of the St. Elias Mountains, by Garry K.C. Clarke and Gerald Holdsworth, this volume). It is expected that about 1,450 of these sheets might be required to provide complete coverage of all the glacierized areas in the country, but only about half have been published. However, the depiction of glaciological features has improved over the years as the mapping agencies have recognized the need for and availability of knowledge to interpret them. Glacier-inventory maps were used for reference when the 1:50,000-scale maps of Baffin Island were being compiled, leading to a vast improvement in the representation of marginal features such as moraines. Of great benefit has been the opportunity to acquire current maps in digital form so digital terrain models can be much more easily constructed. The move by some mapping agencies towards publication of new maps at scales as large as 1:20,000, also in digital form, may reduce the need for glaciologists to produce special large-scale maps of the glaciers on which they are working. Instead they may be able to concentrate their efforts on determining the changes taking place.

Conclusions

One of the most fruitful collaborations in glacier mapping was between Fritz Müller of the McGill University Axel Heiberg Island Expedition and the PRS-NRCC. This collaboration resulted in the preparation of large-scale topographic maps and stereo-orthophoto maps of several of the island's glaciers. Another productive relationship was that of Gottfried Konecny, University of New Brunswick, with the Defence Research Board, the Water Survey of Canada, and the National Geographic Society. The role of the Glaciology Division in the production of glacier maps for the IHD, specialty maps of Peyto Glacier and the Columbia Icefield, and orthophoto maps, has also been significant. Unfortunately, none of the above are still involved in any glacier mapping activity, and the Glaciology Division has since been disbanded. Glacier-mapping activity in Canada is limited to a few small projects where the product is unlikely to be published or distributed widely (Cogley, 1999), and this trend will likely continue. Scientists and lay people alike may well regret the loss of this valuable aid. However, financial resources for producing high-quality, multicolored, large-scale maps are no longer readily available. The only possible exception may be Parks Canada (the Canadian Parks Service), which has a large tourist clientele that might make such a venture viable.

With the proliferation of personal computers and growth in their storage capacity, the future may see much greater use of digital terrain models and satellite images by individual glaciologists. Optical disks permit the storing, exchange, and analysis of photographic and cartographic information so that the printed thematic map may become a collector's item.

We know that the next generation of satellites will be capable of providing greatly improved spectral and spatial resolution and more current information on glaciers. The technology for analysis of this information using personal computers is developing rapidly.

Although the heyday of the printed glacier map may be past in Canada, there are exciting prospects and challenges ahead for glaciologists in digital cartography, GIS, and analysis of remotely sensed data.

References Cited

American Geographical Society, 1960, Nine glacier maps, northwestern North America: New York, American Geographical Society, AGS Special Publication No. 34, 37 p.

Arnold, K.C., 1966, The glaciological maps of Meighen Island, N.W.T: Canadian Journal of Earth Sciences, v. 3, no. 6, p. 903–908.

———1977, White Glacier; 1:2,500, lowest 2 kilometers (terrestrial photogrammetry), *in* Fluctuations of glaciers 1970–1975, v. III: Paris, Unesco, International Association of Hydrological Sciences (IAHS), United Nations Educational, Scientific, and Cultural Organization (UNESCO), p. 255–258.

———1981, Ice ablation measured by stakes and terrestrial photogrammetry—a comparison on the lower part of the White Glacier—Axel Heiberg Island, Canadian Arctic Archipelago: Montréal, Québec, McGill University, Axel Heiberg Island Research Reports, Glaciology No. 2, 98 p., maps.

Bayr, K.J., Hall, D.K., and Kovalick, W.M., 1994, Observations on glaciers in the eastern Austrian Alps using satellite data: International Journal of Remote Sensing, v. 15, no. 9, p. 1733–1742.

Blachut, T.J., 1963a, Photogrammetric and cartographic results of the Axel Heiberg Expedition: Canadian Surveyor, v. 17, no. 2, p. 79–80.

———1963b, Photogrammetric determination of glacier movement, rate of ablation, and profiles: Canadian Surveyor, v. 17, no. 2, p. 112–122.

Blachut, T.J., and Müller, Fritz, 1966, Some fundamental considerations on glacier mapping, *in* Gunning, H.C., ed., Symposium on Glacier Mapping: Canadian Journal of Earth Sciences, v. 3, no. 6, p. 747–759.

Brandenberger, A.J., and Bull, C.[B.B.], 1966, Glacier surveying and mapping program of the Ohio State University: Canadian Journal of Earth Sciences, v. 3, no. 6, p. 849–861.

Brugman, M.M., Pietroniro, Alain, and Shi, Jiancheng, 1996, Mapping alpine snow and ice using Landsat TM and SAR imagery at Wapta Icefield: Canadian Journal of Remote Sensing, v. 22, no. 1, p. 127–136.

Champoux, André, and Ommanney, C.S.L., 1986, Evolution of the Illecillewaet Glacier, Glacier National Park, B.C., using historical data, aerial photography and satellite image analysis: Annals of Glaciology, v. 8, p. 31–33.

Cialek, C.J., 1977, The Cathedral Massif, Atlin Provincial Park, British Columbia: Department of Geography, Michigan State University, sponsored by the Foundation for Glacier and Environmental Research, Pacific Science Center, Seattle, Washington, map.

Cogley, J.G., 1999, Photogrammetric rectification of oblique trimetrogon imagery: Peterborough, Ont., Trent University, Department of Geography, Trent Technical Note No. 99–1, 9 p.

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

Falconer, George, Henoch, W.E.S., and Østrem, Gunnar, 1966, A glacier map of southern British Columbia and Alberta: Geographical Bulletin, v. 8, no. 1, p. 108–112 (includes glacier map of southern British Columbia and Alberta).

Field, W.O., 1966, Mapping glacier termini in southern Alaska, 1931–1964: Canadian Journal of Earth Sciences, v. 3, no. 6, p. 819–825.

Foundation for Glacier and Environmental Research (FGER), 1976, Glacier at Cathedral Peak: compilation and printing by the Technical University of Hannover, F.R. Germany, through the Foundation for Glacier and Environmental Research, Juneau Icefield, Alaska—Atlin, B.C., Canada, Glaciological and Arctic Sciences Institute, map.

Fremlin, Gerald, and Mindak, H.E., 1968, Lakes, rivers and glaciers—a map commentary: The Canadian Cartographer, v. 5, no. 2, p. 133–137.

Gosson, C.M.C., 1985, Canada—Glaciers: Ottawa, Ontario, Energy, Mines and Resources Canada, Surveys and Mapping Branch, Geographical Services Division, map. (MCR–4080.)

Gunning, H.C., ed., 1966, Proceedings of the Symposium on Glacier Mapping: Canadian Journal of Earth Sciences, v. 3, no. 6, p. 737–915.

Hall, D.K., Ormsby, J.P., Bindschadler, R.A., and Siddalingaiah, Honnappa, 1987, Characterization of snow and ice reflectance zones on glaciers using Landsat Thematic Mapper data: Annals of Glaciology, v. 9, p. 104–108.

Hall, D.K., Chang, A.T.C., and Siddalingaiah, Honnappa, 1988, Reflectances of glaciers as calculated using Landsat-5 Thematic Mapper Data: Remote Sensing of Environment, v. 25, no. 3, p. 311–321.

Hall, D.K., Williams, R.S., Jr., and Bayr, K.J., 1992, Glacier recession in Iceland and Austria: EOS (Transactions, American Geophysical Union), v. 73. no. 12, p. 129, 135, and 141.

Haumann, Dieter, 1960, Photogrammetric and glaciological studies of Salmon Glacier: Arctic, v. 13, no. 2, p. 75–110, map.

———1963, Surveying glaciers on Axel Heiberg Island: Canadian Surveyor, v. 17, no. 2, p. 81–93.

Hell, Günther, 1981, Geodätische und photogrammetrische Arbeiten an der Oobloyah Bay, N-Ellesmere Island, N.W.T., Kanada, im Rahmen der "Heidelberg-Ellesmere Island-Expedition 1978" [Geodetical and photogrammetric studies during the Heidelberg Ellesmere Island Expedition 1978 to Oobloyah Bay, northern Ellesmere Island, N.W.T., Canada]: Heidelberger Geographische Arbeiten, v. 69, p. 35–46.

Henoch, W.E.S., 1969, Topographic maps of Canada in glaciological research: Canadian Cartographer, v. 6, no. 2, p. 118–129.

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

Henoch, W.E.S., and Stanley, A.D., 1968a, Glacier map of northern Queen Elizabeth Islands (District of Franklin): produced by the Glaciology Subdivision, Inland Waters Branch, printed by the Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa, Ontario, map. (IWB 1003.)

Henoch, W.E.S., and Stanley, A.D., 1968b, Glacier map of southern Queen Elizabeth Islands (District of Franklin): produced by the Glaciology Subdivision, Inland Waters Branch, printed by the Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa, Ontario, map. (IWB 1004.)

———1970, Glacier maps of Canada: Journal of Glaciology, v. 9, no. 55, p. 149 plus map.

Holdsworth, Gerald, 1977, Ice flow and related measurements of d'Iberville Glacier, Ellesmere Island, N.W.T., Canada: Ottawa, Ontario, Environment Canada, Inland Waters Directorate, Glaciology Division, Internal report, 1977, 28 p.

Holdsworth, Gerald, Crabtree, P., and Croizet, J., 1976, Provisional map of the north-west col area of Mount Logan: Ottawa, Inland Waters Directorate, Fisheries and Environment Canada (1:10,000/20 m).

Holdsworth, Gerald, Demuth, Michael, and Beck, T.M.H., in press, Map of Peyto Glacier, in Demuth, Michael, ed., Peyto Glacier Research: Ottawa (1:10,000/10 m).

Holdsworth, Gerald, and Sawyer, B., 1993, Mount Logan map, research and reference folio: Calgary, Alberta., Arctic Institute of North America, two map sheets.

Holdsworth, Gerald, Titus, D., and Gregory, P., 1992, Revised map of the north-west col and PR col areas of Mount Logan: Ottawa, Environment Canada (1:10,000/20 m).

Howarth, P.J., and Ommanney, C.S.L., 1983, LANDSAT digital data for updating glaciological information on topographic and glacier inventory maps, *in* Wellar, B.S., ed., Automated Cartography: International Perspectives on Achievements and Challenges v. II: p. 504–513. (Proceedings of the Sixth International Symposium on Automated Cartography, 16–21 October 1983, National Capital Region of Canada.)

Institute of Cartography, 1998, Thompson Glacier, Canada 1:5000, *in* Haeberli, Wilfried, Hoelzle, Martin, Suter, Stephan, and Frauenfelder, Regula, eds., Fluctuations of glaciers 1990–1995 with addendas from earlier years, v. VII: Wallingford, Oxfordshire, U.K., International Association of Hydrological Sciences (IAHS), Nairobi, United Nations Environment Programme (UNEP), Paris, United Nations Educational, Scientific, and Cultural Organization (UNESCO), p. 60.

Jeffries, M.O., and Serson, H.V., 1986, Survey and mapping of recent ice shelf changes and landfast sea ice growth along the north coast of Ellesmere Island, NWT, Canada: Annals of Glaciology, v. 8, p. 96–99.

Konecny, Gottfried, 1964, Glacier surveys in western Canada: Photogrammetric Engineering, v. 30, no. 1, p. 64–82.

———1966, Application of photogrammetry to surveys of glaciers in Canada and Alaska, *in* Gunning, H.C., ed., Symposium on Glacier Mapping: Canadian Journal of Earth Sciences, v. 3, no. 6, p. 783–798.

Lodwick, G.D., and Paine, S.H., 1985, A digital elevation model of the Barnes ice-cap derived from Landsat MSS data: Photogrammetric Engineering and Remote Sensing, v. 51, no. 12, p. 1937–1944.

Luckman, B.H., Harding, K.A., and Hamilton, J.P., 1987, Recent glacier advances in the Premier Range, British Columbia: Canadian Journal of Earth Sciences, v. 24, no. 6, p. 1149–1161.

Mauelshagen, L., 1984, Zur Entstehungsgeschichte und Herstellung der Karte des Cathedral Gletscher Vorfeldes in British Kolumbien (Kanada), *in* Festschrift zum 60, Geburtstag von Prof. Dr. Ing. G. Kupfer, Bonn, Germany: p. 90–99.

Mauelshagen, L., and Slupetzky, Heinz, 1985, Cathedral Massif Glacier and forefield (Atlin Provincial Wilderness Park, B.C., Canada): Salzburg, Austria, Universität Salzburg, Institut für Geographie, map. (Published in Zeitschrift für Gletscherkunde und Glazialgeologie, v. 24, no. 2, 1988.)

McKortel, T.A., 1963, The reproduction of the Thompson Glacier Map: Canadian Surveyor, v. 17, no. 2, p. 93–95.

Miller, G.H., Bradley, R.S., and Andrews, J.T., 1975, The glaciation level and lowest equilibrium line altitude in the High Canadian Arctic: maps and climatic interpretation: Arctic and Alpine Research, v. 7, no. 2, p. 155–168.

Molenaar, D., 1990, Glacier Bay, Juneau Icefield region and the glacierized ranges of Alaska-Northwestern Canada: Burley, Washington, Molenaar Maps, map.

Müller, Fritz, 1977, Fluctuations of glaciers: 1970–1975. International Hydrological Programme; Compiled for the Permanent Service on the Fluctuations of Glaciers (IUGG-FAGS/ICSU), United Nations Educational, Scientific and Cultural Organization, International Association of Hydrological Sciences, v. 3, 269 p.

Müller, Fritz, and others, 1963, Jacobsen-McGill Arctic Research Expedition 1959–1962; preliminary report 1961–1962 and map supplement: Montréal, Québec, McGill University, Axel Heiberg Island Research Reports, 241 p., 6 maps.

Norges Vassdrags- og Energiverk (NVE), 1991, Part of Grinnell Glacier, Baffin Island, N.W.T: Oslo, Norway, Norwegian Water Resources and Energy Administration, map, scale 1:20,000.

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

Ommanney, C.S.L., 1980, The inventory of Canadian glaciers: procedures, techniques, progress and applications, *in* World Glacier Inventory Workshop, Riederalp, Switzerland, 17–22 September, 1978: IAHS-AISH Publication No. 126, p. 35–44.

———1989, Glacier Atlas of Canada: Saskatoon, Saskatchewan, Environment Canada, National Hydrology Research Institute, Scientific Information Division, Limited edition, 2 p., 52 maps.

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

Reid, I.A., 1973, Glacier surveys by the Water Survey of Canada, *in* The Role of Snow and Ice in Hydrology, Proceedings of the Banff Symposium, September 1972: IAHS-AISH Publication No. 107, v. 2, p. 1133–1143.

Reid, I.A., and Charbonneau, J.O.G., 1980, Glacier surveys in British Columbia —1978: Ottawa, Ontario, Environment Canada. Inland Waters Directorate, Water Resources Branch, IWD Report Series No. 66, 23 p., maps.

———1981, Glacier surveys in Alberta—1979: Ottawa, Ontario, Environment Canada, Inland Waters Directorate, Water Resources Branch, IWD Report Series No. 69, 19 p., maps.

Ricker, Karl [E.], 1977, Wedgemount lake and lower Glacier basin: Map drawn by K. Ricker with additional contour information provided by K. Bracewell, W. Tupper, and the British Columbia Institute of Technology, available from Mountain Equipment Coop., 428 West 8th Avenue, Vancouver, B.C., map, scale 1:5,000.

Riggs, G.A., Hall, D.K., and Salomonson, V.V., 1994, A snow index for the Landsat Thematic Mapper and Moderate Resolution Imaging Spectoradiometer, *in* Proceedings, International Geoscience and Remote Sensing Symposium (IGARSS '94, v. 4): IEEE, Piscataway, N.J., p. 1942–1944.

Römmer, Susanne, and Hell, Günther, 1986, Veräungen der Zunge eines Gletschers am Harefjord (NWT, Kanada) zwischen 1958 und 1978: Diplomarbeit im Studiengang Kartographie, FH Karlsruhe, Germany, map, scale 1:20,000.

Royal Canadian Geographical Society, 1998, The glaciers of Canada: Canadian Geographic, v. 118, no. 7, with supplementary map.

Sedgwick, J.K., and Henoch, W.E.S., 1970, Peyto Glacier—general information. Accompanying text for Peyto Glacier map, Provisional edition: Ottawa, Ontario, Department of Energy, Mines and Resources, Inland Waters Branch, Glaciology Subdivision, text and map, scale 1:10,000. (IWD 1008.)

Sidjak, R.W., and Wheate, R.D., 1999, Glacier mapping of the Illecillewaet Icefield, British Columbia, Canada, using Landsat TM and digital elevation data: International Journal of Remote Sensing, v. 20, no. 2, p. 273–284.

Slupetzky, Heinz, Mauelshagen, L., and Gruber, W., 1988, Cathedral Massif Glacier, Canada, 1:5000 (terrestrial/aerial photogrammetric map), *in* Haeberli, W., and Müller, P., eds., Fluctuations of glaciers 1980–1985, v. V: Wallingford, Oxfordshire, U.K., International Association of Hydrological Sciences (IAHS), Nairobi, United National Environment Programme (UNEP) and United Nations Educational, Scientific, and Cultural Organization (UNESCO), p. 68–70, map.

Stanley, A.D., 1969, Observations of the surge of the Steele Glacier, Yukon Territory, Canada: Canadian Journal of Earth Sciences, v. 6, no. 4, pt. 2, p. 819–830.

Washburn, [H.]B., 1971a, The mapping of Mount Hubbard and Mount Kennedy, 1965: National Geographic Society Research Reports, v. 1965, p. 249–277.

———1971b, Oblique aerial photography of the Mount Hubbard-Mount Kennedy area on the Alaska-Yukon border: National Geographic Society Research Reports, v. 1966, p. 283–297.

Washburn, H.B., Konecny, Gottfried, Gloss, G., and Miller, M.M., 1965, Aerial photogrammetric mapping of the Mt. Hubbard-Mt. Kennedy massif, St. Elias Mountains, Alaska-Yukon, 1965, *in* Proceedings, 16th Alaskan Science Conference, 30 August–1 September 1965, Juneau, Alaska: American Association for the Advancement of Science, Alaska Division, p. 123–124.

Whalley, W.B., and Martin, H.E., 1986, The problem of "hidden" ice in glacier mapping: Annals of Glaciology, v. 8, p. 181–183.

Williams, R.S., Jr., 1986, Glacier inventories of Iceland: Evaluation and use of sources of data: Annals of Glaciology, v. 8, p. 184–191.

———1987, Satellite remote sensing of Vatnajökull, Iceland: Annals of Glaciology, v. 9, p. 127–135.

Williams, R.S., Jr., Hall, D.K., and Benson, C.S., 1991, Analysis of glacier facies using satellite techniques: Journal of Glaciology, v. 37, no. 125, p. 120–128.

Williams, R.S., Jr., Hall, D.K., Sigurðsson, Oddur, and Chien, J.Y.L., 1997, Comparison of satellite-derived with ground-based measurements of the fluctuations of the margins of Vatnajökull, Iceland, 1973–92: Annals of Glaciology, v. 24, p. 72–80.

Wood, W.A., 1963, Map of a portion of the Icefield Ranges, St. Elias Mountains, Yukon Territory, Canada: New York, American Geographical Society (1:30,000/10 m and 50 m) (see also The Geographical Review, 1963, v. 53, Plate II).

Young, G.J., and Arnold, K.C., 1978, Orthophotomaps of glaciers; an evaluation of an automated method applied to Peyto Glacier, Alberta: Zeitschrift für Gletscherkunde und Glazialgeologie, v. 13, no. 1–2, 1977, p. 99–110.