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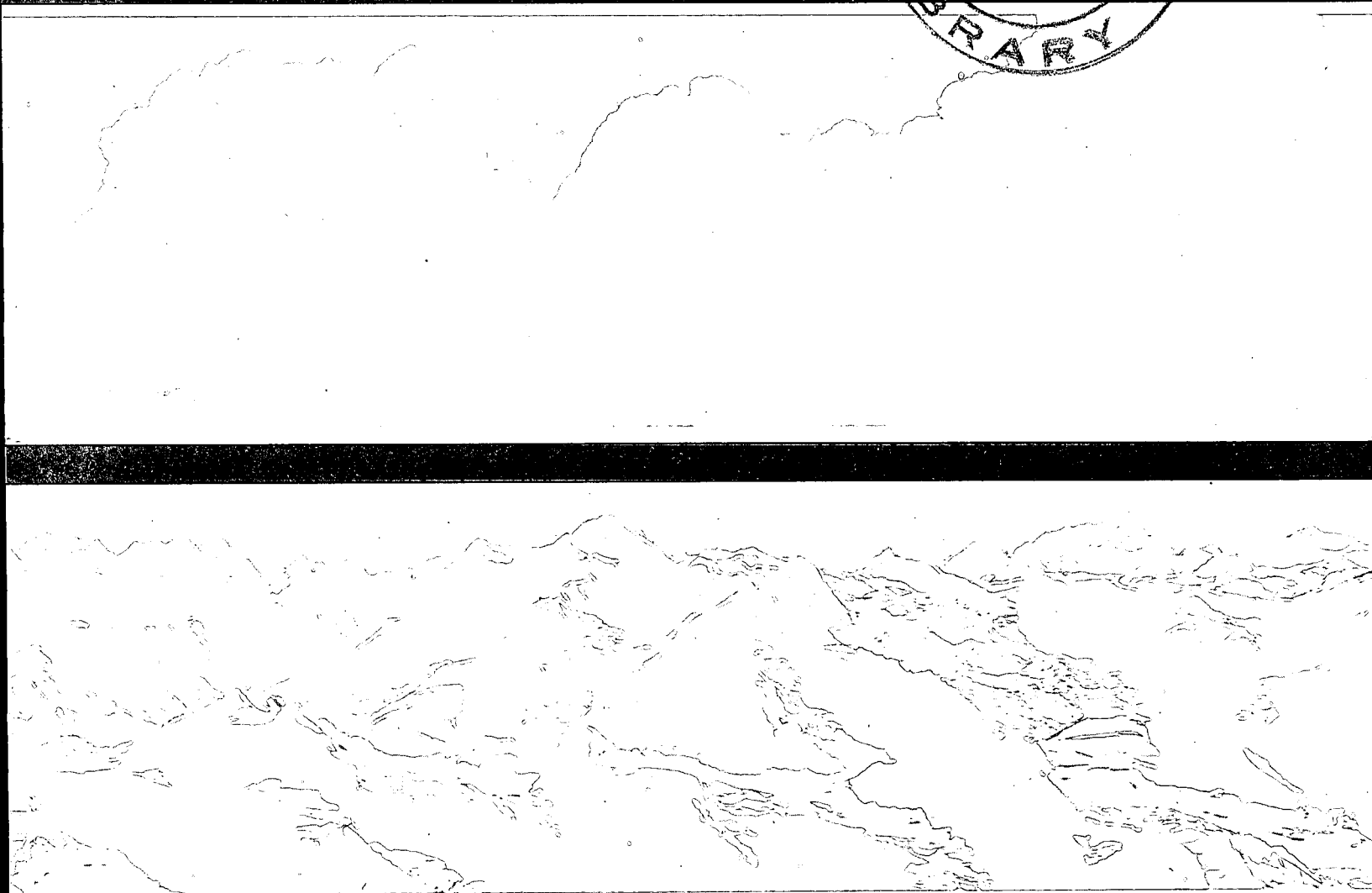


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# Glacier Surveys in Alberta - 1971

I.A. Reid and J.O.G. Charbonneau



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(Résumé en français)

**INLAND WATERS DIRECTORATE,  
WATER RESOURCES BRANCH,  
OTTAWA, CANADA, 1975.**



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## Abstract

Glaciers act as natural regulators, storing water in winter and releasing it in summer. To gain some understanding of this phenomenon and the contribution which glaciers make to streamflow, the predecessors of the Water Survey of Canada began glacier surveys in 1945. The earlier surveys offered some clue to the role of the glacier, but the data collected were not sufficient to provide the overall picture. Following adoption of photogrammetric survey techniques, however, the glacier surveys have evolved to the extent that it is now feasible to produce a series of maps from which the linear, areal, directional and volumetric changes can be determined.

The surveys have revealed that the glaciers, in general, are becoming smaller in size; hence the regulation effect is diminishing in the area of ablation.

## Résumé

Les glaciers jouent un rôle de régularisation naturelle, emmagasinant l'eau pendant l'hiver et la laissant s'écouler durant l'été. Pour arriver à comprendre quelque chose à ce phénomène et aussi à la contribution que les glaciers apportent au ruissellement, les prédécesseurs de la Division des relevés hydrologiques du Canada avaient commencé en 1945 une étude des glaciers. Ces premières études apportèrent certains indices quant au rôle des glaciers mais les observations compilées n'étaient pas suffisantes pour donner une idée d'ensemble. À la suite de l'adoption de relevés photogrammétriques, cependant, l'étude des glaciers a évolué au point qu'il est maintenant possible de produire une série de cartes à partir desquelles on peut déterminer les changements linéaires, directionnels, de superficie et de volume.

Les études ont révélé, qu'en général, le volume des glaciers diminue et que de ce fait, l'effet de régularisation diminue aussi dans la zone d'ablation.

## Introduction

An important function of the Water Resources Branch is the systematic collection of water resource data throughout Canada. This work is of vital importance in the development of Canada's water resources because the feasibility, safety and cost of water use or water control projects depend largely on the availability and reliability of such information.

Since glaciers form part of Canada's water resources, some glaciers are surveyed on a continuing basis by the Applied Hydrology and Water Survey of Canada Divisions in an effort to determine the extent and pattern of a glacier's influence on surface water runoff. Of the large number of glaciers in Canada, however, only a few are surveyed (Fig. 1).



Figure 1. Key map showing location of glaciers.

This report summarizes the history of glacier surveys conducted in Canada by these Divisions and describes present glacier survey practices. Tables of results for the period of record, some interpretation of these results and the most recent glacier maps are also included. Only those surveys conducted partially by or under the supervision of the Applied Hydrology Division are described in detail; brief reference, however, is made to surveys conducted

entirely by Water Survey of Canada District Office staff to make the historical summary coherent and the Tables of data as complete as possible.

In response to a directive recommending greater use of the metric system, the Applied Hydrology Division decided to change from English to SI units in the determination of biennial glacier variations. In 1968, the year of the changeover, it was necessary to compile separate sets of maps using both English and SI units in order that data produced prior to 1968 might be compared to data obtained after 1968. To assist the reader in converting units, a table of equivalents follows:

SI units	English units
1 metre (m)	3.2808 feet (ft)
1 square metre (sq m)	10.7639 square feet (sq ft)
1 cubic metre (cu m)	35.3147 cubic feet (cu ft)

## HISTORICAL SUMMARY

Surveys of selected glaciers in the Rocky, Columbia and Coast mountains were begun in 1945. The surveys of glaciers located in the Rocky Mountains were carried out by WSC Calgary staff, and the Columbia and Coast mountain surveys were performed by the WSC Vancouver staff. These surveys, in general, were designed to determine the position of the glacier toe, to define the movement of a plaque line on the glacier's surface and to provide a transverse and a longitudinal profile for the lower portion of the glacier. Reports describing the 1945 survey and subsequent surveys conducted by the District Offices are available from

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More information concerning the evolution of the glacier surveys may be obtained from "Glacier Surveys by the Water Survey of Canada," a paper by I.A. Reid in the *Proceedings of the Banff Symposia on "The Role of Snow and Ice in Hydrology,"* held in September 1972.

A glacier's contribution to the volume of runoff can be calculated if two quantities are known: 1) the change in volume of a glacier during a given period of time and 2) the amount of ice that flows from the source icefield to the glacier during the same period of time. Surveys have been designed to measure the first quantity directly, but since no direct method of measuring the second quantity was known until recently, it has been determined only indirectly.

A paper entitled "A Simple Method of Measuring the Average Amount of Water Produced Annually by Melting of Ice on a Glacier" by I.A. Reid and W.S.B. Paterson was presented at the Symposium on "Hydrology of Glaciers" at Cambridge, England, in September 1969. The Symposium's *Proceedings* were published by the Glaciological Society, Cambridge, in 1974.

Since the information obtained for each glacier by District Office staff was applicable only to the lower portion of the glaciers, volumetric and linear changes could be obtained for only the lower portion. In an effort to increase the areal coverage of the glaciers surveyed, an aerial photogrammetric survey of the Athabasca Glacier was undertaken as a pilot project in July 1959. Permanent survey plugs were established around the perimeter of the glacier and tied-in by means of a triangulation survey. From the aerial photographs, a topographic map was produced using a high-precision plotter. This was the first time that a topographical map of high quality was prepared by the Branch, and the precedent was set for later maps.

In 1963, a survey party composed of staff from the Calgary District Office and Ottawa participated in a surveying experiment with a team from the University of New Brunswick led by Dr. G. Konecny, Head of the Department of Survey Engineering. Optical-electronic distance measuring equipment together with standard equipment and normal triangulation procedures was used to reconfirm the location of plugs in the somewhat modified triangulation network around Athabasca Glacier

and to define the co-ordinates of the newly established plugs around Saskatchewan Glacier. Only Saskatchewan Glacier was photographed in 1963, implementing terrestrial photogrammetry in place of aerial photogrammetry for the first time. The map was plotted by the University of New Brunswick under contract.

During the summer of 1964, high-quality maps of five selected glaciers in British Columbia were prepared by stereoscopic terrestrial photogrammetric methods. It was found by study that for the survey of glaciers, stereoscopic terrestrial survey methods have certain advantages over aerial surveys.

Since 1965 stereoscopic terrestrial photographs of the Athabasca and Saskatchewan glaciers have been taken by Calgary District Office and Applied Hydrology Division personnel in odd-numbered years. The plotting of the maps was performed by Applied Hydrology Division staff, using a first order plotter located at the Surveys and Mapping Branch, Department of Energy, Mines and Resources.

This method is now used to map glaciers in British Columbia in even-numbered years and to map glaciers in Alberta in odd-numbered years. From the maps, linear and volumetric changes in the glaciers are determined. Results of earlier work have also been published in this *Report Series*.

The Calgary District staff continues to observe plaque line movements and the position of the toe of the Athabasca and Saskatchewan glaciers in the even-numbered years, i.e., 1966, 1968 ....

The continuation of these surveys, apart from more fundamental scientific observations made by the Branch's Glaciology Division, is an important aspect of Branch activities for two reasons: 1) the surveys provide a basis for obtaining greater knowledge of Canada's freshwater resources and 2) they fulfil our announced commitment to the International Association of Hydrologic Sciences (IAHS) to monitor glacial changes as part of a world-wide surveillance of glacier trends. We can only speculate on the ultimate usefulness of the information being collected. Yet it could well be that the trends of a glacier's behaviour over a period of time will prove to be a very useful prediction tool in hydrological studies of the future.

These glacier surveys are closely co-ordinated with other activities of the Water Resources Branch. The information contained in these survey reports is provided to individuals, scientific agencies and to various libraries throughout the world.



## Description of Glaciers

### ATHABASCA GLACIER

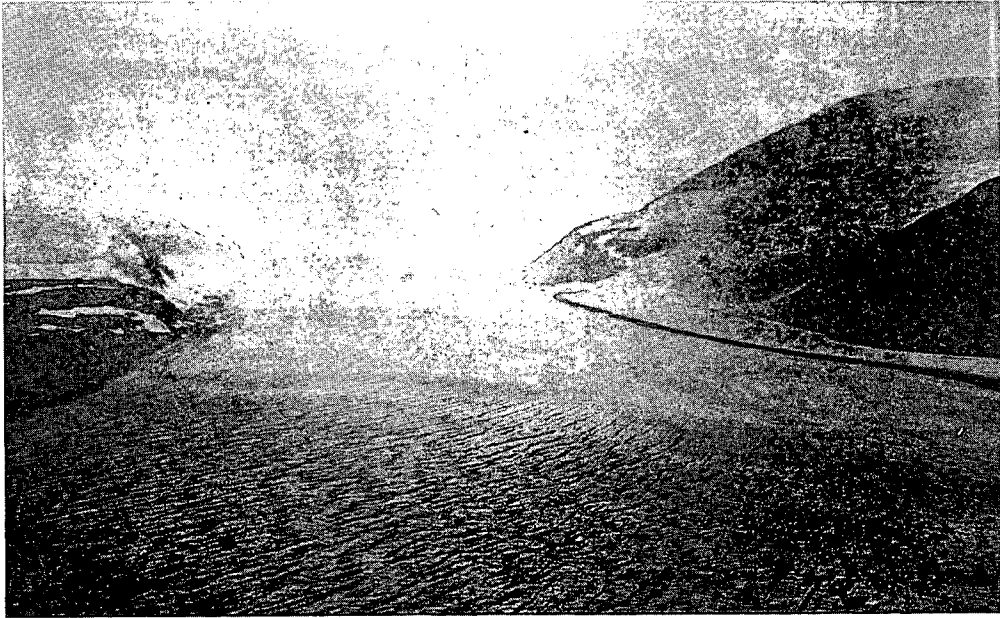
Athabasca Glacier is located at latitude  $52^{\circ} 12'$ , longitude  $117^{\circ} 14'$ , on the eastern slopes of the Rocky Mountains in Jasper National Park (Fig. 2). This glacier was selected because of its accessibility. The Branch has made periodic surveys around the toe area since 1945. It is one of the main outlet glaciers from the Columbia Icefield, and the meltwater from the Athabasca flows into the Arctic Ocean via the Sunwapta, Athabasca and Mackenzie rivers.

### SASKATCHEWAN GLACIER

Saskatchewan Glacier is located at latitude  $52^{\circ} 08'$ , longitude  $117^{\circ} 12'$ , on the eastern slopes of the Rocky Mountains in Banff National Park (Figs. 3 & 4). The glacier was selected on account of its accessibility. The Branch has made periodic surveys around the toe area since 1945. It is the major outlet glacier from the Columbia Icefield, and its meltwater flows into Hudson Bay via the North Saskatchewan, Saskatchewan and Nelson rivers.



Figure 2. Athabasca Glacier, August 12, 1971.



**Figure 3. Saskatchewan Glacier, upper base, August 6, 1971.**



**Figure 4. Saskatchewan Glacier, lower base, August 9, 1971.**

## Field Work

During the summer of 1959, a Branch survey party established 21 control points on rock around the periphery of Athabasca Glacier. These control points were established in connection with the preparation of an aerial photogrammetric survey.

In 1963, Dr. G. Konecny, in conjunction with Branch personnel (Chapter 1), conducted a stereoscopic terrestrial photogrammetric survey of Saskatchewan Glacier.

The control established in 1959 and 1963 is used for the stereoscopic terrestrial surveys of the Athabasca and Saskatchewan glaciers.

Since the surveys of the two glaciers are basically the same, only the Athabasca Glacier is described in detail. The triangulation control network for Saskatchewan Glacier is an extension of the control for Athabasca Glacier.

### CONTROL

A schematic sketch of the control net for Athabasca Glacier is shown in Figure 5.

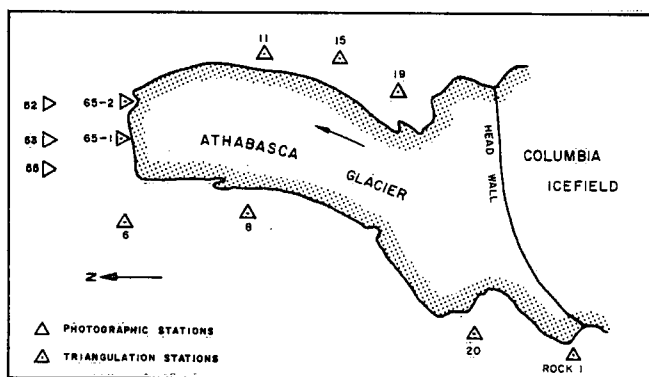


Figure 5. Sketch showing distribution of photographic and triangulation stations, Athabasca Glacier.

Triangulation stations, numbers 6, 8, 11, 15, 19, 20, 65-1, 65-2 and Rock 1, were used as the control for the terrestrial survey. The other stations, shown on the map (in pocket), were implemented in the 1959 aerial photogrammetric survey. These stations, with the exception of Rock 1, were marked by a standard Water Resources

Branch bench-mark plug cemented in bedrock where possible (Fig. 6).



Figure 6. Photograph showing the standard WRB plugs used to locate the photographic stations.

The photographic stations, numbers 52, 53 and 55, are located on the chalet ridge overlooking the glacier and are also marked by a standard Water Resources Branch bench-mark plug. Small rock cairns were built close to each plug for ease in locating them in the field.

### INSTRUMENTS AND EQUIPMENT

A Wild T-2 theodolite and a Wild P-30 phototheodolite were used to measure all horizontal and vertical angles. All readings were to the nearest second.

A Wild P-30 phototheodolite was used to photograph the glaciers. The camera was tested at the National Research Council, Division of Applied Physics, before plotting the glacier maps. This test is necessary only once unless the camera sustains a violent shock. Kodak spectroscopic type plates were used for the photography.

### BASE LINE

The base line for the Athabasca Glacier map is based on measurements made between triangulation stations 1 and 3 using a 300-foot invar tape.

Table 1. Sample Field Notes for Triangulation – Athabasca Glacier Survey

$\nabla$ @ Stn. 4    H.I. = 4.00 ft    Overcast, cold, sunny intervals, windy						Date
						$\nabla$
Stn.	Horizontal angle	Mean	Reduced mean	Vertical angle	Mean	Remarks
67-1	36° 59' 44" 216° 59' 41"	36° 59' 42.5"	00° 00' 00"	84° 44' 23" 275° 16' 09"	84° 44' 07"	on plug
65-1	115° 30' 36" 295° 30' 22"	115° 30' 29"	78° 30' 43.5"	91° 18' 01" 268° 42' 24"	91° 17' 48.5"	top of $\nabla$
67-1	96° 59' 46" 276° 59' 37"	96° 59' 41.5"	00° 00' 00"	84° 44' 27" 275° 16' 14"	84° 44' 06.5"	on plug
65-1	175° 30' 32" 355° 30' 22"	175° 30' 27"	78° 30' 45.5"	91° 18' 20" 268° 42' 24"	91° 17' 58"	top of $\nabla$

Table 2. Sample Field Notes for Taking Photographs with a Phototheodolite – Athabasca Glacier Survey

Phototheodolite @ Stn. 55 Backsight on Stn. 53 Ht. of tripod = 4.25 ft						Date
Began 11:00 a.m. Finished 11:55 a.m.						$\nabla$
Angle	Aversion (rt.)	Inclin. (grad.)	Plate no.	Photo no.	Exp. time (sec)	Remarks
270° 00' 00"	00° 00' 00"	+7	8	8	1/2	high overcast
270° 00' 00"	00° 00' 00"	+7	9	9	1/2	light winds
270° 00' 00"	00° 00' 00"	+7	10	10	1/10	light winds
263° 00' 00"	7° Rt	0	11	11	1/10	light winds
263° 00' 00"	7° Rt	0	12	12	1/5	light winds
263° 00' 00"	7° Rt	0	13	13	1/2	light winds

Measuring stakes about 4 in. x 2 in. x 3 ft were set along the base line at 300-foot intervals. For optimum measuring accuracy, the method used by the National Research Council in calibrating the invar tape was duplicated in the field. In this method, the tape is supported at 75-foot intervals along its length. Support stakes, 1 in. x 1 in. x 4 ft, were set in line by eye at 75-foot intervals between the measuring stakes, and a nail was driven horizontally on grade into each stake to support the tape. An aluminum plate, 4 in. x 4 in., was nailed on top of each measuring stake, and a scratch was made in line-of-sight on each plate at the 300-foot marks.

During the chaining operation, with the position of one end of the tape at zero, the spring balance reading and the

tape alignment and grade all correct, a scratch was made on the aluminum plate perpendicular to the line-of-sight at the other end (300-foot mark) of the tape. Two thermometers, one at each end of the tape, were read and all measurements were recorded.

## TRIANGULATION

After reaching the glacier, the party made a reconnaissance survey of the toe area to determine the best locations for the photographic stations. The locations of photographic stations should be about the same elevation and on a high ridge facing the glacier. The ratio between the distance separating the base-line stations, and the

distance to the area to be stereoscopically photographed should not be less than 1:4 nor greater than 1:20. To meet this criterion, measurements were made from the best general area for the photographic stations to the toe area of the glacier and the upper limit of the glacier. When these distances were known, the party established photographic stations on a ridge to give the best possible results.

The triangulation was carried out using a Wild T-2 theodolite and a Wild P-30 phototheodolite. Each horizontal and vertical angle was observed three times using the telescope in a direct position and three times in an inverted position. The mean angle was used in the

computations for distance, positions and differences in elevation (Table 1).

## PHOTOGRAPHY

The photographs taken from stations 52 and 55 (long base) were used to plot distant areas of the glacier, and the photographs taken from stations 52 and 53 (short base) were used to plot near areas. Sample field notes for taking photographs with a phototheodolite are shown in Table 2.

Photography instructions are outlined in the booklet which accompanies the phototheodolite. These instructions, as well as those contained in the *Text Book of Photogrammetry* (Zeller, 1952), were followed closely.

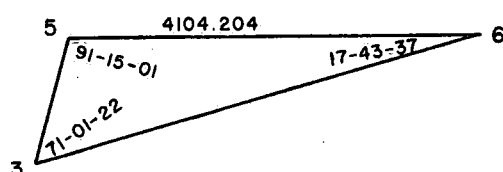
## Office Work

Since the triangulation net for Athabasca Glacier was not connected to any existing net, it was necessary to compute geodetic positions of triangulation stations from an assumed position of triangulation station no. 1 (Athabasca Glacier). The position of station no. 1 was scaled from a large-scale topographic map.

Positions of the other triangulation stations were calculated by the method outlined in *Tentative Instructions for Computation of Geodetic Positions* (United States Department of the Interior, 1951).

### COMPUTATIONS

The computations of co-ordinates were carried out with a basic calculator using seven-place natural trigonometric functions.



### BASE LINE

The distance between triangulation stations 1 and 3 was measured with a 300-foot standardized invar tape. Corrections for slope and temperature were made to the measured distance. In addition, the base length was reduced to sea level by the formula  $-B \frac{h}{R}$ , where B is the measured length of the base in feet, h is the altitude above sea level in feet, and R is the radius of the sector of the earth in feet, at the location.

### HORIZONTAL ANGLE

When the notes for all stations were reduced, the coordinate for triangulation station no. 1 was assigned the value, latitude  $52^{\circ} 13' 12''$ , longitude  $117^{\circ} 13' 30''$ . The position of station no. 1 was ascertained from a large-scale topographic map.

$$\frac{5-3}{\sin L_6} = \frac{5-6}{\sin L_3}$$

$$5-3 = \frac{4104.204 \times 0.3044810}{0.9456479}$$

$$5-3 = 1321.47 \text{ ft}$$

Figure 7. Computations for distance using the sinelaw.

Table 3. Typical Calculations for Elevations – Athabasca Glacier Survey

@ Stn. 3					Elevation of Stn. 3 = 6490.18 ft				
Stn.	Distance	Vertical angle from Stn. 3	Diff. of elev.	Ref.*	Total diff. of elev.	Ht. of target	Ht. of inst.	Mean diff. of elev.	Elev. (Z)
B.L.E.	1742.05	-00 -29 -00	- 14.70	+0.06	- 14.64	0.5	+ 5.00	- 10.14	6480.04
2	2609.29	-00 -25 -10	- 19.10	+0.14	- 18.96	1.5	+ 5.00	- 15.46	6474.72
4	3115.69	-02 -02 -43	-111.26	+0.20	-111.06	1.5	+ 5.00	-107.56	6382.62
5	1321.48	+08 -26 -00	+195.92	+0.04	+195.96	1.5	+ 5.00	+199.46	6689.64

\* In the column marked Ref., corrections are obtained from Tables of Earth's Curvature and Refraction (Breed and Hosmer, 1947)

The azimuth of line 1 to 3 was determined from observations on the star "Polaris." The orientation of the glacier is therefore referenced to true north. Computations showing an example of the sine law to compute distances are shown in Figure 7.

The geodetic positions of the triangulation stations, with the exception of triangulation station no. 1, were calculated by the method outlined in *Tentative Instructions for Computation of Geodetic Positions*.

### ELEVATIONS

The elevation of triangulation station no. 1 was obtained by running a line-of-levels from Geodetic Bench

Mark 713-E. The elevations for the other stations were calculated by trigonometry using five-place trigonometric tables and the tangent law for right-angle triangles. The mean vertical angle was calculated from the field notes. Typical computations are shown in Table 3.

### PLOTTING

The plotting of the Athabasca and Saskatchewan Glacier maps was carried out by using a Wild A-7 plotter located at the Surveys and Mapping Branch, Department of Energy, Mines and Resources.

## Volumetric Change of Glaciers

The only means of determining the change in the quantity of water held in storage by a glacier is by computing the volumetric change (Tables 4 to 15). Several methods for computing the volumetric change are possible. Four methods are described in the *Canadian Journal of Earth Sciences* (Brandenberger and Bull, 1966). Two methods are by Davey, one by Finsterwalder and one by Haumann, but none was found adequate for our particular needs. In 1963, R.O'N. Lyons<sup>1</sup> and I.A. Reid<sup>2</sup> modified the Haumann method by relating the contours to a fixed vertical plane oriented perpendicularly to the general direction of flow of the glacier. In 1966, the concept of completely enclosing the desired portion of the glacier by fixed co-ordinates was devised by R. O'N. Lyons and J. Shastal.<sup>3</sup> This method was used to determine the volumes listed in this report and is described here.

The advantages of this method are

- 1) the visible rock-ice edge does not need to be defined,
- 2) the maps compared do not need to be of the same scale,
- 3) the changes in moraine-covered ice can be detected,
- 4) the original manuscripts can be used, whereas with other methods one map had to be transparent,
- 5) the surface of the glacier at time of survey need not be assumed to be parallel to the surface at time of previous surveys,
- 6) it takes lateral, as well as longitudinal ice growth or loss into consideration, and
- 7) it provides an excellent positive check of the areas planimetered.

The basic equation of this method is: area multiplied by average height equals volume.

In Figure 8, the glacier ice edge is represented by the dashed line, and the contours are shown by the solid lines A, B, C, etc. The map is divided into squares (grid pattern). Points 1, 2, 3, etc. are co-ordinates in the grid system

which are selected and joined in such a manner that snow areas can be eliminated. In the resulting enclosure, only the ice and snow are variable and can change the volume — the rock is stable. Once the co-ordinates are selected, the area in the enclosure can be determined by trigonometry and is called the computed area. The next step is to planimeter the area between contours.

In year "X", the area formed between contour "A" and the enclosure near the contour is planimtered ( $dA_{LL}$ ). Next, the area formed between contour "A" and contour "B" in the enclosure is planimtered ( $dA_B$ ). The process is continued for contours "B" and "C", etc. until contour "F" is reached. The area formed between contour "F" and the enclosure near contour "F" is called  $dA_{UL}$ . The total area of the enclosure is then equal to  $dA_{LL} + dA_B + dA_C + \dots dA_{UL}$  or

$$\text{Total planimtered area} = \sum_{\text{lower limit}}^{\text{upper limit}} dA$$

where lower limit = enclosure in the vicinity of contour A

upper limit = enclosure in the vicinity of contour F.

If the areas are carefully planimtered, the difference between the computed area and planimtered area should be less than one percent of the total area. Any resulting difference is proportionally distributed throughout the partial areas  $dA_{LL}$ ,  $dA_B$  etc. until the planimtered area exactly equals the computed total area. This same procedure is repeated for the year "X + A".

Refer to Figure 8 and assume grid line 1000 is the centre line of the longitudinal section. The resulting profiles are shown in Figure 9.

The enclosures from Figure 8 are shown in Figure 9 as the lower and upper limits and are in the same positions for both years. The locations of the intersections of contours and the centre line of the longitudinal profile are shown as A', A'', B', B'' ... F' F''. The horizontal plane is located at the same elevation as the lowest contour, i.e., contour "A" and is called "datum." This elevation is identical for

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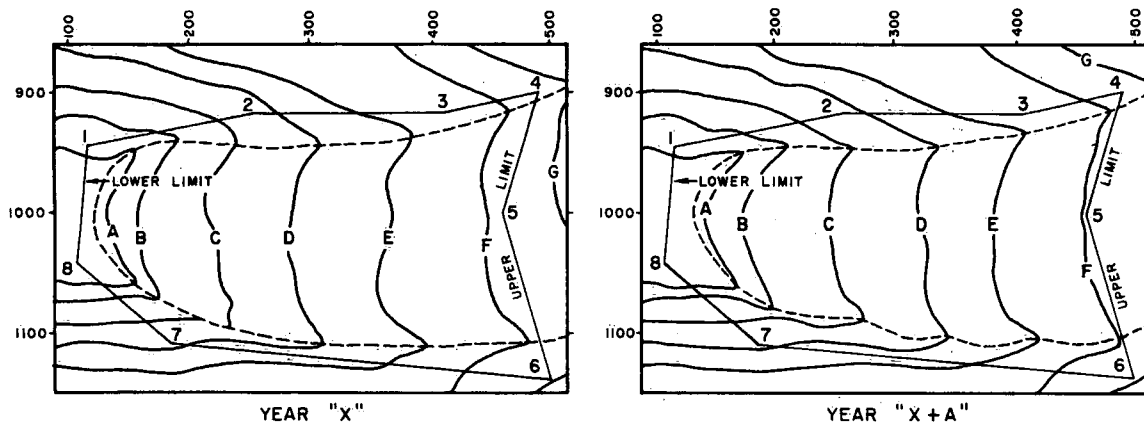


Figure 8. Representations of glacier at different dates.

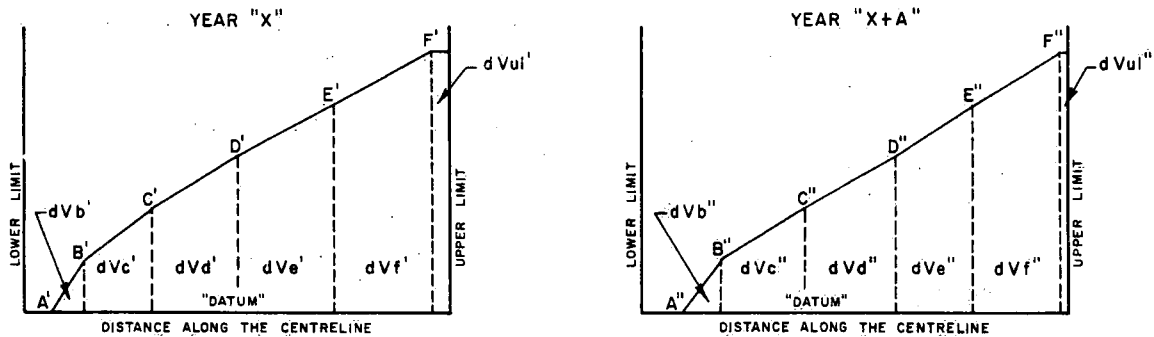


Figure 9. Longitudinal profiles of glacier.

both years. In this method, the area from the lower limit to contour "A'" is considered to be level. It is also assumed that the area from contour "F'" to the upper limit is level. With these assumptions a hypothetical volume can be computed. The partial volume between contour A' and contour B' (year "X") is the corrected area  $dA_B$  multiplied by:

$$\frac{\text{contour A' - datum} + \text{contour B' - datum}}{2}$$

or

$$dV_B = dA_B \left[ \frac{(\text{contour A' - datum})}{2} + \frac{(\text{contour B' - datum})}{2} \right]$$

Since datum = contour A'

then

$$dV_B = dA_B \frac{(\text{contour B' - datum})}{2}$$

It may be noted that there is no volume between the lower limit and contour A' because it is considered level:

$$dV_C = dA_C \left[ \frac{(\text{contour B' - datum})}{2} + \frac{(\text{contour C' - datum})}{2} \right]$$

The partial volumes are computed for each pair of contours in this manner until the highest contour is

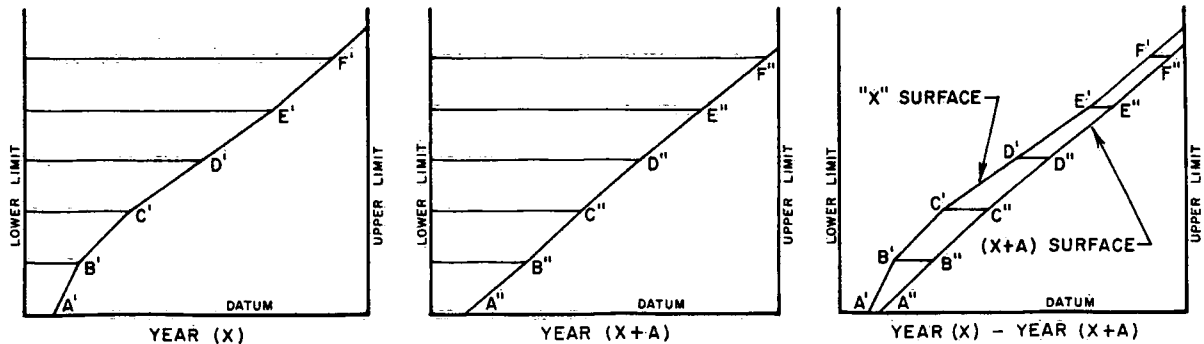


Figure 10. Profiles for computing volumetric changes in height zones.

reached (in this case contour F', which is treated in this manner):

$$dV_{UL} = dA_{UL} \left[ \frac{(\text{contour } F' - \text{datum})}{2} + \frac{(\text{elevation of the upper limit} - \text{datum})}{2} \right]$$

where  $dA_{UL}$  = area (corrected) formed by contour "F'" and the enclosure, but since the glacier is considered level from contour F' to the upper limit, the equation is reduced to:

$$dV_{UL} = dA_{UL} \left[ \frac{(\text{contour } F' - \text{datum})}{2} + \frac{(\text{contour } F' - \text{datum})}{2} \right] = dA_{UL} (\text{contour } F' - \text{datum})$$

The sum of all the partial volumes is the total hypothetical volume for year "X".

$$\text{Total volume} = \sum_{\text{lower limit}}^{\text{upper limit}} dV$$

The procedure is repeated for year "X + A", and the difference between the two volumes is the volumetric change:

Volumetric change

$$= \sum_{\text{lower limit}}^{\text{upper limit}} dV(\text{year "X"}) - \sum_{\text{lower limit}}^{\text{upper limit}} dV(\text{year "X + A"})$$

To ascertain where loss or gain in storage is occurring, it is necessary to compute the volumetric change between various elevations. The term "height zone" is defined as the space between a pair of contours, i.e., height zone A-B is that space between contours A and B. Using the profiles of Figure 9, volumetric changes in height zones can be represented as shown in Figure 10.

The formula used for computing volumetric changes in the various height zones is that of Finsterwalder and Haumann, but the procedure is slightly different. The theory in this work is as follows. The volumetric change of a height zone is the mean of the two areas, one produced by the horizontal movement of the lower contour and the other by the horizontal movement of the upper contour multiplied by the difference in elevation of the two contours. Referring to Figure 10

height zone "C-D",  $dV$

$$= \left[ \frac{(\text{Area } C' - C'') + (\text{Area } D' - D'')}{2} \right] (\text{contour } D - \text{contour } C)$$

where Area C' - C'' = (the area formed between the lower limit and C') - (the area formed by the lower limit and C'')

Therefore Area C' - C'' =  $(dA_{LL} + dA_{B'} + dA_{C'}) - (dA_{LL''} + dA_{B''} + dA_{C''})$  from Figure 9

and Area D' - D'' =  $(dA_{LL} + dA_{B'} + dA_{C'} + dA_{D'}) - (dA_{LL''} + dA_{B''} + dA_{C''} + dA_{D''})$

Since the volumetric change figures are quite large and difficult to conceive, an abstract dimension called the

"effective change in surface" was created. This is simply a way of expressing volumes in terms of one dimension.

$$\text{Volumetric change} = \text{Vol}_{(X)} - \text{Vol}_{(X+A)}$$

but volume = area x height.

$$\begin{aligned} \text{Thus volumetric change} &= (\text{Area}_X) (\text{ht}_X) \\ &\quad - (\text{Area}_{X+A}) (\text{ht}_{X+A}) \end{aligned}$$

By taking the mean of  $\text{Area}_{(X)}$  and  $\text{Area}_{(X+A)}$

$$\text{we obtain Area (mean)} = \frac{\text{Area}_{(X)} + \text{Area}_{(X+A)}}{2}$$

Now volumetric change

$$\begin{aligned} &= [\text{Area (mean)}] [\text{ht}_X] - [\text{Area (mean)}] [\text{ht}_{X+A}] \\ &= [\text{Area (mean)}] [\text{ht}_X - \text{ht}_{X+A}] \end{aligned}$$

Volumetric change =  $\text{ht}_{(X)} - \text{ht}_{(X+A)}$  = effective change in surface area (mean).

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**Table 4. Athabasca Glacier –  
Volumetric Change Co-ordinates of Maps for 1959, 1962, 1965,  
1967, 1969 and 1971, U.T.M. Grid System**

	North-South	East-West		North-South	East-West
A	5,784,500	483,700	J	5,780,900	482,000
B	5,784,500	484,100	K	5,780,900	481,700
C	5,784,200	484,300	L	5,781,300	481,300
D	5,783,900	484,300	M	5,781,800	481,800
E	5,783,100	483,900	N	5,782,000	481,800
F	5,782,400	483,200	O	5,782,500	482,200
G	5,781,800	482,700	P	5,783,600	483,300
H	5,781,000	482,300	Q	5,784,400	483,700

**Table 5. Athabasca Glacier –  
Summary of Changes for 1959 vs 1962 Maps**

Height zone (ft)	dV (cu ft)	Mean 59 & 62 areas (sq ft)	Effective surface change (ft)	Effective surface change (ft/yr)
6,330-6,350	- 2,466,330	197,052	- 12.52	- 4.17
6,350-6,400	- 8,100,075	367,704	- 22.03	- 7.34
6,400-6,450	- 7,854,825	310,232	- 25.32	- 8.44
6,450-6,500	- 7,245,600	333,229	- 21.74	- 7.25
6,500-6,550	- 6,736,450	377,822	- 17.83	- 5.94
6,550-6,600	- 6,051,450	448,090	- 13.50	- 4.50
6,600-6,650	- 5,678,575	586,311	- 9.69	- 3.23
6,650-6,700	- 5,200,925	706,673	- 7.36	- 2.45
6,700-6,750	- 4,854,875	875,958	- 5.54	- 1.85
6,750-6,800	- 4,625,700	927,023	- 4.99	- 1.66
6,800-6,850	- 6,613,575	1,115,939	- 5.93	- 1.98
6,850-6,900	- 10,787,150	1,438,038	- 7.50	- 2.50
6,900-6,950	- 11,142,775	1,455,744	- 7.65	- 2.55
6,950-7,000	- 8,910,175	1,219,396	- 7.31	- 2.44
7,000-7,050	- 8,391,950	1,185,847	- 7.08	- 2.36
7,050-7,100	- 7,626,675	1,203,460	- 6.34	- 2.11
7,100-7,150	- 7,050,550	1,640,362	- 4.30	- 1.43
7,150-7,200	- 5,920,125	2,088,394	- 2.83	- 0.94
7,200-7,250	+ 110,000	2,966,116	+ 0.04	+ 0.01
7,250-7,300	+ 4,962,550	3,161,376	+ 1.57	+ 0.52
7,300-7,350	+ 4,043,150	2,371,502	+ 1.70	+ 0.57
7,350-7,400	+ 849,950	2,570,886	+ 0.33	+ 0.11
7,400-7,450	- 1,664,250	2,037,756	- 0.82	- 0.27
7,450-7,500	- 45,775	1,385,504	- 0.03	- 0.01
7,500-7,550	+ 653,600	623,512	+ 1.05	+ 0.35
7,550-7,600	- 159,425	499,444	- 0.32	- 0.11
7,600-7,650	+ 965,250	457,150	+ 2.11	+ 0.70
7,650-7,700	+ 3,373,625	652,942	+ 5.17	+ 1.72
7,700-7,750	+ 7,213,075	1,119,292	+ 6.44	+ 2.15
7,750-7,800	+12,001,100	1,374,137	+ 8.73	+ 2.91

Volumetric change of height zone (dV)  
Mean of 1959 & 1962 areas = Effective change in  
surface elevation

**Table 6. Athabasca Glacier –  
Summary of Changes for 1962 vs 1965 Maps**

Height zone (ft)	dV (cu ft)	Mean 62 & 65 areas (sq ft)	Effective surface change (ft)	Effective surface change (ft/yr)
6,330-6,350	- 2,433,190	252,642	- 9.63	- 3.21
6,350-6,400	- 8,058,700	390,313	- 20.65	- 6.88
6,400-6,450	- 8,079,350	283,131	- 28.54	- 9.51
6,450-6,500	- 7,636,500	339,289	- 22.51	- 7.50
6,500-6,550	- 8,037,925	369,606	- 21.75	- 7.25
6,550-6,600	- 8,239,775	446,642	- 18.45	- 6.15
6,600-6,650	- 8,266,475	580,836	- 14.23	- 4.74
6,650-6,700	- 7,935,500	695,975	- 11.40	- 3.80
6,700-6,750	- 7,834,325	877,710	- 8.93	- 2.98
6,750-6,800	- 8,220,475	928,410	- 8.85	- 2.95
6,800-6,850	- 6,907,050	1,128,042	- 6.12	- 2.04
6,850-6,900	- 7,900,725	1,529,280	- 5.17	- 1.72
6,900-6,950	- 6,614,975	1,345,900	- 4.91	- 1.64
6,950-7,000	- 4,767,925	1,247,648	- 3.82	- 1.27
7,000-7,050	- 5,365,750	1,159,187	- 4.63	- 1.54
7,050-7,100	- 2,799,675	1,163,494	- 2.41	- 0.80
7,100-7,150	- 5,837,875	1,729,570	- 3.38	- 1.13
7,150-7,200	- 6,963,425	1,999,088	- 3.48	- 1.16
7,200-7,250	- 1,812,775	2,831,806	- 0.64	- 0.21
7,250-7,300	- 4,345,900	3,249,287	- 1.34	- 0.45
7,300-7,350	- 3,778,150	2,290,634	- 1.65	- 0.55
7,350-7,400	- 2,211,475	2,684,286	- 0.82	- 0.27
7,400-7,450	- 3,291,250	1,996,236	- 1.65	- 0.55
7,450-7,500	+ 98,200	1,326,865	+ 0.07	+ 0.02
7,500-7,550	+ 871,525	652,698	+ 1.34	+ 0.45
7,550-7,600	+ 1,794,900	468,051	+ 3.83	+ 1.28
7,600-7,650	+ 2,124,200	459,463	+ 4.62	+ 1.54
7,650-7,700	+ 1,115,300	622,639	+ 1.79	+ 0.60
7,700-7,750	+ 1,509,250	1,064,926	+ 1.42	+ 0.47
7,750-7,800	- 3,779,100	1,438,509	- 2.63	- 0.88

Volumetric change of height zone (dV)  
Mean of 1962 & 1965 areas = Effective change in  
surface elevation

**Table 7. Athabasca Glacier –  
Summary of Changes for 1965 vs 1967 Maps**

Height zone (ft)	dV (cu ft)	Mean 65 & 67 areas (sq ft)	Effective surface change (ft)	Effective surface change (ft/yr)
6,330-6,350	+ 360,400	276,310	+ 1.30	+ 0.65
6,350-6,400	+ 707,850	410,023	+ 1.73	+ 0.86
6,400-6,450	- 132,575	280,642	- 0.47	- 0.24
6,450-6,500	- 104,625	332,362	- 0.31	- 0.16
6,500-6,550	+ 779,550	366,879	+ 2.12	+ 1.06
6,550-6,600	+ 826,025	452,476	+ 1.83	+ 0.92
6,600-6,650	+ 720,650	577,643	+ 1.25	+ 0.62
6,650-6,700	+ 221,225	702,538	+ 0.31	+ 0.16
6,700-6,750	+ 798,475	857,580	+ 0.93	+ 0.47
6,750-6,800	+ 3,554,200	901,149	+ 3.94	+ 1.97
6,800-6,850	+ 3,977,875	1,120,560	+ 3.55	+ 1.77
6,850-6,900	+ 5,311,100	1,529,970	+ 3.47	+ 1.74
6,900-6,950	+ 5,363,875	1,318,438	+ 4.07	+ 2.03
6,950-7,000	+ 6,481,775	1,215,810	+ 5.33	+ 2.67
7,000-7,050	+10,387,475	1,124,868	+ 9.23	+ 4.62
7,050-7,100	+ 9,530,675	1,163,628	+ 8.19	+ 4.10
7,100-7,150	+11,977,200	1,741,270	+ 6.88	+ 3.44
7,150-7,200	+13,504,300	1,979,357	+ 6.82	+ 3.41
7,200-7,250	+ 8,044,775	2,857,714	+ 2.82	+ 1.41
7,250-7,300	+ 3,693,400	3,361,059	+ 1.10	+ 0.55
7,300-7,350	- 1,536,575	2,272,116	- 0.68	- 0.34
7,350-7,400	- 6,329,325	2,767,324	- 2.29	- 1.14
7,400-7,450	- 7,922,450	1,966,655	- 4.03	- 2.01
7,450-7,500	- 4,614,225	1,222,492	- 3.77	- 1.89
7,500-7,550	- 28,625	649,892	- 0.04	- 0.02
7,550-7,600	- 215,300	456,123	- 0.47	- 0.24
7,600-7,650	+ 436,050	451,778	+ 0.97	+ 0.48
7,650-7,700	+ 1,326,025	632,702	+ 2.10	+ 1.05
7,700-7,750	+ 2,246,725	1,028,570	+ 2.18	+ 1.09
7,750-7,800	+ 3,387,475	1,557,818	+ 2.17	+ 1.09

Volumetric change of height zone (dV)  
Mean of 1965 & 1967 areas = Effective change in  
surface elevation

**Table 8. Athabasca Glacier –  
Summary of Changes for 1967 vs 1969 Maps**

Height zone (ft)	dV (cu ft)	Mean 67 & 69 areas (sq ft)	Effective surface change (ft)	Effective surface change (ft/yr)
6,330-6,350	- 282,220	275,007	- 1.03	- 0.52
6,350-6,400	- 1,028,100	421,640	- 2.44	- 1.22
6,400-6,450	- 1,134,050	287,953	- 3.94	- 1.97
6,450-6,500	- 1,031,700	322,445	- 3.20	- 1.60
6,500-6,550	- 1,139,575	361,270	- 3.15	- 1.58
6,550-6,600	- 1,055,750	455,480	- 2.32	- 1.16
6,600-6,650	- 364,275	562,918	- 0.65	- 0.32
6,650-6,700	+ 1,001,750	699,931	+ 1.43	+ 0.72
6,700-6,750	+ 469,800	859,280	+ 0.55	+ 0.28
6,750-6,800	- 2,353,950	900,809	- 2.61	- 1.30
6,800-6,850	- 3,377,800	1,132,904	- 2.98	- 1.49
6,850-6,900	- 2,052,850	1,464,463	- 1.40	- 0.70
6,900-6,950	- 732,700	1,356,487	- 0.54	- 0.27
6,950-7,000	- 690,775	1,154,566	- 0.60	- 0.30
7,000-7,050	- 1,506,650	1,124,316	- 1.34	- 0.67
7,050-7,100	- 857,475	1,168,332	- 0.73	- 0.36
7,100-7,150	+ 2,345,275	1,623,580	+ 1.44	+ 0.72
7,150-7,200	+ 1,757,500	2,078,260	+ 0.85	+ 0.42
7,200-7,250	+ 7,078,800	2,783,299	+ 2.54	+ 1.27
7,250-7,300	+ 11,645,450	3,409,446	+ 3.42	+ 1.71
7,300-7,350	+ 7,404,325	2,413,152	+ 3.07	+ 1.54
7,350-7,400	+ 10,806,650	2,654,098	+ 4.07	+ 2.04
7,400-7,450	+ 15,484,000	2,018,197	+ 7.67	+ 3.84
7,450-7,500	+ 8,040,075	1,253,664	+ 6.41	+ 3.20
7,500-7,550	+ 1,977,925	648,250	+ 3.05	+ 1.52
7,550-7,600	+ 1,848,100	464,094	+ 3.98	+ 1.99
7,600-7,650	+ 1,474,425	438,254	+ 3.36	+ 1.68
7,650-7,700	+ 2,636,650	605,183	+ 4.36	+ 2.18
7,700-7,750	+ 1,702,550	1,056,357	+ 1.61	+ 0.80
7,750-7,800	+ 4,055,500	1,460,156	+ 2.78	+ 1.39

Volumetric change of height zone (dV)  
Mean of 1967 & 1969 areas = Effective change in  
surface elevation

**Table 9. Athabasca Glacier –  
Summary of Changes for 1969 vs 1971 Maps**

Height zone (m)	dV (cu m)	Mean 69 & 71 areas (sq m)	Effective surface change (m)	Effective surface change (m/yr)
1,940-1,950	- 22,002	20,640	- 1.07	- 0.53
1,950-1,960	- 37,266	19,027	- 1.96	- 0.98
1,960-1,970	- 49,340	19,028	- 2.59	- 1.30
1,970-1,980	- 67,850	19,670	- 3.45	- 1.72
1,980-1,990	- 86,304	21,608	- 3.99	- 2.00
1,990-2,000	- 88,513	25,157	- 3.52	- 1.76
2,000-2,010	- 106,701	28,378	- 3.76	- 1.88
2,010-2,020	- 115,023	33,867	- 3.40	- 1.70
2,020-2,030	- 97,334	38,059	- 2.56	- 1.28
2,030-2,040	- 109,066	41,334	- 2.64	- 1.32
2,040-2,050	- 108,264	49,088	- 2.20	- 1.10
2,050-2,060	- 94,424	54,899	- 1.72	- 0.86
2,060-2,070	- 145,115	55,541	- 2.61	- 1.31
2,070-2,080	- 192,477	66,202	- 2.91	- 1.45
2,080-2,090	- 186,972	78,052	- 2.40	- 1.20
2,090-2,100	- 236,064	83,743	- 2.82	- 1.41
2,100-2,110	- 276,409	89,225	- 3.10	- 1.55
2,110-2,120	- 262,016	81,493	- 3.22	- 1.61
2,120-2,130	- 296,113	69,572	- 4.26	- 2.13
2,130-2,140	- 304,543	69,899	- 4.36	- 2.18
2,140-2,150	- 252,620	66,761	- 3.78	- 1.89
2,150-2,160	- 308,002	70,313	- 4.38	- 2.19
2,160-2,170	- 411,833	84,502	- 4.87	- 2.44
2,170-2,180	- 525,547	121,595	- 4.32	- 2.16
2,180-2,190	- 691,028	125,142	- 5.52	- 2.76
2,190-2,200	- 834,009	140,623	- 5.93	- 2.97
2,200-2,210	- 1,235,375	216,103	- 5.72	- 2.86
2,210-2,220	- 1,404,774	202,538	- 6.94	- 3.47
2,220-2,230	- 1,174,030	162,548	- 7.22	- 3.61
2,230-2,240	- 1,213,997	150,945	- 8.04	- 4.02
2,240-2,250	- 1,389,363	147,718	- 9.41	- 4.70
2,250-2,260	- 1,322,818	146,097	- 9.05	- 4.53
2,260-2,270	- 1,077,390	118,223	- 9.11	- 4.56
2,270-2,280	- 846,971	76,671	- 11.05	- 5.52
2,280-2,290	- 565,602	51,874	- 10.90	- 5.45
2,290-2,300	- 355,478	33,503	- 10.61	- 5.30
2,300-2,310	- 316,284	27,701	- 11.42	- 5.71
2,310-2,320	- 331,891	28,667	- 11.58	- 5.79
2,320-2,330	- 353,952	26,412	- 13.40	- 6.70
2,330-2,340	- 398,472	38,650	- 10.31	- 5.16
2,340-2,350	- 587,709	52,490	- 11.20	- 5.60
2,350-2,360	- 757,319	72,795	- 10.40	- 5.20
2,360-2,370	- 904,167	76,650	- 11.80	- 5.90

Volumetric change of height zone (dV)  
Mean of 1969 & 1971 areas = Effective change in  
surface elevation

**Table 10. Athabasca Glacier –  
Summary of Volumetric Changes in the Period 1959-1971**

Period	Total volumetric change (cu m)	Number of years	Vol. change/yr (cu m)	Effective surface change/yr (m)
1959-62	- 2,630,000	3	- 1,320,000	- 0.26
1962-65	- 3,780,000	3	- 1,890,000	- 0.37
1965-67	+ 2,060,000	2	+ 1,030,000	+ 0.30
1967-69	+ 1,730,000	2	+ 860,000	+ 0.26
1969-71	- 21,090,000	2	- 10,550,000	- 3.13
1959-71	- 23,710,000	12	- 11,860,000	- 0.27

Table 11. Saskatchewan Glacier - Volumetric Change Co-ordinates, U.T.M. Grid System

1963-65 Map		1965-67 Map		1967-69 Map		1969-71 Map	
North-South	East-West	North-South	East-West	North-South	East-West	North-South	East-West
A 5,779,300	491,000	A 5,779,300	491,000	A 5,779,300	491,000	A 5,779,200	490,400
B 5,778,700	491,000	B 5,778,700	491,000	B 5,778,700	491,000	B 5,779,000	490,600
C 5,778,600	490,500	C 5,778,600	490,500	C 5,778,600	490,500	C 5,778,800	490,700
D 5,776,700	488,000	D 5,776,700	488,000	D 5,775,700	487,000	D 5,778,300	490,000
E 5,775,600	486,400	E 5,775,600	486,400	E 5,775,500	486,400	E 5,777,500	489,000
F 5,775,400	485,200	F 5,775,400	485,200	F 5,775,400	485,200	F 5,776,700	488,000
G 5,775,500	485,000	G 5,775,500	485,000	G 5,775,500	485,000	G 5,775,600	486,400
H 5,775,500	484,300	H 5,775,700	485,000	H 5,775,700	485,000	H 5,775,500	485,300
J 5,775,900	484,700	J 5,776,000	485,400	J 5,776,000	485,400	I 5,776,800	485,200
K 5,776,200	484,500	K 5,776,800	485,400	K 5,776,800	485,400	J 5,776,800	485,400
L 5,776,300	484,200	L 5,777,300	486,700	L 5,777,300	486,700	K 5,777,300	486,700
M 5,776,600	484,800	M 5,778,100	487,600	M 5,778,100	487,600	L 5,778,100	487,700
N 5,776,800	485,000	N 5,778,900	489,000	N 5,778,900	489,000	M 5,778,800	489,000
O 5,776,800	485,400	O 5,779,200	490,000	O 5,779,200	490,000	N 5,779,100	490,000
P 5,777,300	486,700						
Q 5,778,100	487,600						
R 5,778,900	489,000						
S 5,779,200	490,000						

Table 12. Saskatchewan Glacier -  
Summary of Changes for 1965 vs 1967 Maps

Height zone (ft)	dV (cu ft)	Mean 65 & 67 areas (sq ft)	Effective surface change (ft)	Effective surface change (ft/yr)
5,880-5,920	- 6,009,180	605,763	- 9.92	- 4.96
5,920-5,960	- 11,872,520	477,720	- 24.85	- 12.43
5,960-6,000	- 15,905,300	518,359	- 30.68	- 15.34
6,000-6,040	- 16,287,560	684,877	- 23.78	- 11.89
6,040-6,080	- 11,893,380	753,664	- 15.78	- 7.89
6,080-6,120	- 9,064,180	787,558	- 11.51	- 5.76
6,120-6,160	- 12,254,700	926,353	- 13.23	- 6.62
6,160-6,200	- 19,257,160	1,245,027	- 15.47	- 7.74
6,200-6,240	- 19,483,080	1,346,240	- 14.47	- 7.24
6,240-6,280	- 12,736,060	1,194,788	- 10.66	- 5.33
6,280-6,320	- 9,009,120	1,339,834	- 6.72	- 3.36
6,320-6,360	- 16,142,220	1,510,604	- 10.69	- 5.34
6,360-6,400	- 27,753,460	1,659,730	- 16.72	- 8.36
6,400-6,440	- 33,202,100	1,820,134	- 18.24	- 9.12
6,440-6,480	- 29,342,540	1,849,250	- 15.87	- 7.94
6,480-6,520	- 30,587,200	1,804,810	- 16.95	- 8.48
6,520-6,560	- 41,179,680	1,778,786	- 23.15	- 11.58
6,560-6,600	- 45,351,600	1,981,686	- 22.89	- 11.44
6,600-6,640	- 49,528,920	2,752,771	- 17.99	- 8.00
6,640-6,680	- 50,585,200	2,999,800	- 16.86	- 8.43
6,680-6,720	- 44,211,220	2,343,260	- 18.87	- 9.44
6,720-6,760	- 43,678,040	2,070,086	- 21.10	- 10.55
6,760-6,800	- 50,141,460	2,021,584	- 24.80	- 12.40
6,800-6,840	- 44,941,040	2,411,464	- 18.64	- 9.32
6,840-6,880	- 37,386,340	2,418,468	- 15.46	- 7.73
6,880-6,920	- 42,806,620	2,629,064	- 16.28	- 8.14
6,920-6,960	- 41,684,660	2,086,786	- 19.98	- 9.99
6,960-7,000	- 37,884,520	1,929,794	- 19.63	- 9.82
7,000-7,040	- 38,042,920	2,457,185	- 15.48	- 7.74
7,040-7,080	- 37,918,440	2,583,572	- 14.68	- 7.34
7,080-7,120	- 36,199,900	2,753,254	- 13.15	- 6.58
7,120-7,160	- 38,210,520	2,401,569	- 15.91	- 7.96
7,160-7,200	- 51,779,560	2,697,384	- 19.20	- 9.60
7,200-7,240	- 56,992,600	3,767,287	- 15.13	- 7.56
7,240-7,280	- 42,561,140	3,820,762	- 11.14	- 5.57
7,280-7,320	- 38,557,920	3,722,452	- 10.36	- 5.18
7,320-7,360	- 41,020,160	2,509,453	- 16.35	- 8.18
7,360-7,400	- 34,201,340	2,465,128	- 13.87	- 6.94
7,400-7,440	- 25,090,640	1,994,416	- 12.58	- 6.29
7,440-7,480	- 12,696,460	1,135,420	- 11.18	- 5.59
7,480-7,520	- 4,138,380	555,652	- 7.45	- 3.72
7,520-7,560	- 4,221,360	600,564	- 7.03	- 3.52
7,560-7,600	- 3,096,360	353,193	- 8.77	- 4.38

Volumetric change of height zone (dV)  
Mean of 1965 & 1967 areas = Effective change in  
surface elevation

Table 13. Saskatchewan Glacier -  
Summary of Changes for 1967 vs 1969 Maps

Height zone (ft)	dV (cu ft)	Mean 67 & 69 areas (sq ft)	Effective surface change (ft)	Effective surface change (ft/yr)
5,880-5,920	+ 4,406,400	893,558	+ 4.93	+ 2.46
5,920-5,960	- 1,372,420	481,556	- 2.85	- 1.42
5,960-6,000	+ 816,740	560,614	+ 1.46	+ 0.73
6,000-6,040	- 179,980	673,334	- 0.26	- 1.30
6,040-6,080	- 3,042,460	719,840	- 4.23	- 2.12
6,080-6,120	- 3,940,240	766,448	- 5.14	- 2.57
6,120-6,160	- 4,417,620	1,045,914	- 4.22	- 2.11
6,160-6,200	- 3,836,200	1,314,209	- 2.92	- 1.46
6,200-6,240	- 459,800	1,235,150	- 0.37	- 0.18
6,240-6,280	- 4,440,200	1,282,204	- 3.46	- 1.73
6,280-6,320	- 13,766,340	1,437,890	- 9.57	- 4.78
6,320-6,360	- 12,214,240	1,597,564	- 7.64	- 3.82
6,360-6,400	- 4,416,740	1,756,790	- 2.51	- 1.26
6,400-6,440	- 4,710,800	1,981,230	- 2.38	- 1.19
6,440-6,480	- 7,723,100	1,885,204	- 4.10	- 2.05
6,480-6,520	- 4,254,380	2,069,678	- 2.06	- 1.03
6,520-6,560	- 7,005,900	2,100,270	- 3.34	- 1.67
6,560-6,600	- 14,111,200	2,091,200	- 6.75	- 3.38
6,600-6,640	- 7,675,660	2,754,290	- 2.79	- 1.40
6,640-6,680	- 4,100,860	3,112,094	- 1.32	- 0.66
6,680-6,720	- 10,005,040	2,421,740	- 4.13	- 2.06
6,720-6,760	- 7,238,000	2,109,965	- 3.43	- 1.72
6,760-6,800	+ 457,840	2,134,493	+ 0.21	+ 0.10
6,800-6,840	+ 428,480	2,352,789	+ 0.18	+ 0.09
6,840-6,880	+ 670,260	2,543,864	+ 0.26	+ 0.13
6,880-6,920	+ 8,314,220	2,874,738	+ 2.89	+ 1.44
6,920-6,960	+ 7,634,060	2,368,278	+ 3.22	+ 1.61
6,960-7,000	+ 3,598,940	2,191,234	+ 1.64	+ 0.82
7,000-7,040	+ 12,090,380	2,848,368	+ 4.24	+ 2.12
7,040-7,080	+ 15,644,720	3,186,996	+ 4.91	+ 2.46
7,080-7,120	+ 17,008,240	3,190,827	+ 5.33	+ 2.66
7,120-7,160	+ 25,387,260	3,643,210	+ 6.97	+ 3.48
7,160-7,200	+ 34,616,520	3,795,337	+ 9.12	+ 4.56
7,200-7,240	+ 34,738,760	3,987,987	+ 8.71	+ 4.36
7,240-7,280	+ 29,640,800	3,612,777	+ 8.20	+ 4.10
7,280-7,320	+ 29,572,520	3,983,745	+ 7.42	+ 3.71
7,320-7,360	+ 18,726,880	2,723,343	+ 6.88	+ 3.44
7,360-7,400	+ 8,889,260	2,502,510	+ 3.55	+ 1.78
7,400-7,440	+ 7,257,260	1,962,526	+ 3.70	+ 1.85
7,440-7,480	+ 2,151,160	1,116,092	+ 1.93	+ 0.96
7,480-7,520	+ 1,811,540	507,060	- 3.57	- 1.78

Volumetric change of height zone (dV)  
Mean of 1967 & 1969 areas = Effective change in  
surface elevation

**Table 14. Saskatchewan Glacier –  
Summary of Changes for 1969 vs 1971 Maps**

Height zone (m)	dV (cu m)	Mean 69 & 71 areas (sq m)	Effective surface change (m)	Effective surface change (m/yr)
1,790-1,800	- 43,386	28,081	- 1.54	- 0.77
1,800-1,810	- 69,853	29,370	- 2.38	- 1.19
1,810-1,820	- 109,317	35,828	- 3.05	- 1.53
1,820-1,830	- 170,928	46,413	- 3.68	- 1.84
1,830-1,840	- 206,213	53,182	- 3.88	- 1.94
1,840-1,850	- 215,711	47,059	- 4.58	- 2.29
1,850-1,860	- 238,098	55,761	- 4.27	- 2.14
1,860-1,870	- 286,234	67,686	- 4.23	- 2.11
1,870-1,880	- 315,994	76,489	- 4.13	- 2.07
1,880-1,890	- 337,083	76,491	- 4.41	- 2.20
1,890-1,900	- 382,948	84,125	- 4.55	- 2.28
1,900-1,910	- 424,545	93,472	- 4.54	- 2.27
1,910-1,920	- 493,729	102,357	- 4.82	- 2.41
1,920-1,930	- 590,419	110,407	- 5.35	- 2.67
1,930-1,940	- 660,966	111,993	- 5.90	- 2.95
1,940-1,950	- 689,333	113,926	- 6.05	- 3.03
1,950-1,960	- 722,563	121,200	- 5.96	- 2.98
1,960-1,970	- 751,108	125,380	- 5.99	- 3.00
1,970-1,980	- 776,531	125,389	- 6.19	- 3.10
1,980-1,990	- 857,132	141,187	- 6.07	- 3.04
1,990-2,000	- 1,081,686	152,997	- 7.07	- 3.54
2,000-2,010	- 1,505,066	185,925	- 8.10	- 4.05
2,010-2,020	- 1,641,862	210,735	- 7.79	- 3.90
2,020-2,030	- 1,391,299	179,426	- 7.75	- 3.88
2,030-2,040	- 1,162,706	155,549	- 7.48	- 3.74
2,040-2,050	- 1,054,514	140,531	- 7.50	- 3.75
2,050-2,060	- 1,021,801	140,531	- 7.27	- 3.64
2,060-2,070	- 1,011,634	150,523	- 6.72	- 3.36
2,070-2,080	- 1,056,210	170,506	- 6.20	- 3.10
2,080-2,090	- 1,116,846	183,077	- 6.10	- 3.05
2,090-2,100	- 1,106,563	175,664	- 6.30	- 3.15
2,100-2,110	- 1,028,627	163,416	- 6.30	- 3.15
2,110-2,120	- 941,067	148,912	- 6.32	- 3.16
2,120-2,130	- 977,357	152,320	- 6.42	- 3.21
2,130-2,140	- 1,072,584	176,534	- 6.08	- 3.04
2,140-2,150	- 1,101,196	191,062	- 5.76	- 2.88
2,150-2,160	- 1,251,068	220,446	- 5.68	- 2.84
2,160-2,170	- 1,249,279	193,304	- 6.46	- 3.23
2,170-2,180	- 1,186,484	189,200	- 6.27	- 3.14
2,180-2,190	- 1,520,936	254,950	- 5.97	- 2.98
2,190-2,200	- 1,771,387	305,236	- 5.80	- 2.90
2,200-2,210	- 1,725,261	280,096	- 6.16	- 3.08
2,210-2,220	- 1,495,501	254,635	- 5.87	- 2.94
2,220-2,230	- 1,169,167	208,543	- 5.61	- 2.80
2,230-2,240	- 1,020,221	188,557	- 5.41	- 2.70
2,240-2,250	- 929,355	172,442	- 5.39	- 2.70
2,250-2,260	- 850,223	154,512	- 5.50	- 2.75
2,260-2,270	- 425,983	190,195	- 2.24	- 1.12

Volumetric change of height zone (dV) = Effective change in  
Mean of 1969 & 1971 areas surface elevation

**Table 15. Saskatchewan Glacier –  
Summary of Volumetric Changes in the Period 1963-1971**

Period	Total volumetric change (cu m)	Number of years	Vol. change/yr (cu m)	Effective surface change/yr (m)
1963-65	- 52,030,000	2	- 26,010,000	- 3.03
1965-67	- 35,810,000	2	- 17,910,000	- 2.34
1967-69	+ 4,190,000	2	+ 2,100,000	+0.25
1969-71	- 40,820,000	2	- 20,410,000	- 2.92
1963-71	- 124,470,000	8	- 62,240,000	- 1.00

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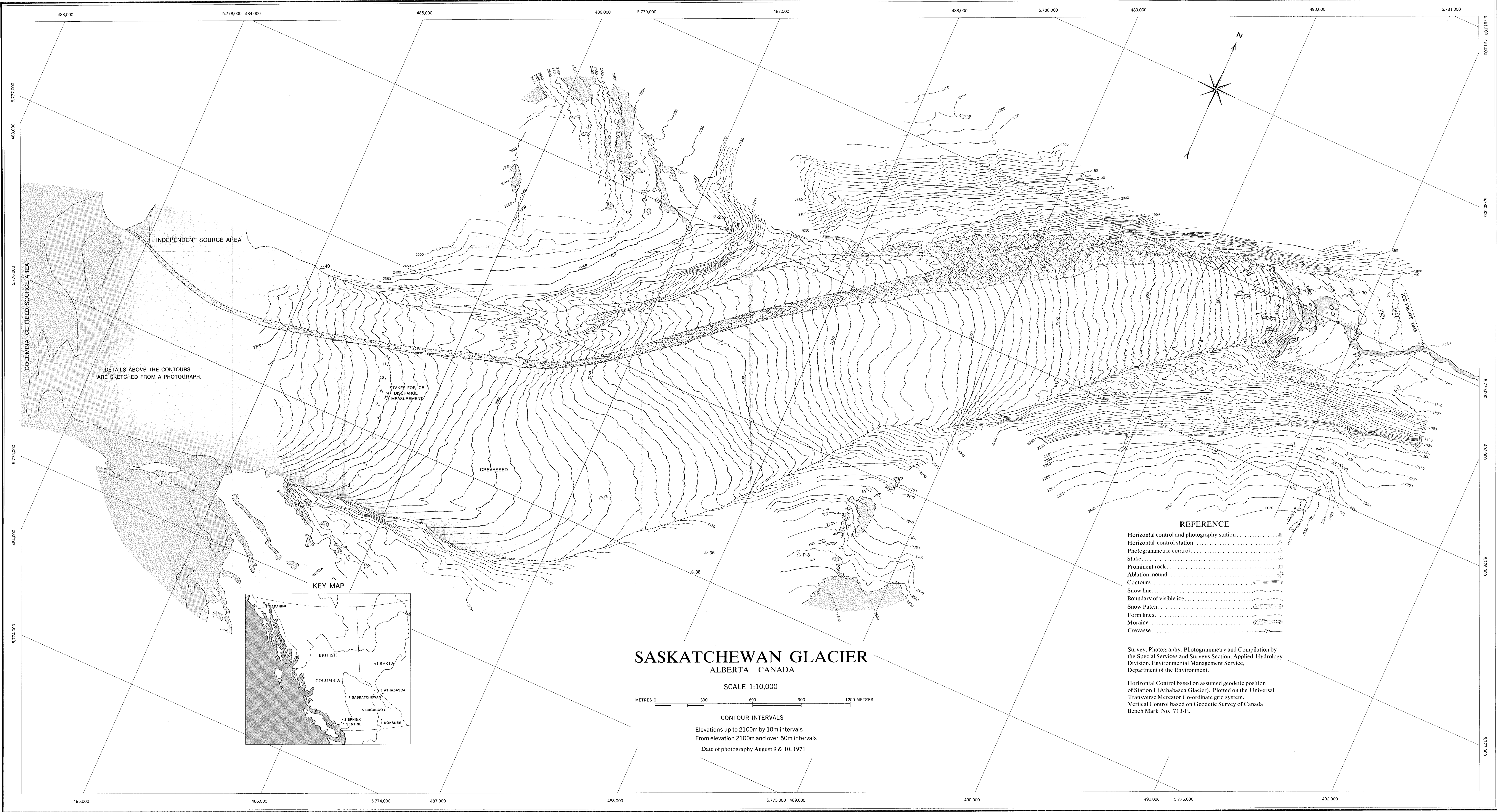
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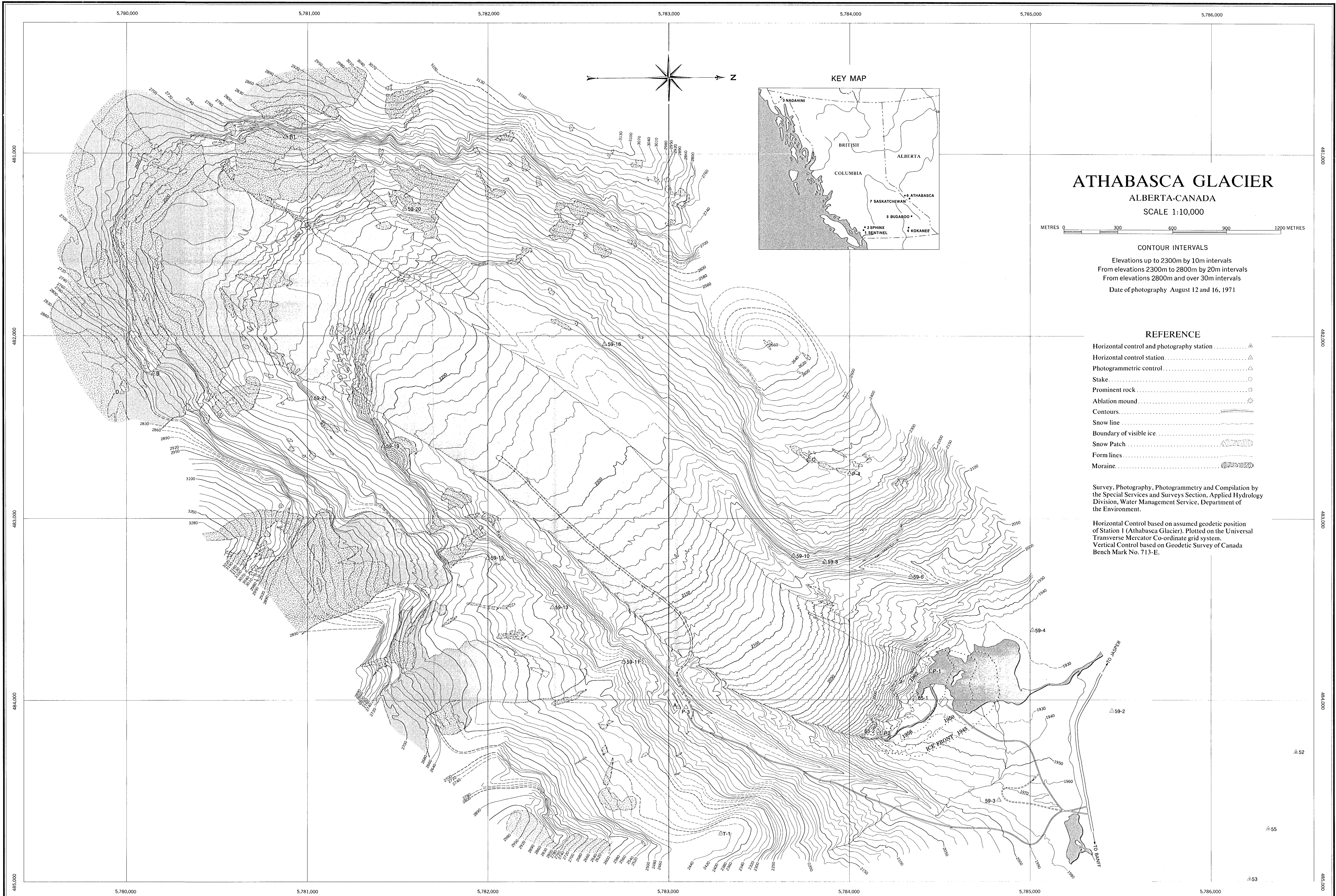
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