Honor Student Paper:

A Comparison of Meltwater Discharge From a Debris-Free and a Debris-Covered Glacier, Canadian Rocky Mountains

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INTRODUCTION

A common characteristic linking most glacial meltwater forecasting models is that they have been developed from glaciers exhibiting relatively "clean" surfaces. In reality, however, a significant portion of the world's glaciers contain either a partial or complete debris cover which masks their ablation zones. It is hypothesized that this debris cover can significantly influence the surficial ablation process, thereby altering the discharge characteristics of their meltwater streams.

PURPOSE

The purpose of this poster paper is to test this hypothesis by comparing and contrasting the surficial ablation and the meltwater discharge characteristics of a debris free glacier and a debris covered glacier.

OBJECTIVES

1) To prove that a debris cover on a glacier's surface does exert a significant influence on ablation;
2) To illustrate that the two basins are similar in all respects with the exception of a debris cover; and
3) To illustrate how meltwater discharge patterns differ between debris-free and debris-covered glaciers.

STUDY SITES

The two basins chosen for this study are the Athabasca (52° 11' N, 117° 15' W) and the Dome (52° 12' N 117° 17' W), both of which are located in the Columbia Icefield (Figure 1). These adjacent basins contain the streams which form the headwaters of the Sunwapta River which, in turn, flows via the Athabasca, Slave, and Mackenzie Rivers to the Arctic Ocean. The hypsometric curves for the two basins are illustrated in Figure 2. A list of the morphometric, morphologic, and dynamic characteristics of the Dome and Athabasca Glaciers is given in Table 1. The extensive debris cover is the most evident characteristic which differentiates the Dome from the Athabasca Glacier. The debris cover extends over the entire glacier surface from the terminus to a point 625 m up-glacier (Figure 1). From this point on, to a distance of 3.5 km, the debris cover dominates the surface of the glacier with a tendency decrease in thickness from the lateral margins (0.5 m thick) to the center axis of the glacier (0.0 m thick). Field observations indicate that debris sources include: snow and ice avalanches, high frequency-low magnitude rockfall, and the emergence of englacial debris.

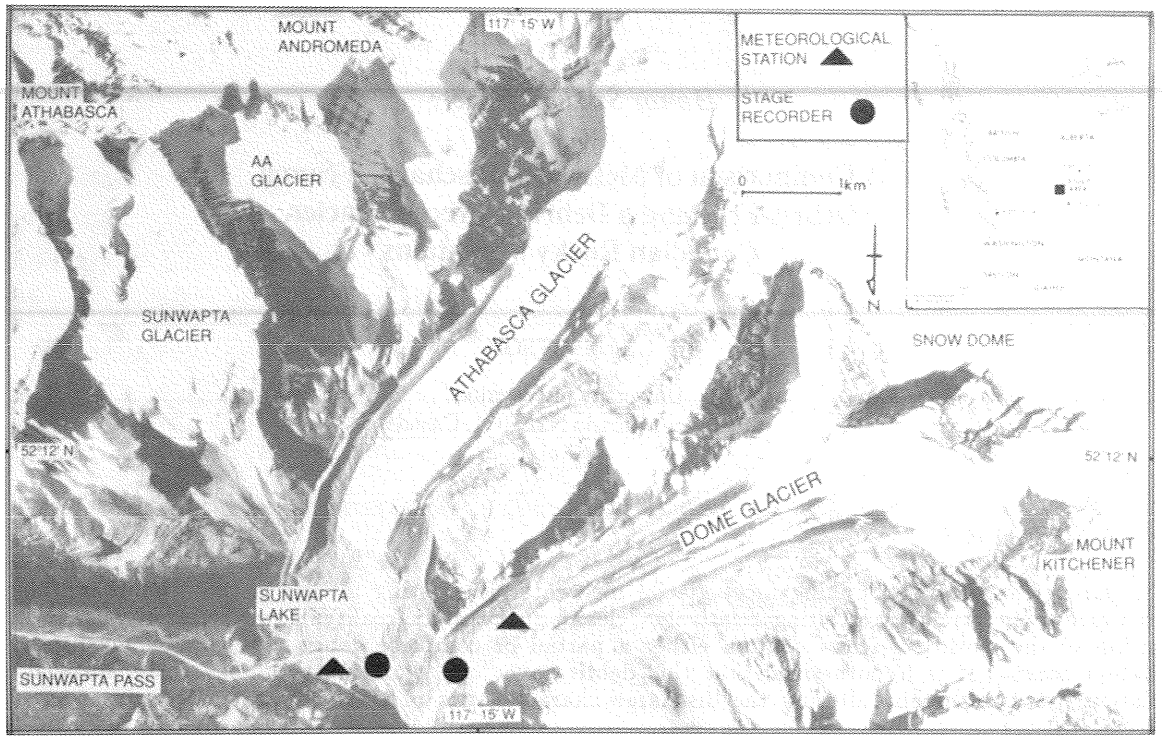

Figure 1: STUDY SITES. The Athabasca Basin covers an area of roughly 28 km^2. Of this, about 65 % or 18 km^2 is covered by glacial ice. The Sunwapta, the AA, and the Andromeda Glaciers cover an area of about 3.7 km^2. The remaining 14.3 km^2 of ice cover is accounted for by the Athabasca Glacier. The Dome Basin covers an area of about 15 km^2 and of this about 68 % or 10 km^2 is ice. There is a single cirque glacier associated with the Dome Basin known as the Saddle Dome Glacier which covers an area of 0.25 km^2. The remaining 9.75 km^2 of ice cover is accounted for by the Dome Glacier.

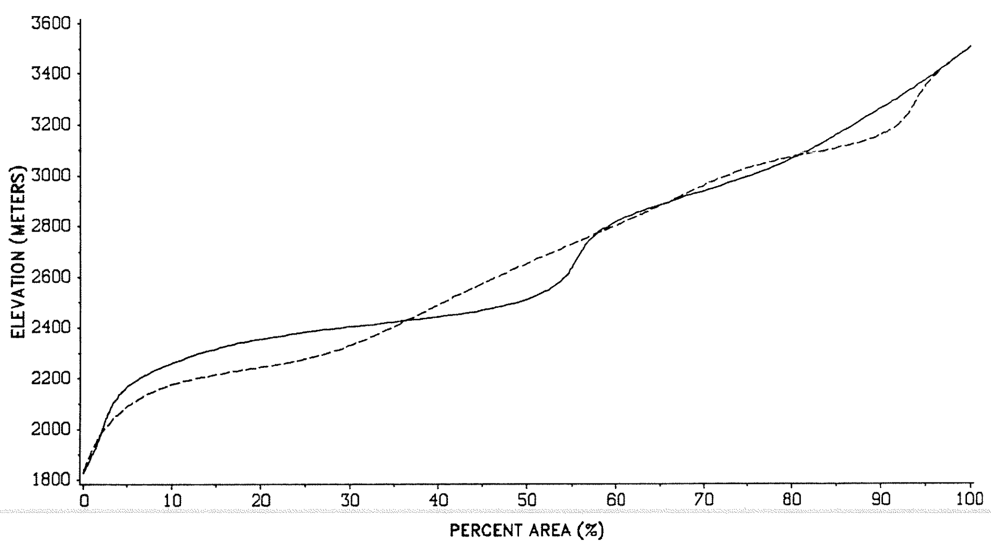

Figure 2: HYPSOMETRIC CURVES. This figure illustrates the similarity of the area to altitude relationship between the two study basins.

Table 1

Morphologic, morphometric, and dynamic characteristics of the Dome and Athabasca Glaciers.

ATTRIBUTE	DOME	ATHABASCA
GLACIER LENGTH (M)	8.5	5.4
MAXIMUM ELEVATION (M A.S.L.)	3460	3460
TERMINUS ELEVATION (M A.S.L.)	2000	2000
ALTITUDINAL RANGE (M)	1460	1460
AVERAGE GRADIENT	1:6	1:4
FIRN LINE ELEVATION (M A.S.L.)	2500	2500
AREA OF ACCUMULATION ZONE (KM^2)	8.3	4.9
AREA OF ABLATION ZONE (KM^2)	6.0	5.5
ICE THICKNESS AT BASE OF ICEFALL (M) *	300	---
VELOCITY AT BASE OF ICEFALL (M YR^{-1}) **	75	35
YEAR OF MAXIMUM HOLOCENE EXTENT ***	1843	1846
RATE OF RETREAT (1721-1953) (M YR^{-1}) ****	4.7	4.7
RATE OF RETREAT (1938-1960) (M YR^{-1})	28	19

* KITE AND REID, 1977
** PATERSON AND SAVAGE, 1963
*** LUCKMAN, 1988
**** DEATON, 1975

DATA COLLECTION

Meltwater discharge was monitored between July 11 and August 23, 1989 for the Dome Basin with the use of a continuous recording stage recorder while discharge data for the Athabasca Basin were derived from previously collected surface water surveys undertaken by Environment Canada at the Sunwapta River gauging station (Figure 1). Meteorological measurements commenced on July 11, 1989 at a standard meteorological station situated at the terminus of the Dome Glacier (Figure 1). Specific variables measured included: continuous relative humidity and air temperature, precipitation type and amount, as well as incident shortwave solar radiation. Daily maximum and minimum air temperatures and precipitation data were also derived from a meteorological station at the Columbia Icefield Information Center (Figure 1). Ablation was monitored on a daily basis through a simple ablation stake network located on the Dome Glacier.

OBSERVATIONS

1. Figure 3 illustrates the relationship between debris-cover thickness and surficial ablation. Past a threshold thickness of approximately 2.0 cm, ablation rates decreased in comparison to "clean" glacier surfaces. It was found that the greatest mean ablation rate (9.5 cm day^{-1}) occurred beneath a debris cover of about 1.0 cm. Those areas with less than 1.0 cm of debris exhibited relatively lower ablation rates. The mean daily ablation rate for a "clean" ice surface was about 7.0 cm day^{-1} compared to a rate of 1.0 cm day^{-1} for ice beneath 39.0 cm of debris.

2. A combination of topographic map analysis, air photo interpretation, reference literature review and field observations reveal that the Dome and Athabasca Basins are relatively similar with respect to their morphological characteristics. These include: size, orientation, slope, altitudinal range and percentage ice cover. Table 1 also indicates that the Dome and Athabasca Glaciers display relatively similar characteristics with respect to their morphology (slopes, lengths, and widths), morphometry (areas and ice depths), and dynamics (ice flow velocities and past rates of retreat).

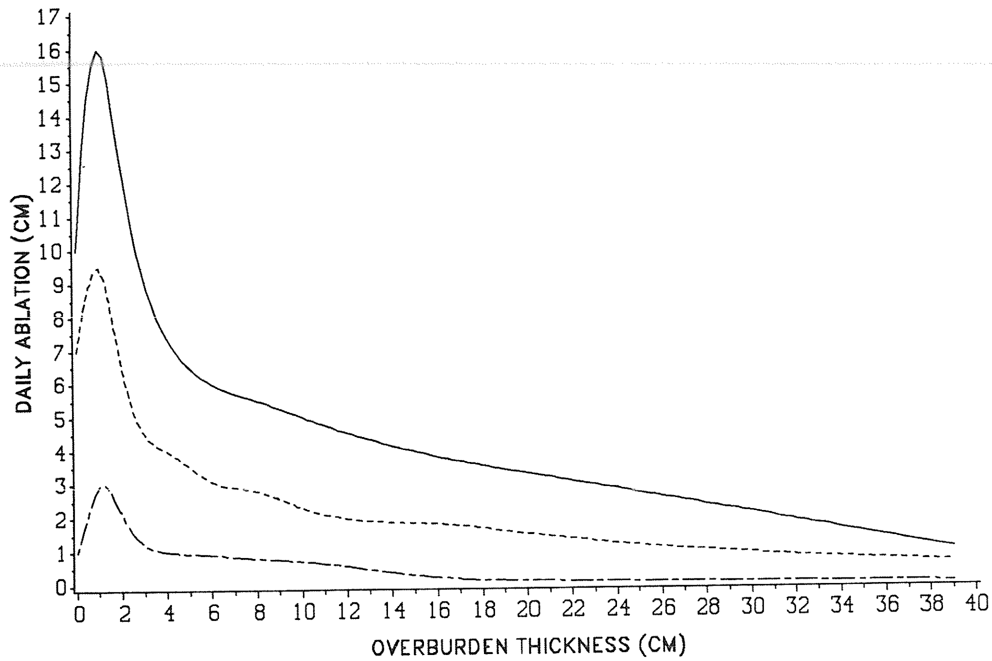

Figure 3: ABLATION VS. DEBRIS THICKNESS. Relationship of mean, maximum, and minimum daily ablation to debris cover thickness for the Dome glacier.

3. Meteorological data derived from the Dome site was relatively similar to that collected at the information center. The mean seasonal maximum air temperature for the Athabasca basin was 17.0 ° C. while that for the Dome was 13.0 ° C.; a difference of 4.0 C. ° The higher values for the Athabasca basin can possibly be explained by the fact that the meteorological station was located in the proglacial zone while that for the Dome was located on the surface of the glacier. The mean seasonal minimum temperature for the Athabasca Glacier was 4.5 ° C. while that for the Dome was 4.3 ° C.; a difference of only 0.2 C °. The similarity in values is most likely a result of cold air drainage off of the icefield during late evening hours. In total, 128.8 mm. of rain fell in the Dome basin compared to 116.6 mm. in the Athabasca, a difference of only 12.2 mm. or 10 %.

4. The seasonal discharge pattern of the Sunwapta and Dome Rivers is characterized by a series of oscillating waves which matched each other in form and amplitude. It is evident that the quantities of water released by both basins is in the same order of magnitude. The mean seasonal discharge for the Athabasca Basin was 5.6 m^3 s^{-1} resulting in a total seasonal discharge of 20,321,280 m^3. The mean seasonal discharge for the Dome Basin was 4.8 m^3 s^{-1} resulting in a total seasonal discharge of 17,418,240 m^3; almost three million cubic meters (14 %) less than that of the Athabasca. The mean daily maximum discharge for the Athabasca Basin was 8.9 m^3 s^{-1} which converts to a daily total of 768,960 m^3. The mean daily maximum discharge for the Dome Basin was 7.0 m^3 s^{-1} which converts to 604,800 m^3. Differences between the two basins for mean daily maximum discharge was 164,160 m^3 in favor of the Athabasca Basin.

5. At the seasonal scale the fluctuations of discharge in both rivers varied uniformly in duration from 4 to 12 days. These general trends in discharge were mainly a function of changes in regional weather conditions. Over the short term, however, the form of each individual wave did not always corresponded with that of the other for the same time period. There are, in fact, short periods which exhibit opposite trends in discharge. For example, on August 03 (215 Julian days) the discharge of the Dome River experienced an increase of 0.26 m^3 s^{-1} while the Sunwapta River experienced a decrease of 2.87 m^3 s^{-1}. Field observations reveal that this anomaly can be explained by a rain storm tracking over one basin as opposed to over both.

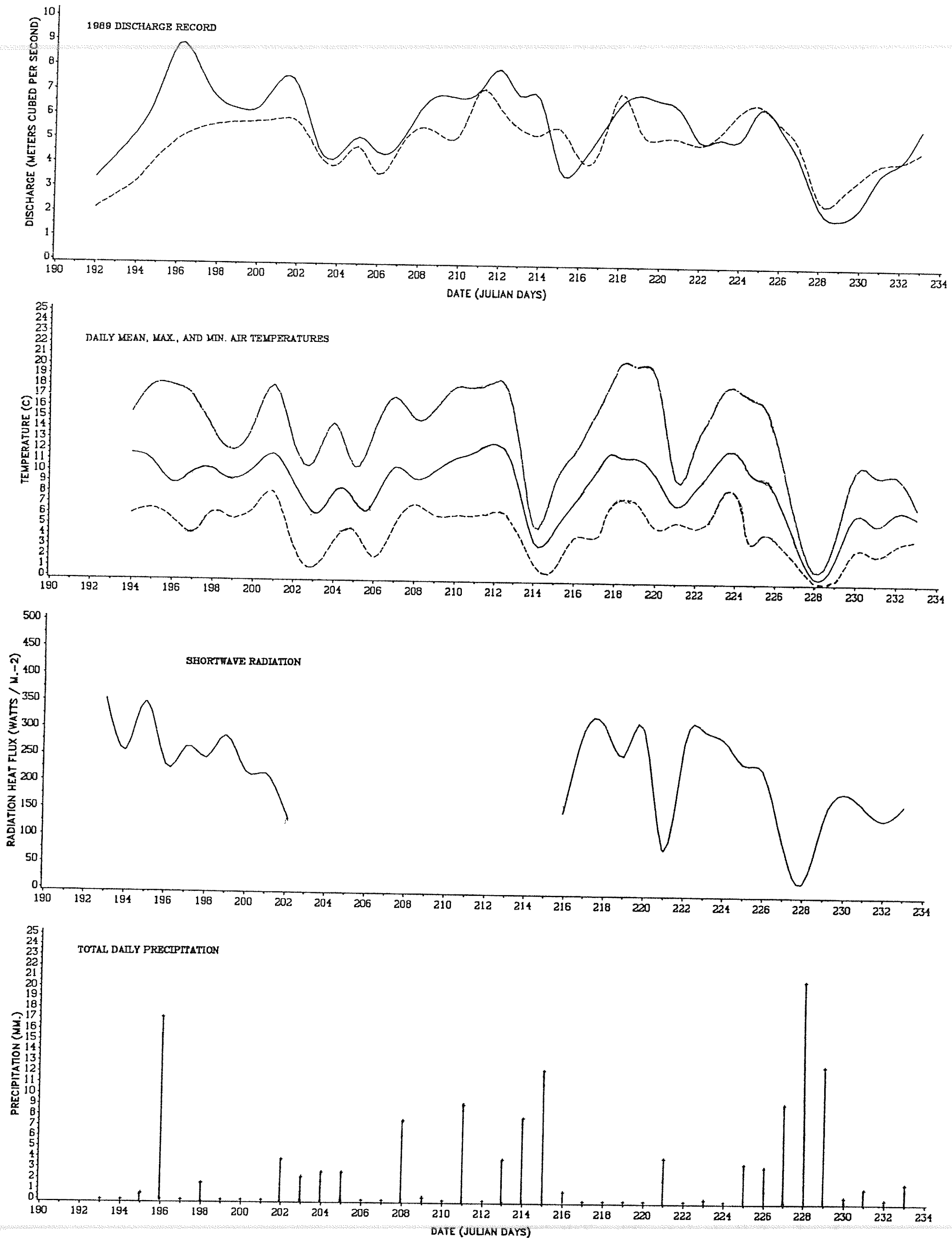

Figure 4: FIELD OBSERVATIONS. Meteorological conditions and meltwater discharge hydrographs for the Dome and Athabasca Basins for the period between July 11 to August 21, 1989 (191 - 233 Julian Days).

6. Analysis indicates that air temperature parameters, daily maximum for the Athabasca and daily minimum for the Dome, present the strongest positive correlations to discharge of all meteorological variables. A weak negative relationship also exists between discharge and precipitation which is surprising considering that precipitation acts as an input to the basin's hydrological cycle. It is assumed that this relationship is the result of some other related factor such as cloud cover.

CONCLUSIONS

The relationship between debris-cover thickness and ablation can be explained in terms of the surficial radiant energy exchanges in conjunction with the storage and transfer of energy within the debris cover. A debris cover equal to or greater than 1.0 cm in thickness will significantly decrease the albedo of the surface thus increasing the amount of absorbed shortwave radiation. Those areas with less than 1.0 cm of debris exhibit less ablation due to higher reflectivity caused by partial ice coverage. However, the debris-cover also acts as a medium through which the energy must be transferred in order to ablate underlying ice. Not all of the energy entering the debris cover reaches the ice. A portion of it is used to increase the internal temperature of the debris cover thus converting it into a state of storage. An increase in debris cover thickness results in an increase in stored energy which, in turn, results in less energy available for ablation. Once the threshold thickness is surpassed, a greater amount of energy is lost to storage than is gained through the increase in absorption.

It can safely be stated that a debris-cover does exert a significant influence on the ablation process at the micro-scale, however, this is not evident at the basin scale. The similarity in shape between the discharge hydrographs indicates that the driving forces behind the production of meltwater are the same for both types of glaciers. There is no indication that debris cover causes a lag or any other related phenomenon on a diurnal basis. The 14 % difference in the volume of discharge released between the two basins is relatively constant and can be explained by the fact that the ablation zones within the Athabasca Basin occupy an area 15 % larger than that of the Dome's. The hypothesis, however, should not be prematurely rejected due to the fact that the Dome Glacier may be an exception where by increased ablation in thin debris-covered areas is counterbalanced by the decreased ablation in thickly covered areas. Further research on other debris covered glaciers is necessary to fully test this hypothesis.

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