NOTE ON THE RELATION BETWEEN THE HEIGHT OF THE FIRN LINE AND THE DIMENSIONS OF A GLACIER

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There are a number of glaciers which maintain a fairly uniform slope and width for long distances. In such cases it is possible to estimate the effect of a small change in the altitude of the firn line on the length of the glacier, if the change has occurred between periods when it was in climatic equilibrium for several years and was due to a variation of temperature rather than precipitation.

(*a*) *Change of Area*

If dh is the change of altitude of the firn line and S the slope per unit of distance in the same region, the displacement of the firn line along the glacier is equal to dh/S.

If the average width in this region is W_f, and is relatively uniform over a small range of altitude, the change of accumulation area is:

$$dAc = W_f \frac{dh}{S} \quad \ldots \quad (2)$$

When the glacier is in equilibrium the ratio of ablation area to accumulation area will be nearly constant for small displacements of the firn line.

$$\frac{Ab}{Ac} = \text{constant} = r, \text{ and } dAb = r\, dAc \quad \ldots \quad (3)$$

And the change in the total area of the glacier, dA, is equal to the sum of (2) and (3):

$$dA = W_f \frac{dh}{S}(1+r) \quad \ldots \quad (4)$$

Nearly all of this change of area will normally occur in the lower part of the ablation region, mostly quite near the snout.

(*b*) *Change of Length*

If sufficient information is available from old moraines, etc., the relation between change of area and length may be calculated with considerable accuracy for the range covered by the recession. In most cases, however, only the change of length is known with any certainty, and it is necessary to use the latter for making an approximation to the change of area.

From a few cases where it was possible to measure the change of dimensions between old moraines, or equilibrium positions, it seems that a good approximation is given by taking the ratio of width to length as constant for the lower tongue. Naturally this would not apply to a deep glacier confined by vertical side walls, where dA is practically equal to the product of width and change of length.

If W is the average width of the lower tongue for length l, and taking W/L as constant between periods when the glacier is in equilibrium, then:

$$\frac{dA}{dl} = 2W \quad \ldots \quad (5)$$

From (4) & (5)

$$dl = \frac{W_f}{2W}\frac{dh}{S}(1+r) \quad \ldots \quad (6)$$

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If this glacier is nearly uniform in width up to the firn line, and its ablation and accumulation areas are about equal, the displacement of its snout will be similar to that of the firn line, but in most cases it is greater because the glacier is wider in the upper part.

It should be noted that a moderate difference in slope between the regions of the snout and firn line is much less important than the difference in widths, but if the glacier is much steeper at the higher level the above relation (6) will give too small a displacement of the snout.

(*c*) *Change of Temperature*

It has been assumed that the changed altitude of the firn line was due to a variation of the temperature only, hence the temperature of the ablation season at the new firn line will be the same as at the old, and relation (6) may be given in terms of long period temperature change by using the normal temperature lapse rate:

$$dh/dt = -150\ m./^{\circ}\ C. \qquad (7)$$

Substituting in (6),

$$dt = -\frac{2\ W \,.\, S \,.\, dl}{150\ W_f(1+r)} \qquad (8)$$

This gives a temperature change corresponding to the observed change of length between two periods when the glacier was in equilibrium. Apart from a possible secular change of precipitation, the accuracy of this figure is mainly dependent on how nearly the ratio of width to length in the lower tongue remained constant (or the difference of $2w \,.\, dl$ from the actual change of area).

For glaciers which have a well-preserved system of old moraines a more accurate estimate of the change of area is sometimes possible, and can be used to obtain the corresponding temperature change:

From (4) & (7)

$$dt = -\frac{S \,.\, dA}{150\ W_f(1+r)} \qquad (9)$$

For a glacier with a slope of 1 in 10 and a rather uniform width up to the firn line, the change of length would be around 2 km. per degree, but where the line crosses a wide upper firn basin the displacement of the snout may be several times as great.

Short shallow glaciers of gentle slope soon disappear completely when a slight rise of temperature occurs, or if the firn line rises over the plateau slopes of small ice caps the recession of the lower glacier tongues is very great. Striking examples of this kind have been much in evidence of late years.

The following example of this method of estimating a long period temperature change makes use of the contour map of Styggedalbreen in the Horung massif, Norway (H. W:son Ahlmann, *Geografisker Annaler*, Årg. 22, Ht. 3–4, 1940, p. 95–130).

The reduction in length of this glacier, from the outermost moraines formed in the eighteenth century to a stable condition in the 1920s, was approximately 780 m. The other factors for equation (8), as measured from the 1920 dimensions of the glacier were as follows:

Slope in the region of the firn line (assumed constant)	$S=0{\cdot}15$
Width ,, ,, ,, ,, ,, ,,	$W_f=800$ m.
Area ratio, ablation/accumulation (assumed constant)	$r=1{\cdot}5$
Width of lower tongue in 1920s	$W=565$ m.

With these values in equation (8) the temperature change becomes: 0·44° C.

This calculation indicates that the mean temperature of April to October in south Norway, was probably about half a degree lower for the period around 1740 to 1770 than it was around 1910 to 1925. Instrument records covering the latter part of the period show a tendency for the winter snowfall to increase slightly in this region, and therefore the true temperature change probably exceeds the above figure by a small fraction of a degree.

Owing to exposure difficulties very old temperature readings can seldom be relied on for such minute changes. Nevertheless glaciers with a scale of perhaps several kilometres per degree provide a wonderful instrument for this purpose. Their value in this respect should be even greater when we have more basic knowledge of their response both to precipitation and temperature. When this method is used accuracy will be much increased if it is possible to secure dimensional changes from several glaciers in any region, but care must be taken to avoid ice streams with exceptional morphological characteristics or large changes of gradient such as deep ice falls.

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THE ORIGIN OF DIRT CONES ON GLACIERS

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ABSTRACT. The characteristics and probable development of dirt cones on Vatnajökull (Iceland) are described. Thick accumulations of debris protect the ice beneath them from ablation, whereas thin ones accelerate the process. Under given conditions of ablation, the nature of the debris covering is the deciding factor—in particular its radiation absorption coefficient, conductivity and thickness. Contrasts are noted between the dirt cones of Vatnajökull and those of other glaciers. The nature of the debris and of the ablation varies greatly from place to place, but all dirt cones result from differential ablation.

ZUSAMMENFASSUNG. Die Kennzeichen und wahrscheinliche Entwicklung von Eisschmelzkegeln auf Vatnajökull (Island) sind beschrieben. Dichte Schuttanhäufungen schützen das Eis darunter vor Ablation, wogegen leichte Anhäufungen dieser Art den Prozess beschleunigen. Unter gegebenen Ablationsverhältnissen ist die Beschaffenheit der Schuttdecke ausschlaggebend, vor allem deren Strahlungs-Absorptionskoeffizient, Leitungsfähigkeit und Dicke. Gegensätze zwischen Eisschmelzkegeln auf Vatnajökull und andern Gletschern sind angegeben. Die Beschaffenheit des Schuttes und der Ablation ist von Ort zu Ort verschieden, aber alle Eisschmelzkegel haben ihren Ursprung in Differential-Ablation.

INTRODUCTION

Dirt cones are found on snow and on ice in both arctic and temperate regions. In Iceland it is not unusual to see many hundreds of them from 1 to 3 m. high, scattered like so many ash heaps over the marginal areas of the glaciers. In exceptional circumstances they may be 30 m. high. Similar forms have been described on the Malaspina Glacier. There they frequently reach a height of 24 m.[1] On the Hispar Glacier a cone was estimated to rise to 85 m. above the level of the surrounding ice surface.[2]

The name "dirt cone" is an unfortunate one, but convenient. It will be used here, since others are unwieldy. The mounds are seldom perfectly conical, being found in a great variety of irregular shapes. The term is also misleading in that it implies that the cones are formed entirely of debris. They are in fact cones formed of pure snow or ice, covered with but a thin veneer of material. Ice pyramids are distinguished from dirt cones by the absence of any such covering.

A. DIRT CONES ON VATNAJÖKULL

1. CONES WITH ICE CORES

While taking part in the Oxford University expedition to Iceland in 1947 I was able to examine a number of dirt cones. Within a kilometre or so of the margin of Skaftárjökull, one of the south-western outlet glaciers of Vatnajökull, at an altitude of about 800 m. above sea level, very many black mounds rise, on an average about 2 m. above the level of the surrounding ice (see Fig. 1, p. 439). The majority occur along crevasse lines. Apart from this, however, there is no regular arrangement. The crevasses, which vary in size from mere cracks in the ice to open fissures 1 m.