BUILD-UP OF THICK FLOATING ICE IN ARCTIC AREAS

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During the operations on T-3, it was found that the upper half, approximately, of this 50- to 60-meter-thick ice mass consists of ice formed by the accumulation of snow on the surface. This part contains many horizontal dirt layers which were deposited by winds blowing over low-lying coastal hills which are ice free during the summer months.

The true origin of the lower part of the ice mass is not apparent. Because it is free of dirt, and because traces of salinity have been obtained in some of the samples, it would appear that this ice had grown by freezing from below, perhaps from fresh or brackish water of coastal streams in the area of origin. However, from petrographic information on this ice, Weeks (personal communication) and Marshall (1955) have reported it to be more similar to accumulated firn or lake ice. It is perhaps possible that during the many years since its growth and due to high pressures during various temperature changes, the ice character has been altered and its original form been destroyed.

Because of the nature of the present Ellesmere ice shelf, and from evidence furnished by carbon-14 datings to be given later, it seems very unlikely that the bases of these ice bodies consist of glacier ice. It is, therefore, assumed that the base consists of ice grown by freezing from the bottom, similar to the manner in which present sea ice forms in arctic waters.

From carbon-14 dating of samples obtained along the Ellesmere Shelf, a few significant factors have been ascertained. Several pieces of driftwood found back of the present shelf, varied in radio carbon age from about 3,000 to 6,000 years. This information establishes definitely that the shelf is younger than 3,000 years, and hence not a remnant of the Wisconsin Ice Age. Marine shells located 38 meters above sea level on Ward Hunt Island and at 60 meters elevation near the present terminus of a glacier in McClintock Bay show an age of about 7200 years. From this, we can conclude, first, that the land has risen at least 38 meters in the last 7200 years at an average rate of 0.5 meters per century, and second, that glaciers have not been active during this time. A sponge found on the ice surface southeast of Ward Hunt Island and dated by carbon-14 was found to be 400 years old. Assuming that this was brought to the surface of the ice by being first frozen into the bottom ice, then coming up by continual thawing at the top and accretion at the bottom, the conditions during the past 400 years must have been such that a net surface ablation has resulted.

Material contained in the dirt layers of ice island T-3 was dated by carbon-14 analysis. The results show an age of 3,000 years for the heavy dirt layers at the base of the accumulated ice and older ages for the intermediate surface dirt layers. This conflicting reversal of age in the wind-blown deposits of dirt may reflect an error caused by the presence of wind eroded older material; the scarcity of carbon

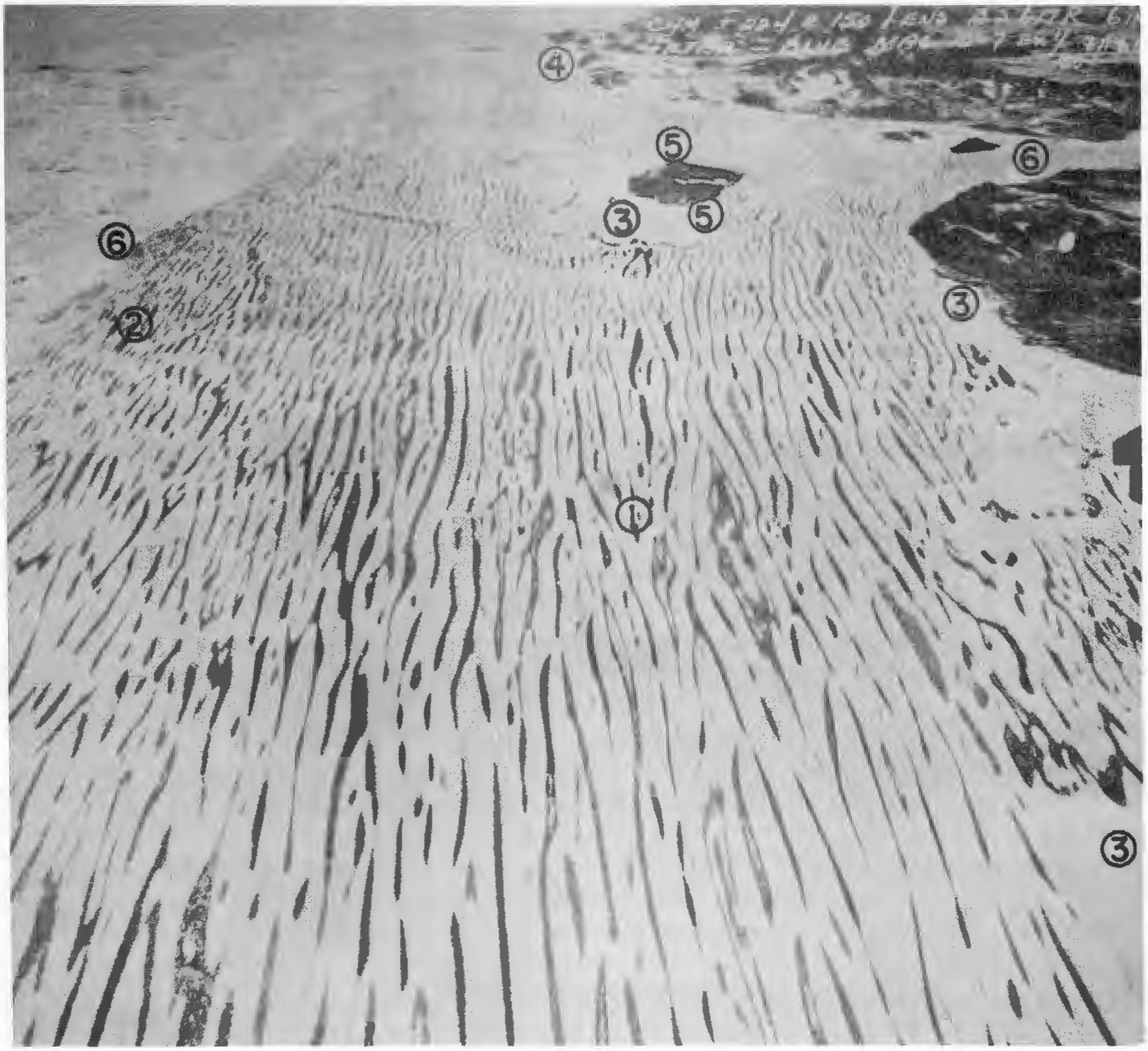

Fig. 1. Royal Canadian Air Force photo of the Ellesmere Ice Shelf. The locations of six suggested areas of study are shown (see text).

material in the dirt; or the possibility of contamination during melting processes. The most accurate age is probably that of the lowest dirt layer, from which sufficient carbon was obtained without having to melt an ice core. An age of 250 years was obtained for surface material, mainly arctic willow particles presumably washed down from higher elevations at the time the ice was attached to a land mass. This confirms the conclusion, deduced from the presence of the sponges near Ward Hunt, that during the last few hundred years there has been a net ablation at the surface in the high arctic areas.

The minimum age of the ice shelf can only be estimated, unless confidence can be placed in ages of the dirt layers on T-3. An estimate based on the total amount of dirt found on and in the ice compared with the annual deposition as given by the smallest layers, gives a figure certainly in the order of at least a thousand years. Another possible approach to age determination is based on the presence of outcroppings of the heavy bottom dirt layer at the surface near the edges of the island. If this heavy layer, found at depths of 10 to 25 meters at the T-3 campsite, was elevated to its present position at the edges of the island by the rising land to which the ice was attached at the time, and if the average rate of uplift were one-half meter per century, as has been suggested above, this would give again an age of 2,000 to 5,000 years.

Assuming then that the T-3 ice island and the Ellesmere Ice Shelf are from 2,000 to 5,000 years old, we will examine the conditions under which this floating ice, up to 60 meters thick, could have formed. Surface conditions at the present indicate that the ice is undergoing considerable ablation. During the period 1952 to 1955 the ice island and ice shelf lost approximately 1.0 meters. Initial reports from the Ellesmere Ice Shelf 1959 Expedition indicated that over 1.5 meters of surface melting had occurred in the four summers since 1954. This obviously could not have been representative of high arctic conditions over a very long period in the past, or the ice rises, shelves and islands would have disappeared long ago. Dirt layer evidence in the upper half of T-3 indicates that the last 7% of the accumulation period, or 400 years, has been one of net melting and that this was preceded by a period three times as long in which average accumulation totalled 10 to 25 meters. The appearance of dirt layers throughout this accumulated zone indicates that no great climatological change took place during this period but that the low-lying hills were probably always free of snow in the summer periods.

The theoretical growth of the lower portion of the ice shelves by freezing at the bottom can easily be calculated. The upward heat flow through the ice sheet is directly proportional to the average temperature difference between the top and bottom of the ice, and inversely proportional to the ice thickness. In the high arctic at the present time the temperature difference is about 15^{o} Centigrade. If there is no surface change and if all of the upward flow of heat is supplied by latent heat of freezing, the annual amount of ice accreted on the bottom should be as follows: 5 meters thick, 64 cm; 10 meters, 33 cm; 20 meters, 17 cm; 30 meters, 11 cm; 40 meters, 8 cm; 50 meters, 7 cm; and 60 meters, 6 cm. The time necessary to form this total ice thickness can also be calculated, and figures obtained are 50 years for 20 meters and 360 years for 50 meters. This period would, of course, be decreased if an average accumulation took place at the surface. If an average ablation occurred at the surface, the thicknesses are limited; with an average ablation of 10 centimeters the limit would be 35 meters, with 50 centimeters it would be 7 meters.

The above figures would need to be revised in the event that ocean waters contribute part or all of the heat flow between the upper and lower boundaries of the ice. Such a heat source is actually present in the relatively warm Atlantic waters that form the main source of Arctic Ocean water below the depth of about 200 meters. The amount of heat contributed to the various areas in the Arctic can only be estimated at the present time due to our lack of knowledge of Atlantic water characteristics and velocities. With an estimated velocity of 150 kilometers per year for Atlantic waters in the vicinity of the northern shores of Ellesmere Island, 2 k $cal/cm^2/yr$ of heat would be lost. This would limit ice thickness values to about 14 meters. It would appear that the present conditions, both meteorological and oceanographic, would not allow 60-meter ice shelves to be formed.

It is difficult to appraise the present climatic conditions in the Arctic since our historical knowledge extends over only a few decades and we are dealing with ice in the order of several thousand years old. In view of the known reduction of area of the shelf during the past fifty years, the present conditions appear exceptional.

The conclusions reached above are open to criticism, and only the collection of additional pertinent data will substantiate them. There are several programs of investigation, particularly on the Ellesmere Ice Shelf, that should be undertaken to verify or disprove the conclusions reached. These are outlined below:

1. A deep hole should be drilled in an area away from the influence of boundary conditions but still in the region of dust deposition in order to substantiate climatic evidence obtained from ice island T-3;

2. A thorough study should be made of the thickness and physical characteristics of the low-lying northern part of the shelf to determine why this is only a quarter to a third as thick as the general ice shelf;

3. Deep holes should be drilled in the ice rises in order to correlate accumulations there with the upper portions of the ice shelf and the ice island;

4. Periodic studies of the thickness of the re-entrant ice in the area north of Markham Bay where an ice island was broken off in about 1947 should be made to develop and substantiate long-term ice growth theories;

5. More evidence should be sought for the uplift of land areas in northern Ellesmere and the correlation of this uplift with ice shelf deformation near the land edges;

6. Oceanographic stations should be obtained periodically to determine the effect of local run-off waters on ice growth.