about $-39°$ C. Cooling below $-39°$ C., either throughout the box, or locally by putting in a cold object, *e.g.* a little solid CO_2, initiates crystallization. The crystals formed are small hexagonal plates.

The cloud can be seeded at higher temperatures than $-39°$ C., by particles of some dusts, giving plate-like crystals of irregular forms.

The addition of various vapours modifies the shape of the crystals, *e.g.* acetic acid causes complex hexagonal plates, nitric smokes cause trigonal plates, and acetone causes hexagonal prisms to form. Any of these unusual types will seed a cloud of supercooled droplets, at temperatures well above $-39°$ C., which then freeze, as usual, into hexagonal plates. It is to be concluded, therefore, that in these modified crystals only the external shape is altered, the internal structure remaining unchanged. It must always be remembered that every crystal is a distinct individual, and that rare forms, though interesting, do not give a reliable indication of internal symmetry.

In the same work considerable studies of natural snow forms have been carried out, and a useful set of photographs of typical forms published. Here again the smallest crystals, produced under cold dry conditions (below 25° F.), were small hexagonal platelets. Warmer, wet snow was found to consist mainly of the larger familiar six-rayed stars. These appear to have begun as small hexagonal plates from whose corners the rays have grown.

These observations suggest that ice does in fact form as hexagonal plates, but that the conditions which allow rapid growth encourage elongated forms. It is well known that rapid growth often results in dendritic crystal forms, such as the rays of stellar snow crystals; but the elongated crystals found in pools of water are not usually of the dendritic type. A possible explanation of their occurrence is that dendritic crystals are, in fact, at first formed in the supercooled water, for long crystals which are too thin to handle certainly do occur. These would then grow more slowly to give more compact crystals and would become, after a time, the crystals of about $5 \times 1 \times 0{\cdot}5$ cm. which are found. This particular crystal form might then be regarded as an intermediate in the unfinished change from a dendritic crystal grown quickly in the supercooled liquid, and a more compact, uniform, and possibly plate-like crystal.

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THE EFFECT OF THE ALTITUDE OF THE FIRN AREA ON A GLACIER'S RESPONSE TO TEMPERATURE VARIATIONS

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The importance of the altitude of the principal accumulation areas of a glacier, when considering its response to temperature changes, has been repeatedly stressed by Ahlmann,[1] Cooper [2] and others, but the reason for the decisive influence of this altitude is not always very obvious to workers in related fields. It may, however, be clearly demonstrated by means of a simple diagram such as the one accompanying this note.

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1. Basis of the Values Used

The ablation and accumulation values, shown in the diagram as water equivalent, are those obtained by Professor Ahlmann[1] on the southern side of Vatnajökull, extending up to about 400 m. above the firn line. The increase of accumulation with altitude was found to average 0·28 per cent (nearly 3 mm. per metre of altitude) for the three years 1936 to 1938. The slope of this line refers to the particular conditions on the south side of Vatnajökull but may be rather typical for the sides of an ice cap facing relatively warm ocean water. The same applies to the variation of ablation in altitude, which was found to average minus 0·48 per cent (nearly 5 mm. per metre) over all except the lowest ice, but in this case the slope probably has a wider significance for it is conditioned by the climate rather than by the local physical features.

At altitudes more than about 400 m. above the firn line the decrease of accumulation has been estimated from various data, and little weight need be given to this part of the curve. A slope of minus 0·15 per cent has been chosen on the assumption that the accumulation would have fallen to about 30 cm. on a plateau 2 km. above the firn line in this climate. (Owing to the extreme cold at this level the air can carry little moisture beyond the margin of the plateau.)

2. The Net Accumulation

The importance of the annual addition of firn remaining at the end of the ablation season needs no emphasis, and its distribution in altitude is also a very significant factor for the glacier's response to variations of climate. The curve in the diagram (p. 575) shows that the increase of this net accumulation immediately above the firn line is extremely rapid. For Vatnajökull the slope is about 0·75 per cent in the first 200 m. above the line. At greater heights this rate of increase rapidly diminishes until it must change into a decrease for ice fields which lie far above the firn line. In the Vatnajökull climate the decrease might be expected to begin some 500 to 700 m. above.

In this connection the height at which the ablation falls to insignificant values is an important factor. It is estimated to lie between 500 and 600 m. above the line in the climate of the south side of Vatnajökull. Presumably it varies directly with the accumulation and inversely with the length of the ablation season at the line, but the tendency near the limit of ablation is for the slight melting, on a few days in summer, to be refrozen in the firn, and this may considerably reduce the height of effective ablation in very cold dry climates.

3. Examples of Firn Fields at Various Heights

The three vertical strips, marked a, b and c in the diagram, within the curve of net accumulation, refer to the altitudes of the principal accumulation areas of three hypothetical firn fields. The broken line curve indicates the net accumulation if the firn line rose 100 m. above its former position, on account of an increase of about 0·7° C. in the temperature of the ablation season, without change of precipitation. It is at once evident that the effect of such a change in firn line altitude is very much greater on ice field (a) than on the field at (b) or (c), in fact there is every reason to suppose that the effect at (c) will be opposite, although probably much smaller.

In general, the effects of such an increase in the altitude of the firn line may be summarized as follows for ice fields at various higher levels which lie in a region of considerable precipitation:

(*a*) *Firn field up to about* 400 *m. above the original line.* Strongly negative. Drainage glaciers will be extremely sensitive to slight temperature changes lasting only a decade or two. Examples: Juneau Ice Field (Lawrence[3]) with up to 15 terminal moraines formed in the last two centuries. Jostedalsbreen is another well-known example of this type.

(*b*) 500 *to* 700 *m.* Indifferent. Amount of ice passing the firn line little affected. Glacier tongues move back to adjust their ablation areas to the new firn line. Vatnajökull during

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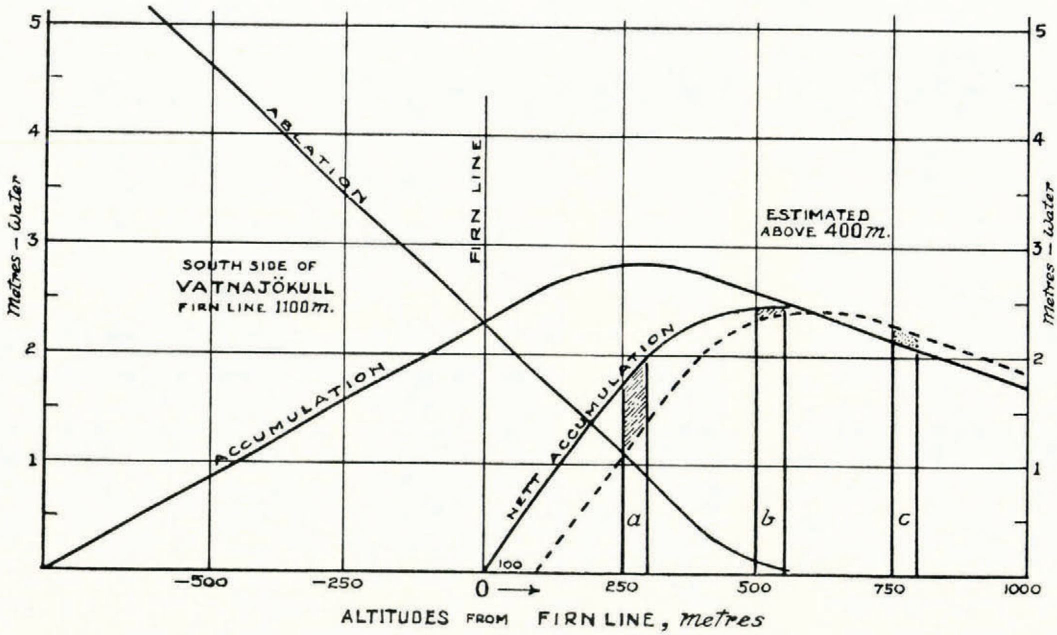
the nineteenth century is a possible example, as much of the firn area lay at 500 to 600 m. above the line, and the outlets showed little net movement (Thorarinsson [4]).

(*c*) *Above about* 700 *m.* Slightly positive with more ice passing the new firn line. Drainage glaciers will at first retreat to adjust their ablation areas, but after a long interval under the new conditions they should advance again. Although Greenland covers too great a range of climate for generalizations of this kind, one could anticipate a recent increase of accumulation on most of the plateau. The effects of intensified ablation are very striking at low levels. Zone (c) covers almost all of the Antarctic continent down to sea-level, but reactions to temperature changes would be exceedingly slow.

It is not the purpose of this note to consider the very complex climatic response of steep glaciers on high mountains, beyond noting that it should be governed by their relative amounts of



firn area in the different zones. In high latitudes some of these glaciers should have a substantial proportion of their accumulation area in zone (c), and might be expected to show a positive tendency in response to a rise in temperature, the more so if the latter is accompanied by greater storminess and precipitation as seems to be the case in these latitudes. Wind drift is another factor of great importance to the climatic response of valley glaciers.

Before closing a word should be said about the mysterious case of the Taku Glacier in the Juneau Ice Field, Alaska, because the recent behaviour of this great glacier serves as a useful warning that simple generalizations seldom have a universal application to complex natural phenomena.

The Taku comes from a firn field lying entirely in the lowest zone (a), but has advanced steadily by no less then 5 km. during the past half-century. Meanwhile, about ten other large tongues from this field have receded rapidly in accordance with the vast majority of glaciers in North America. The Juneau Ice Field is at present under active investigation in the capable hands of Mr. W. O. Field [5] of the American Geographical Society and Mr. M. Miller, and perhaps we may anticipate an early solution of the Taku mystery.

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EARLY DISCOVERERS

VI

ROBERT HOOKE

Obſervables in figur'd Snow *

Expoſing a Piece of black Cloth . . . to the falling Snow I have often with great Pleaſure obſerved ſuch an infinite variety of curiouſly figur'd Snow, that it would be almoſt as impoſsible to draw the Figure and Shape of every of them (*sic*) as to imitate exactly the curious and Geometrical Mechaniſme of Nature in any one. . . .

I obſerved, that if they were of any regular Figures, they were always branched out with Six principal branches, all of equal length, Shape and make, from the center (*sic*), being each of them inclin'd to either of the next branches on either Side of it, by an angle of Sixty degrees. . . .

Now as all theſe ſtems were for the moſt part in one flake exactly of the ſame make, ſo were they in differing Figures of very differing ones; ſo that in a very little time I have obſerv'd above an hundred ſeveral cizes & ſhapes of theſe ſtarry flakes.

The branches alſo out of each ſtem of any one of the flakes, were exactly alike in the ſame flake . . . that is, if the branchings of the one were ſmall *Parallelipipeds* or Plates the branches of the other five were the ſame. . . . The bigger [the flakes] were magnify'd, the more irregularities appear'd in them; but this irregularity ſeem'd aſcribable to the thawing & breaking of the flake by the fall, and not at all to the defect of the plaſtick virtue of nature ——; yet I am very apt to think, that could we have a ſight of them through a *Microſcope* as they are generated in the clouds before their Figures are vitiated by external accidents, they would exhibit abundance of curioſity & neatneſs there also. For ſince I have obſerv'd the Figures of *Salts* and Minerals to be some of them so exceeding ſmall that I have been ſcarcely able to perceive them with the *Microſcope* and yet have been regular and ſince (as far as I have yet examin'd it) there ſeems to be but one and the ſame cauſe that produces both theſe effects, I think it not irrational to ſuppoſe that theſe pretty figur'd Stars of *Snow*, when at firſt generated might alſo be very regular and exact.

Of Several kindes of frozen Figures

I have very often in a Morning, when there has been a great hoar-froſt, with an indifferently magnifying *Microſcope*, obſerv'd the ſmall *Striœ*, or Cryſtalline beard, which then uſually covers

* From *Micrographia, or Some Phyſiological Deſcriptions of Minute Bodies made by Magnifying Glaſs, with Obſervations and Inquiries thereupon*. By R. Hooke, Fellow of the Royal Society, **London 1665**.