REVIEWS

THE GLACIAL ANTICYCLONE THEORY EXAMINED IN THE LIGHT OF RECENT METEOROLOGICAL DATA FROM GREENLAND, PART I. F. E. Matthes. *Trans. American Geophysical Union*, Vol. 27, 1946, pp. 324–41

For nearly forty years Professor W. H. Hobbs has devoted a large part of his abundant energy to the study of the meteorological conditions over and around great ice sheets, and to the support of his theory of the "glacial anticyclone." That theory has been questioned from time to time, notably by W. Meinardus and to some extent by Sir George Simpson; the most recent criticism comes from F. E. Matthes and is based on a detailed study of conditions in central Greenland.

Briefly, the hypothesis starts with the inference that since cold air is relatively heavy and the air over an ice sheet is cold, barometric pressure must be higher over a large ice sheet than at the same level over neighbouring seas. This is interpreted to imply that an ice sheet is the site of a nearly permanent anticyclone, with outflowing winds on all sides, supplied by air which flows in aloft and descends over the ice sheet. This raises the difficult question of the supply of moisture to maintain the flow of ice, for descending air is warmed by compression and is normally dry; but Hobbs points out that the surface of the ice is intensely cold and may be much colder than the air at a height of several thousand feet at which it is brought in from outside. The moisture in the upper winds reaches ground level as vapour, but a large part of it is immediately condensed as ice mist or deposited directly as hoar frost. The outflowing winds sweep these crystals before them and so maintain the marginal parts of the ice sheet.

There is undoubtedly a good deal of truth in this idea. Owing to difficulties in reduction to sea-level, pressure on the surface of a large ice sheet cannot be compared directly with that over the surrounding ocean, but the winds do on the whole tend to blow outwards and must be made good by descending currents, while the vertical distribution of temperatures is such that there must be some precipitation in the form of ice crystals or hoar frost. On the other hand, the supposed high pressure may be entirely due to a quite thin layer of air near the ground, above which the structure ceases to bear any relation to an anticyclone, while the outflowing winds may be purely katabatic—rivers of cold air such as flow down any slope on a cold clear night—and have no relation to the general pressure distribution. Hobbs recognizes these objections to some extent by insisting that "glacial anticyclone" is a compound noun which must not be indexed, for example, under "anti-cyclone, glacial." The third difficulty is more fundamental, namely, that it is very unlikely that the deposit of hoar frost can suffice to supply the enormous quantities of ice which issue from an ice sheet each year as glaciers and icebergs.

Matthes discusses the light thrown on this question by recent observations at "Eismitte" near the centre of Greenland during the Wegener expeditions of 1929 and 1930–31, the latter covering more than a year of continuous instrumental readings. These observations show clearly that quiet, fine conditions are the exception and stormy, cloudy conditions the rule, that the katabatic winds are feeble and easily overpowered by storm winds, and that by far the greatest factor in the nourishment of the ice sheet is the precipitation of ordinary snow. The great oscillations of pressure and temperature closely resemble, though much lower on the scale, those in typical cyclonic regions such as New England. The winds are often strong, but although Matthes implies that they most often blow from south, the observations show a very marked predominance from east, with only a secondary maximum from SSE. True precipitation is actually more frequent than on the west

https://doi.org/10.3189/S0022143000007693 Published online by Cambridge University Press

coast of Greenland and not much less common than on the rain-swept coast of Norway, but owing to the low temperatures the total amount is not large, the average being estimated from the firn layers as equivalent to 12·4 in. of water a year. Direct measurement of the snowfall was impracticable owing to drift.

The frequency of easterly winds was not due entirely to katabatic winds from the ice divide to the east, for it is as marked in the strong winds as in the weak. Rather it implies that depressions pass mainly to the south, but extend their influence right to the centre of the ice cap. There is now no difficulty about the supply of moisture, which is derived from the Atlantic Ocean and carried inland, overriding the violent but shallow katabatic winds of the coast, to be condensed into snow over the ice shed and swept on to be gradually deposited on the leeward slopes. Atmospheric pressure is undoubtedly higher than it would be if the surface, at the same level, were not ice covered, but it appears that the subcontinent is not big enough to form the basis for a self-supporting glacial anticyclone. Antarctica is another question ; owing to its greater extent and polar position a permanent glacial anticyclone is more likely to be found there than in Greenland, but even in Antarctica, as Sir George Simpson has shown, Hobbs' mechanism for the supply of ice is inadequate and must be replaced by something more effective.

C. E. P. Brooks

PERMANENTLY FROZEN GROUND AND FOUNDATION DESIGN. R. M. Hardy (Part I), and E. D'Appolonia (Part II). *The Engineering Journal*, Montreal, January 1946, pp. 1–11

During recent years a number of practical papers have appeared relating to construction difficulties in lands where the ground is subject to transient or permanent deep freezing. As is often the way, natural phenomena are not studied quantitatively until they become involved in economic problems. In the development of the Canadian North the frozen ground, which may extend to a depth of several hundred feet, is stated to be the most serious obstacle to the engineer. It is estimated that one fifth of the earth's land surface is permanently frozen. Further studies may therefore be expected as development proceeds in northern North America and Siberia,[9] particularly in relation to the extension of air travel and mining operations. In consequence the present time seems opportune to review the phenomena broadly in conjunction with an abstract of this recent paper.

Apparently most of the permanently frozen ground is frost heaved. Frost heaving occurs when the freezing of the soil results in the formation of layers of segregated ice at various depths. Each lens of ice is generally separated by a layer of soil, whose water content does not change but simply freezes solid. The ice lenses vary in thickness from a fraction of an inch to a foot or more, and their spacing is of the same order. The total heave of the soil surface is approximately equal to the total thickness of all the ice lenses.[1, 3, 7] Therefore the water which goes to form the latter is drawn in from the unfrozen soil beneath. The process, in fact, introduces more water into a soil than is possible by any other means and under favourable conditions the volume increase may be over 100 per cent., whereas the volume increase caused by the water in the soil voids changing direct to ice is only about 5 per cent. Consequently when frost heaved ground is suddenly thawed at the surface, large volumes of water are released within its mass and this water cannot drain through the still frozen ground below. The soil thus becomes like mud and is incapable of supporting any appreciable load. The effects of frost heaving upon the soil and the site conditions under which it occurs are fairly clear, but the physics of the process is by no means fully understood.

Part I of the paper sets down the theory of frost heaving as broadly presented by Stephen Taber,[7] who carried out some pioneer work on the mechanics of the process. This is the generally

https://doi.org/10.3189/S0022143000007693 Published online by Cambridge University Press