Photo: R.C.A.F.

Fig. 1. The shelf ice on the north coast of Ellesmere Island, with Disraeli Bay upper right, and Ward Hunt Island at its mouth, 16 July 1950.

ARCTIC ICE ISLANDS

L. S. Koenig, K. R. Greenaway, Moira Dunbar, and G. Hattersley-Smith

Introduction

At the First Alaskan Science Conference, held in Washington, D.C. in November 1950, the work of the U.S.A.F. in discovering and following the movement of exceptionally large masses of ice in the Arctic Ocean was first made public. The largest of these masses is some 300 square miles[1] in area, and because of their size and stability they were first referred to as "floating islands" and later as "ice islands".

From the air ice islands are readily distinguished from the pack ice by their homogeneous appearance and strikingly regular surface pattern. Their surface looks ridged or rolling, with wide intervening troughs. The ridges, or rolls, are as much as half a mile and more from crest to crest, and are roughly parallel, running from one edge of the island to the other. There is often some indication of a drainage system with small streams cutting across the large troughs. Most striking of all is the ability of the islands to keep their shape over a period of years, which suggests great thickness and hardness. Ordinary pack ice, by contrast, breaks and reforms continually under the influence of pressure, and although particularly heavy floes may remain substantially unchanged for several years they cannot be distinguished from the surrounding floes which they closely resemble.

The ice islands can be divided into two groups: a few large islands which are drifting in the Arctic Ocean and a number of smaller islands which have found their way into the channels of the Canadian Archipelago. They almost certainly originated on the north coast of Ellesmere Island, where there is a fringe of ice showing the same unusual surface pattern.

Since 1946 members of the U.S.A.F. have been following the drift of three large islands in the Arctic Ocean, and on 19 March 1952 a landing was made on T3, the smallest of these, which was then two degrees from the north pole.[2] We hope to publish a detailed report on the surface observations when these are available. The following accounts deal with the discovery of the two groups of islands, references to possible ice islands in the accounts of earlier travellers, and some speculative comments on their origin.

[1]Throughout these papers on ice islands measurements are given in nautical miles.

[2]At this time another ice island, which was at first mistaken for T3, was discovered some 40 miles to the west of T3.

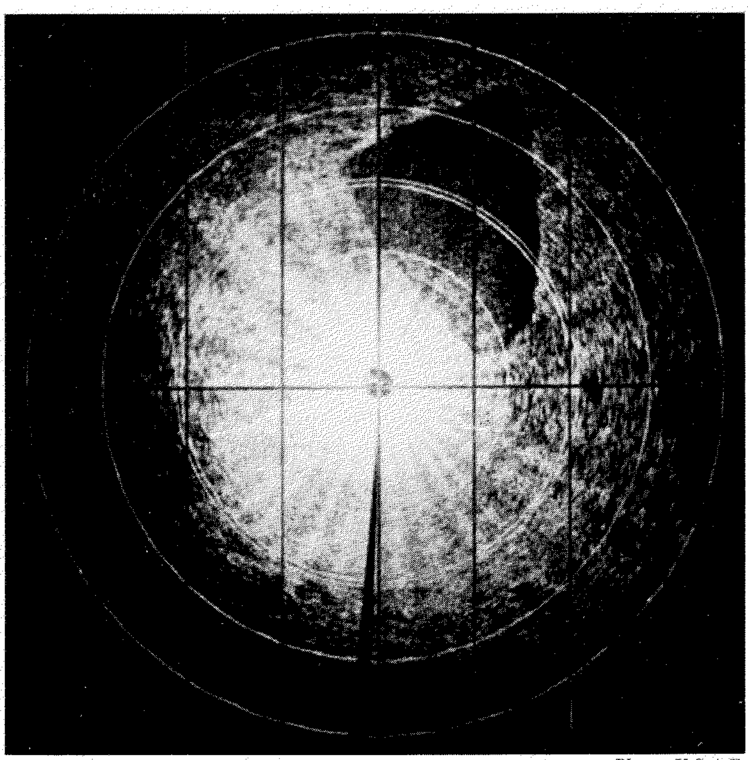

Photo: U.S.A.F.

Fig. 2. Recent radar photograph of T1, January 1952.

PART I. DISCOVERY OF ICE ISLANDS ON U.S.A.F. FLIGHTS OVER THE ARCTIC OCEAN. *By Major L. S. Koenig, U.S.A.F.*[1]

On 14 August 1946 an enormous mass of floating ice, considerably thicker than the pack ice and more than 200 square miles in area, was discovered less than 300 miles north of Point Barrow by an aircrew of the 46th Strategic Reconnaissance Squadron (Photo) stationed at Ladd Field, Fairbanks, Alaska. This original sighting was by radar and the ice mass was designated Target X or T1; its existence was classified secret, and speculation began as to its possible origin and probable future.

During the next three years T1 was observed many times, either visually, in the rare clear periods, or by radar, in darkness or under clouds, by aircrews of the 46th Reconnaissance Squadron (VLR) Weather (now the 58th Strategic Reconnaissance Squadron). As T1 continued to move farther from the routine reconnaissance flight paths it was lost for twenty-two months, the last sighting being on 6 October 1949. This last position, 86°05N., 72°00 W., was over 1,400 miles from its first reported position at 76°15N., 160°15W. (see Fig. 3). T1 measures approximately 15 by 18 miles, and in shape resembles an arrowhead or a chicken's heart. No landing was made on T1 and its characteristics were not recorded in great detail.

[1]Ice Reconnaissance Officer, 58th Strategic Reconnaissance Squadron (M) Weather, U.S.A.F.

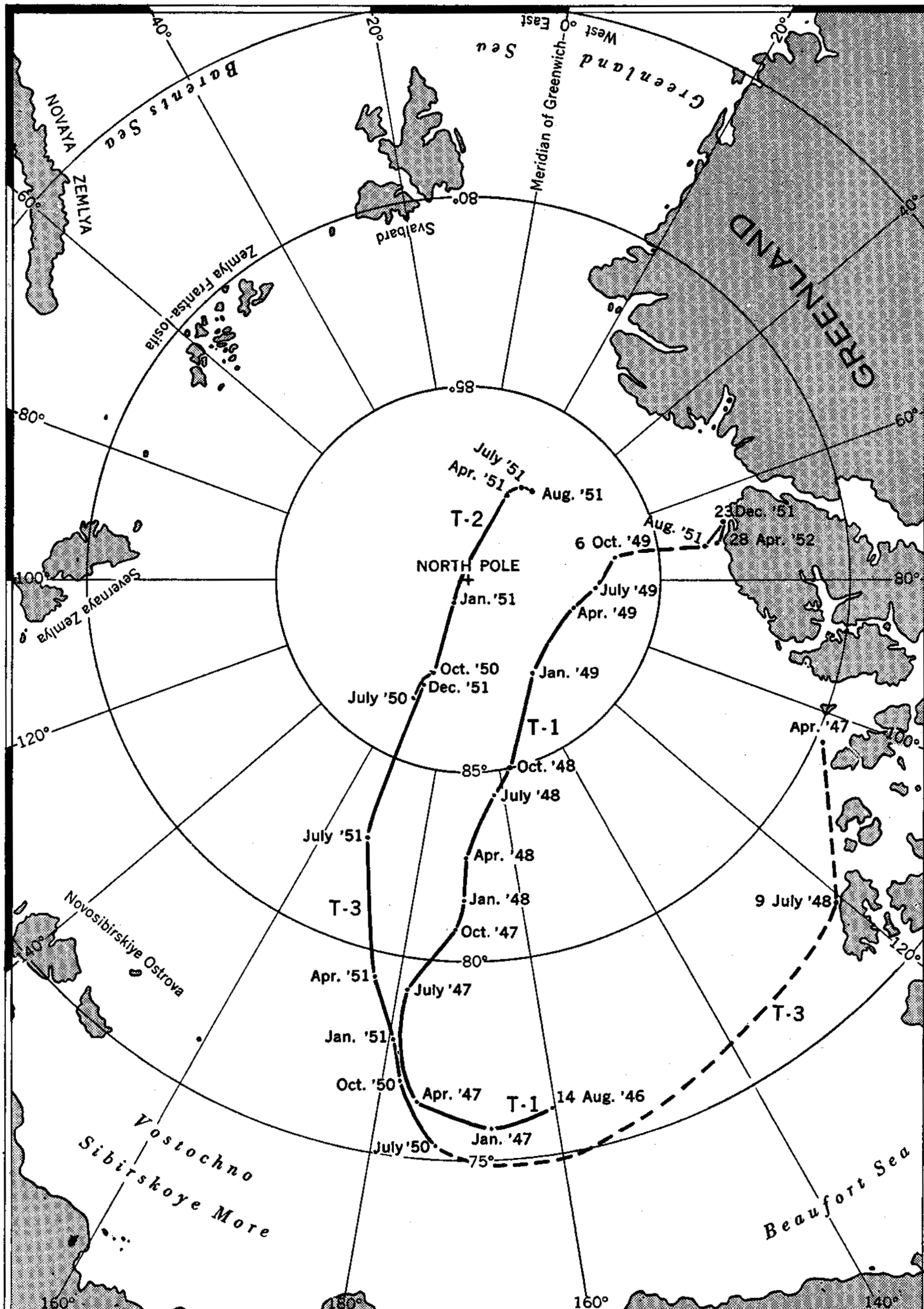

Fig. 3. Approximate paths of T1, T2, and T3 plotted at 3-monthly intervals.

Although routine weather reconnaissance flights were in continuous progress from March 1947, no other ice islands were discovered.[1] This was

[1]The discovery of T3 on a joint U.S.A.F./R.C.A.F. flight in April 1947 was not known to us at this time.

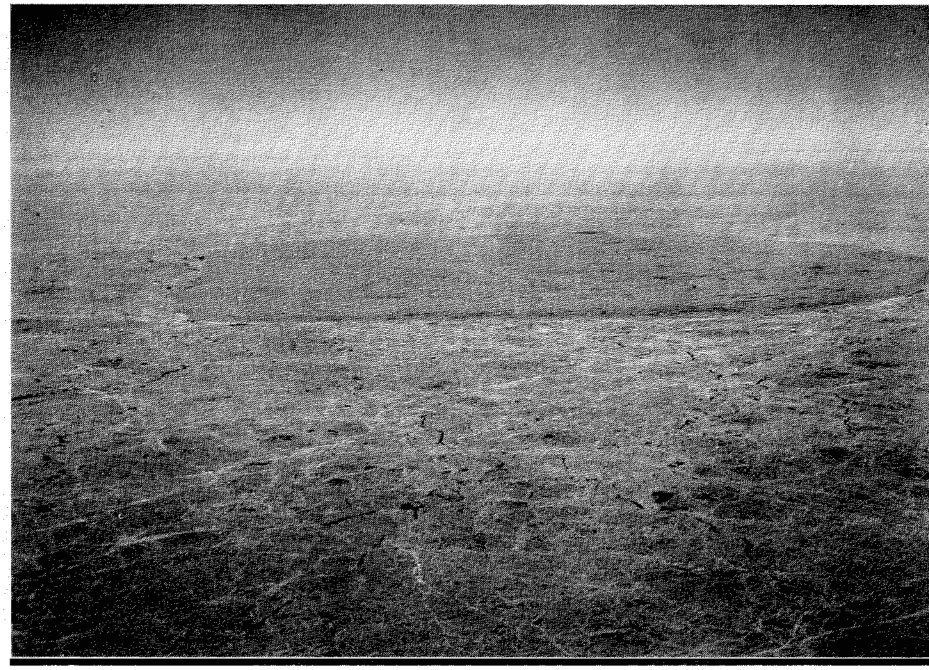

Photo: U.S.A.F.

Fig. 4. T2 from a range of 45 miles, 22 July 1950.

not, however, proof that other ice islands did not exist, for during nearly ten months of the year visual observation of the pack ice is virtually impossible because of darkness or cloud cover.

Beginning in late May 1950 the aircrews of the 58th Strategic Reconnaissance Squadron began a concerted search for other ice islands along the regular Ptarmigan weather flight track north from Alaska, using radar as a primary tool. This search continued without results until 21 July 1950 when a second ice island, T2, about 300 square miles in area, was discovered by visual observation at 86°40N., 167°00E. T2 had, in fact, been discovered and photographed by another aircraft of the U.S.A.F. on 19 July 1950 but had not been reported at the time. At a distance of 75 miles T2 was distinguishable from the surrounding pack ice by a difference in colour. At closer range it stood out by reason of its massive size—17 by 18 miles—and its corrugated surface relief. Parallel troughs ran from one end of the island to the other. They seemed to be filled with water and were connected by what appeared to be streams of running water. (Low-level observations at a later date showed that all these were frozen solid).

Spurred on by the success of July 21 the search was intensified. Our efforts were rewarded when T3 was discovered on 29 July 1950 at 75°24N., 173°00W. Small in comparison with T1 and T2, it was a kidney-shaped ice mass approximately 4.5 by 9 miles. This radar discovery was verified by visual observation on 24 August 1950. On T3 the characteristic ridges and troughs are more pronounced than on T1 or T2.

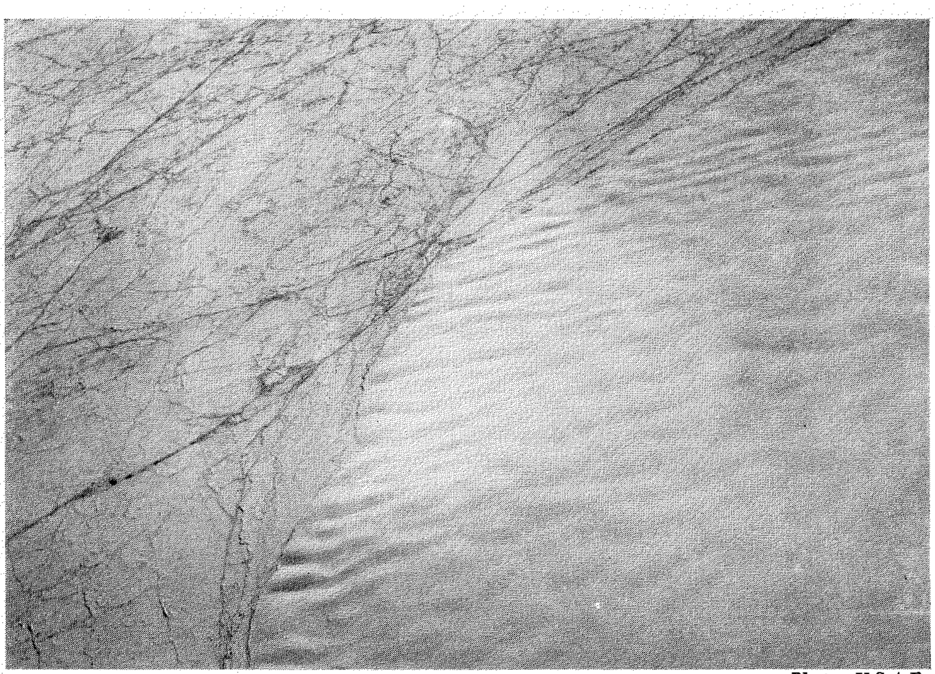

Photo: U.S.A.F.

Fig. 5. Part of T3, showing the difference in surface from the pack ice, 10 May 1951.

In September 1950 ice islands T2 and T3 were the subject of Special Report No. 3, 'Floating islands in the Arctic Ocean', of the 375th Reconnaissance Squadron (VLR) Weather, which formed the basis for Lt. Colonel J. O. Fletcher's paper at the First Alaskan Science Conference. This report left many questions unanswered. To answer some of them, particularly those concerning number and possible places of origin, an extensive reconnaissance program of the Arctic Ocean was planned. It was suggested that the ocean area north of Alaska and the Canadian Archipelago could be searched methodically in conjunction with flying routine weather reconnaissance if the Ptarmigan flight tracks were changed slightly. Fifteen Special Ptarmigan flight tracks were proposed to search the sector of the Arctic Ocean bounded by the 30°W. and the 180°W. meridians, both by radar and by visual observation.

Since the effectiveness of the search depended on visibility below the aircraft flying at about 18,000 feet (500-millibar level), the months of March and April were chosen for the flights to coincide with the period of the year having both daylight and minimum cloudiness. The search began on 14 March 1951 and the ice reconnaissance program continued until April 30, when the last scheduled flight was flown, but no new islands were discovered.

In addition to this series of flights a reconnaissance flight has been made about once a month to keep track of the known ice islands. One of these reconnaissance flights was arranged to explore the land masses bordering the Arctic Ocean from Prince Patrick Island to the eastern shore of Greenland. Photographs and reports from Canadian observers had already suggested that the ice islands might originate from the north coast of Ellesmere Island. On the night of 19 March 1951 a B-29 aircraft of the 58th Strategic Reconnaissance Squadron (M) Weather took off on Flight Ptarmigan Special Roger. Considerable difficulty, including severe icing over the Brooks Range and adverse winds, prevented complete coverage of the intended track. Nevertheless the flight was far from being a failure. Much of the coastline of Ellesmere Island from Nansen Sound to the turning point at Ward Hunt Island was covered

Photo: U.S.A.F.

Fig. 6. Low-level photograph of part of T1, 1 August 1951. The coast of Ellesmere Island in the background, with Ward Hunt Island and Disraeli Bay upper right.

with ridged ice similar to that of T3. This ice also extended up some of the fiords, and photographs were taken of several promising areas. On the return flight a small ice island was discovered in Prince Gustaf Adolf Sea. It was about two miles in diameter, and was almost circular in shape. The success of this flight prompted the squadron to plan a similar flight for later in the season when the effects of the summer melting would be evident.

On 1 August 1951 the weather was excellent and another Ptarmigan Special Roger was flown. Aboard the Weather Reconnaissance B-29 aircraft was a standard crew with the Ice Reconnaissance Officer as Weather Observer, a photographer, and two special observers: Dr. Terris Moore, President of the University of Alaska, and Mr. Maynard W. Miller of the American Geographical Society.

The flight to Ellesmere Island was without incident and the weather continued perfect for visual observation. Most of the coastline was photographed with both still and movie cameras. The ice foot or ice shelf was more obvious in summer than it had been in March, and extended out from the coast for from five to ten miles. The demarcation line between the solid ridged shelf ice and the loose pack ice was clearly marked. At 73°W. there was a stretch of shelf ice (with Ward Hunt Island in the centre) at least fifty miles long and up to ten miles wide with a surface pattern very similar to that of T3, which unknown to us had been first sighted on a joint U.S.A.F./R.C.A.F. flight in April 1947 about 300 miles west-southwest of this area. As a result of the flight of 1 August 1951 it was concluded that the ice islands could have originated from the ice shelf off the northern shore of Ellesmere Island.

During the approach to Ward Hunt Island a large mass of ice was sighted about fifty miles north of the island. This proved to be T1 which had been lost for twenty-two months. A low-level investigation of the island was made on two runs at approximately 250 feet. The surface was surprisingly flat, with the familiar gently rolling pattern. There appeared to be running water in some of the small transverse drainage channels, but all the water in the large parallel troughs was frozen solid. There was no noticeable change in the size or shape of the island since it was last seen in 1949.

To make the success of the flight complete, T2 was sighted at 87°07N., 25°00W. a few hours after sighting T1 and a low-level investigation was made. T2 has a smoother surface than T1 and the troughs and streams were all frozen solid.

Comments on low-level observations

During the past four years five low-level observations have been made over the three large islands. T1 and T2 were both observed twice, each time in the month of August. Crew members were amazed at the smoothness of the surface and the absence of water compared with the surrounding pack ice. From 100 feet it could be seen that the crests of the ridges are only 2 to 3 feet higher than the troughs on T1, and only inches higher than the troughs on T2. Maynard M. Miller's comment sums up our observations: "By low level flying, we were able to observe how incredibly smooth T2 was. (T1 was slightly rougher). This smoothness can perhaps be explained by the fact that melt-water—both from surface ablation and from that flowing in stream channels . . . becomes impounded in the linear lows during the summer months. . . . In late summer or autumn, such melt-water refreezes and the relief of the 'undulated structure' is consequently reduced. This process can be repeated, perhaps without all of the blue ice frozen during the previous year becoming melt again in subsequent seasons. (This could happen especially if the 'island' broke out and drifted to more northerly climes). At any rate, it is possible to visualize a progressive cycle of melting and freezing, which not only tends to level the surface, but also to add considerable structural strength to the overall mass." (Fletcher and Koenig, 1951, p. 25).

T3 was observed from low level during the month of May 1951 before any melting could have taken place. The entire island was covered with a layer of snow. The rolls were much more pronounced than on T1 or T2, yet the surface was still relatively smooth parallel to the troughs and crests. T3 has a more marked resemblance to the shelf ice of north Ellesmere Island than T1 or T2, which appear to have weathered considerably.

Pilots who have made the low-level flights were almost unanimous in stating that an emergency landing could be made safely on all three ice islands, especially T2.

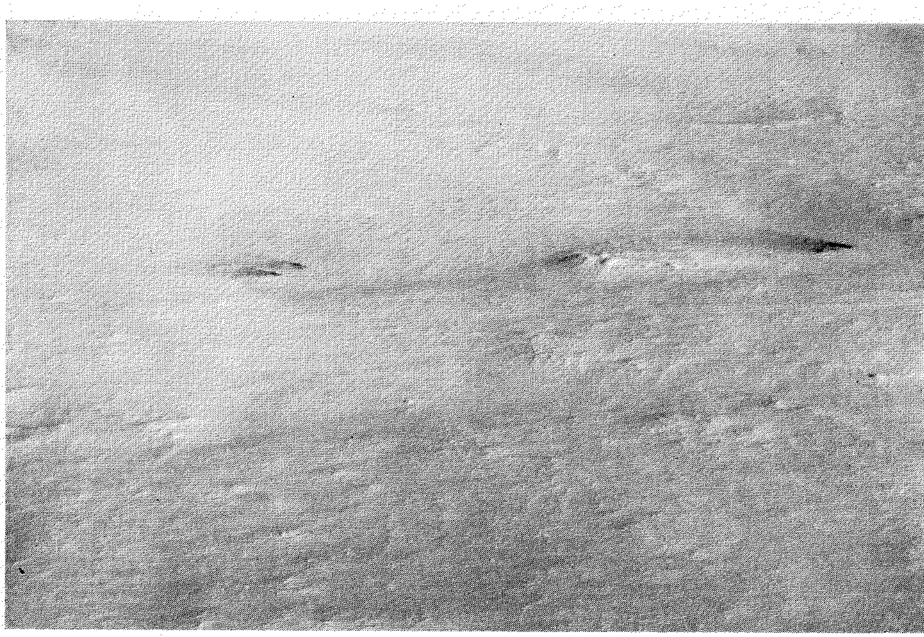

Photo: U.S.A.F.

Fig. 7. T3 under snow from 250 feet, showing mounds probably of morainic material (cf. Fig. 16), 10 May 1951. From this altitude the undulations are barely perceptible.

Movements of the ice islands

The movements of T1, T2, and T3 are shown on Fig. 3. The somewhat erratic paths followed by these islands have been smoothed out to compensate for navigational errors. Celestial navigational fixes are often impossible in high latitudes because of daylight or twilight conditions.

Over a period of thirty-eight months (14 August 1946 to 6 October 1949) during which T1 was followed with some regularity, the island moved a distance of some 1,400 miles, giving an average rate of approximately 1.2 mile per day. As there is no record of the movement from 6 October 1949 to 1 August 1951, the recent positions were not included in the calculations.

T2 has been observed for a much shorter period than T1, and our figures on the movement of this island cover only fifty-seven weeks. During this time T2 was north of 86°N. and moved approximately 460 miles at a rate of 1.1 mile per day.

During the fifty-four weeks that T3 has been under continuous observation (from 4 December 1950 to 18 December 1951) it has moved approximately 500 miles at a rate of 1.3 mile per day. For a period of thirty-nine months (from 27 April 1947 to 29 July 1950) T3 moved from a point about forty miles north of Cape Isachsen to a position at 75°30N., 175°00W. The only intermediate observation was at 77°15N., 121°00W., near the west coast of Prince Patrick Island. Assuming a movement shown by the dashed line on Fig. 3, T3 would have moved approximately 1,200 miles at a rate of 1.0 mile per day, which seems a reasonable figure.

From Fig. 3 it is noticeable that there is a northerly movement of the islands once they reach 175°W.; there also seems to be a definite slowing down in movement when they reach the area north of Greenland; and finally it appears that there must be some current that originally brought them from the region of Ellesmere Island and Greenland to the area north of Point Barrow.

Visual observations and radar sightings have shown that the ice islands frequently have open water at one or more sides. This is the case even when there is no open water elsewhere in the immediate vicinity. This suggests a movement differential between the ice islands and the pack ice. It is well known that icebergs move with the ocean currents rather than with the winds which move the pack ice. Ice islands would presumably behave like icebergs and their movements should therefore be a valuable assistance in determining the direction and rate of the subsurface currents in the Arctic Ocean because they are so easily seen and recognized.

We may conclude that in the period of one to three years during which the three large ice islands have been under regular observation they have moved at a rate of approximately 1.2 mile a day, and have followed what appears to be a circular track from north Ellesmere Island along the edge of the Canadian Archipelago to about 75°00N., thence west to 175°00W., and northwards across the region of the north pole.

PART II. ADDITIONAL INFORMATION FROM FLIGHTS AND AIR PHOTOGRAPHS IN THE CANADIAN ARCTIC. *By Squadron-Leader K. R. Greenaway, R.C.A.F.*[1]

The interest aroused by the work of the U.S.A.F. in plotting the courses of T1, T2, and T3, and by the photographs taken of the three islands, led to a re-examination of certain photographs taken on flights in the Canadian Arctic. On 27 April 1947, in the course of a joint U.S.A.F./R.C.A.F. flight, a large ice floe with an unusual rippled surface pattern was photographed by the writer at 79°50N., 104°00W., 30 miles north of Isachsen Peninsula, Ellef Ringnes Island. There was considerable discussion at the time as to its origin. Similar ice, attached to the shore, had been seen and photographed by the same crew on the north coast of Ellesmere Island three days earlier, and it was therefore decided that the floe was a piece of land-fast ice, very possibly from north Ellesmere Island, which had broken off and was drifting with the pack. On comparing the photograph with those of the three Ts it was found that it was clearly identifiable as T3. An ice island photographed

[1]Arctic Section, Defence Research Board, Canada.

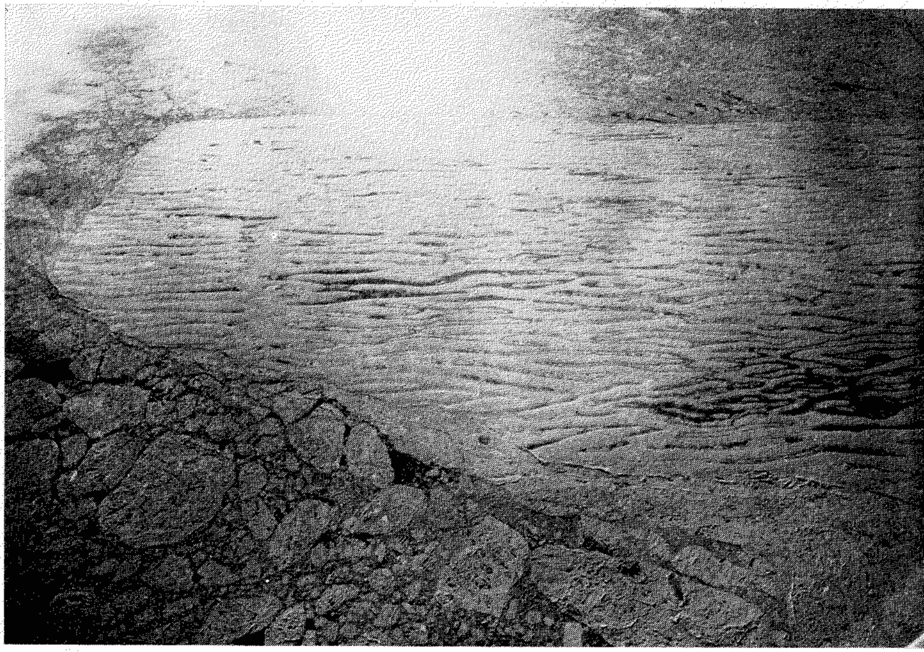

Photo: U.S.A.F.

Fig. 8. Ice island off Cape Columbia, July 1947. This island must have broken away from the shelf ice shown in Fig. 9. The apparently greater relief of the island is due to meltwater in the furrows at the end of July while the shelf ice in the June photograph is still snow-covered.

on 9 July 1948 from a U.S.A.F. aircraft engaged in survey photography under a joint Canadian/U.S. agreement also turned out to be T3. At this date its position was 77°15N., 121°00W., near the west coast of Prince Patrick Island. Thus three years were added to the known life of T3, which was first seen by the 58th Strategic Reconnaissance Squadron, U.S.A.F. on 29 July 1950.

The U.S.A.F. survey photo flights revealed two further ice islands in the Arctic Ocean, neither of which can be identified as any of the three Ts. One was photographed on 28 June 1948 at 82°45N., 104°30W., about 100 miles northwest of Cape Stallworthy, Axel Heiberg Island. This island, which has not been seen since, was about 7–8 miles long and 6–7 miles wide.[1]

The other island, which has also been "lost" since 1948, is of very special interest because the photographs reveal not only the island but also the place from which it apparently came. It was first photographed in July 1947 about 5 to 10 miles from the north coast of Ellesmere Island off Cape Columbia, at approximately 83°10N., 70°00W. (Fig. 8).[2] The same series of photographs shows a place near Cape Nares where a large section of the shelf ice appears to have broken away and into which two sides of the ice island could be fitted like a piece of a jig-saw puzzle. The space had been filled with

[1]It is possible that this may be the same island seen by the U.S.A.F. near T3 in March 1952.

[2]This island is shown on the Robeson Channel (No. 8) World Aeronautical Chart. The smaller island lying to its east could not be found on a careful search of the air photographs.

ordinary smooth fast ice, and the outline of the broken edge had not changed when the R.C.A.F. photographed the coast in June 1950 (Fig. 9). The surface of this island was very similar to that of T1 and it was about the same size and therefore one of the largest seen up to the present time. It was photographed again in May 1948, when it was 20 miles east of its previous position and about the same distance from the coast. Assuming a constant rate of drift, it is very likely that the island broke away from the shelf ice in 1946. It is interesting to note that this island was moving eastward. T1, which also drifted east in the same area but a little farther offshore, appears now to be moving slowly westward.

T1 was sighted by the 58th Strategic Reconnaissance Squadron, U.S.A.F. on 23 December 1951 a few miles off the coast of Ellesmere Island. On 28 April 1952 a Lancaster from the R.C.A.F. Central Navigation School sighted it about 50 miles west of this position, at 83°25N., 72°00W. Its shape had

Photo: R.C.A.F.

Fig. 9. Shelf ice off Cape Nares, June 1950, showing a jagged line marking where the island in Fig. 8 has broken away. The gap left has been filled with smooth fast ice.

remained unchanged, but timed runs across the island suggested that it was about 17 miles long and 13 miles wide, slightly smaller than previously reported. Its surface appeared to be very smooth and it was considered that in an emergency it would be perfectly practicable to make a "wheels down" landing. Pack ice in the form of pressure ridges was piled up to a height of about 10 to 15 feet around its edges. No part of the island's edge protruded above the surrounding pack; it is very doubtful if the total thickness of the ice exceeds 70 feet.

When looking through some of the R.C.A.F. trimetrogon photographs of the Canadian Arctic Islands a few smaller ice islands had from time to time been noted. A more thorough search was therefore undertaken. As a result twenty-eight ice islands, varying in size from a quarter of a mile to 7 or 8 miles across were found, as well as a considerable number of smaller fragments. They were distributed as follows:—

Arctic Ocean: 3

An ice island about 6 by 3 miles in area appears in photographs taken in the summer of 1950 about 10 miles east of Alert Point, Ellesmere Island. It is on the very edge of the pack ice. Two smaller islands are near it. A few others were found among the fast ice on the north coast of Ellesmere Island, but as they have not yet broken loose they have not been counted.

Nansen Sound–Eureka Sound: 3

Three ice islands were discovered on the photographs of the Nansen Sound–Eureka Sound area, all taken in July 1950. One was at the entrance to Nansen Sound, at 81°33N., 92°40W. This island was 3 miles long and 2 miles wide and had a curious vermicular pattern quite unlike any of the others (Fig. 13). The second and smallest island, 2 miles long and a little over one mile wide, was in Eureka Sound just north of the entrance to Slidre Fiord. The third was larger than the other two, about 5½ by 3 miles, and was between the eastern end of Stor Island and the Ellesmere Island coast (Fig. 17). This island was recognized as one that had appeared on the U.S.A.F. survey photographs taken in the summer of 1948, when it was in Nansen Sound near the entrance to Otto Fiord. It had thus moved about 120 miles in two years. In late August 1950, shortly after the air photograph was taken, the icebreaker U.S.C.G.C. *Eastwind* attempted without success to force a passage through the island on her way to resupply Eureka Weather Station. Fortunately, Eric Fry of the Canadian Topographical Survey, an observer on the icebreaker, took several photographs of the island (Fig. 16). Before the landing on T3 these were the only photographs of an ice island taken from the surface. The flatness of the ice surface in these photographs is most striking, as from the air the island appears to be one of the roughest. It was thought that it might be aground on Stor Island, but another photo line flown in 1951 showed that it was no longer there.

Peary Channel: 5

A group of five islands, three of which were about 1 mile square and the other two somewhat smaller, appear on photographs taken in July 1950 at 79°05N., 96°30W., some 15 miles north of Amund Ringnes Island.

Prince Gustaf Adolf Sea: 1

Photographs taken in July 1950 show a small island midway between Cape Malloch, Borden Island, and Cape Isachsen, Ellef Ringnes Island. It was about

Fig. 10. Ice islands shown on air photographs in the Canadian Archipelago. The areas of the islands are not correct for scale, but do give their approximate relative sizes.

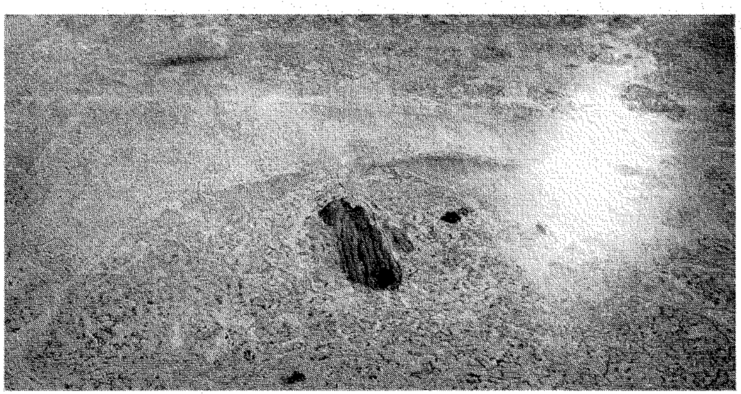

Photo: R.C.A.F.

Fig. 11. A small ice island in Maclean Strait, taken in August 1950.

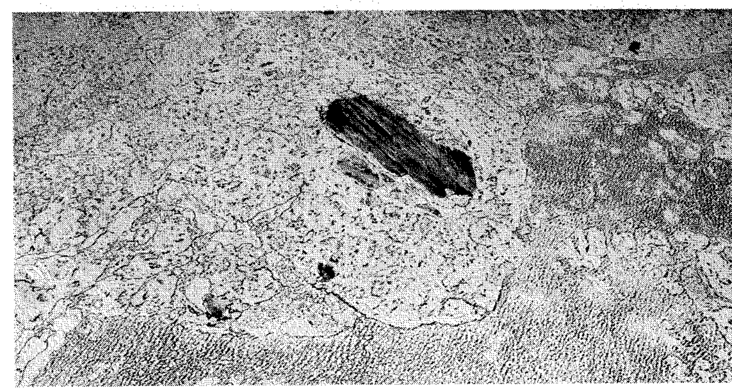

Photo: R.C.A.F.

Fig. 12. The same ice island from the other side, taken in July 1951, 60 miles from its former position.

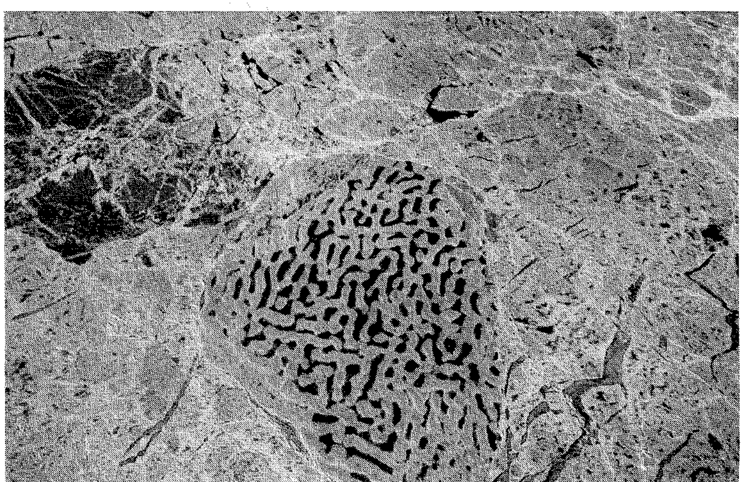

Photo: R.C.A.F.

Fig. 13. Near the entrance to Nansen Sound, July 1950. The surface pattern of this ice island is very unusual.

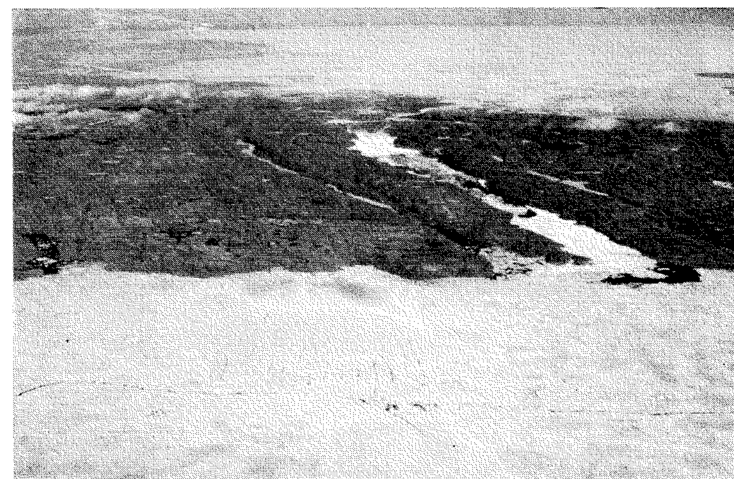

Photo: R.C.A.F.

Fig. 14. Ice island in Peel Sound just north of Bellot Strait, August 1950.

2 miles square. In March 1951 the 58th Strategic Reconnaissance Squadron, U.S.A.F. reported seeing an ice island in this area, and it is possible it may be the same one, but the R.C.A.F. photographs are taken from too great a distance to allow a satisfactory comparison.

Maclean Strait: 3

A small ice island about 1½ mile long by ½ mile wide is shown on photographs taken in August 1950 and in July 1951. In the course of this time it moved from 77°56N., 105°30W., ten miles north of Lougheed Island, to 77°08N., 102°30W., 20 miles east of Edmund Walker Island. This represents a straight line distance of 60 miles in a southerly direction. A small fragment which lies a few yards off the southeast side of the island in the earlier photographs is still in the same relative position in the later ones. Indeed quite a large section of the pack seems to have moved as one whole (Figs. 11 and 12). Two other islands were photographed in 1951, one at 76°54N., 102°50W., and one 10 miles off the southwest corner of King Christian Island. Both were about half a mile square, and there were two fragments lying off the southeast corner of the second one.

Byam Martin Channel: 1

An ice island measuring 5 by 2 miles appears on photographs taken in August 1950 east of Sabine Peninsula, at 76°30N., 106°30W.

Hecla and Griper Bay: 4

One of these islands, 4 by 2 to 3 miles in area, appears on two photographs, one taken in July 1948 and the other in August 1950. In both its position is the same, 76°20N., 113°30W. off Cape Grassy about 4 miles east of Depot Island. It may be aground, but it is likely that the ice in the bay has not broken up during this period. The island has a very flat, worn down surface. The other three islands, all of which appear on August 1950 photographs, were much smaller, only about half a mile square. Their positions were: 76°22N., 111°50W.; 76°30N., 111°25W.; and 76°45N., 112°00W.

Peel Sound: 1

An ice island about 2½ miles square appears on photographs taken in August 1950 approximately 1½ mile offshore 3 miles north of the western entrance to Bellot Strait (Fig. 14).

James Ross Strait: 3

On photographs taken in August 1951 three islands were found close together between Cape Felix, King William Island, and Cape Adelaide Regina, Boothia Peninsula. One was about 3 miles square and the others about ¾ mile square and 1 by ¼ mile respectively. The large one was not the same as the one photographed in Peel Sound the year before.

Victoria Strait: 4

This is the farthest south that ice islands have been found. Photographs taken in August 1949 reveal one large and three small islands in Erebus Bay on the west coast of King William Island. The large one was about 3 miles square and the smallest 1 mile by ¼ mile. There were also a large number of fragments, many of them long slivers which were easily distinguishable from the surrounding loose brash ice (Fig. 15). It appears as if the large island is breaking up and the slivers have broken off parallel to the ridged pattern.

In addition to these twenty-eight ice islands two rather similar ones were found in *Greely Fiord*, which however appeared to be of local origin. Photographs taken in July 1950 show one of them, 1½ by ¾ mile in size, at about 80°50N., 77°30W.

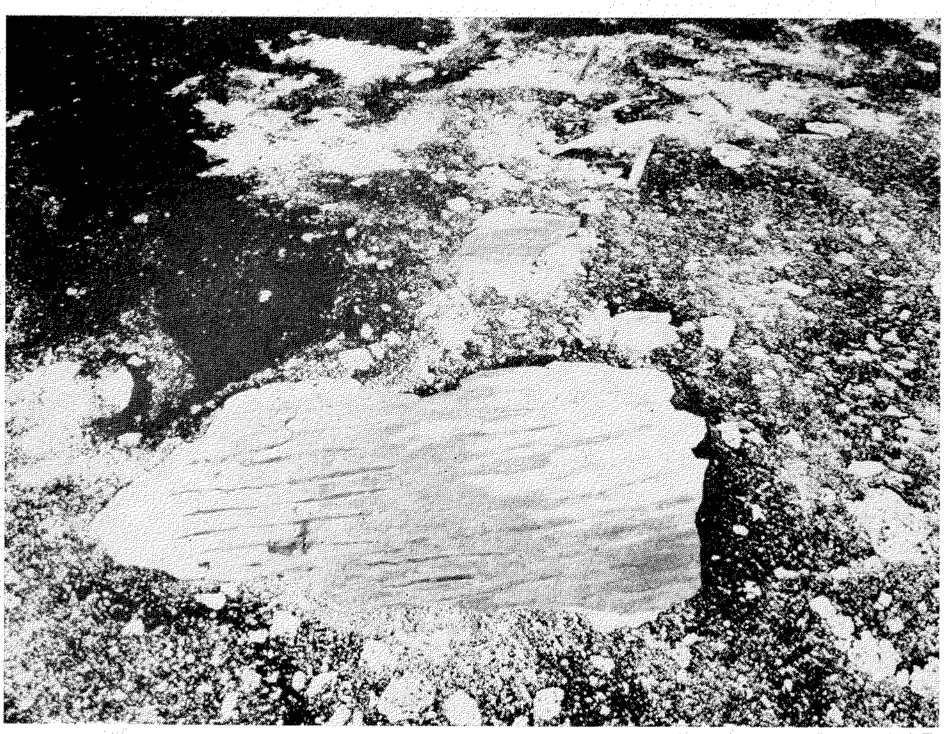

Photo: R.C.A.F.

Fig. 15. Ice island in Victoria Strait, August 1949. A smaller island is beyond it and also several slivers which have probably broken off it.

Photographs taken in July 1947 show the same piece of ice in the process of breaking away from a glacier at the head of Antoinette Bay. The same photographs show another island (or berg) about the same size in the central part of the fiord. These resemble ice islands in every way except that the surface pattern is more confused and lacks any suggestion of the characteristic parallel ridges.

There are no doubt other islands to be found on the trimetrogon photographs. The search carried out was by no means exhaustive, though good coverage was given to the most likely areas. Moreover, photographs are not available of all water areas. No flight lines, for instance, cross M'Clure Strait or Melville Sound, and the coverage of M'Clintock Channel is far from good. It is felt, however, that most of the islands shown in the photographs have been spotted.

No ice islands were found in the channels to the east of Ellesmere Island, though it might seem probable that some would drift eastward and down Robeson Channel. Nor were any found in M'Clure Strait, though owing to poor coverage this does not necessarily mean very much. It is likely though that those that reach Prince Patrick Island without being drawn into the archipelago are more apt to be carried out into the Arctic Ocean than into M'Clure Strait. The general movement within the archipelago is, as might be expected, south and southeast.

Part III. Historical references to Ice Islands. *By Moira Dunbar*[1]

The name "ice island" is by no means a new one. It has been used from the very earliest times to describe a wide variety of phenomena. Frobisher and Baffin, for instance, both speak of "Ilands of Yce". From the accompanying description it is quite clear that they mean icebergs. Among later writers, de Long uses the term to describe detached floes which his party used to ferry themselves and their equipment across open leads during their summer retreat from the wrecked *Jeannette*. In this case, of course, it is used merely as a handy descriptive phrase and is not intended to be taken as a technical term. There is, however, one technical use which should be mentioned, although it applies only to the Antarctic. Wright and Priestley use the term "ice island" to describe a certain type of tabular berg which is roughly conical in shape and looks very like an ice-covered island with high ground in the middle of it.

To trace the use of a name, however, is one thing; to trace the occurrence of a particular type of ice is quite another. The traveller cannot bring back samples of the ice he sees, nor as a rule can he state with any degree of certainty that the ice he has described is in such and such a position and may be seen by anyone who cares to go and look. This has led to confusion of terminology and it is sometimes hard to correlate the accounts of different observers.

It is therefore not possible to say with certainty that ice islands have been seen by earlier explorers. Any old ice, whether it be glacial ice or rafted sea ice, will display some of the characteristics of the ice islands, and as study of them by living observers has so far been almost exclusively from the air, it is not yet known whether they stand out as clearly to the ground traveller as they do from the air. From the only available photographs taken from ground level it would appear that they may look much flatter than they do from the air. The island in Figs. 16 and 17 looks very uneven in the air photograph, but on the ground flat, though rough. This is probably because the distance between the crests is long and the slopes generally gradual, so that it may be necessary to have the perspective of height in order to see the pattern.

There are, however, many descriptions of ice that might very well be of the same formation as the ice islands. There are also very good descriptions of the ice in the probable source area on the north coast of Ellesmere Island from the two parties that have sledged over it.

Parry, on his first voyage in 1819-20, describes a large floe in M'Clure Strait which sounds temptingly like an ice island: "an immense floe which formed the principal, or at least the nearest, obstruction to the westward, was covered with large hummocks, giving to its upper surface the appearance of hill and dale. . . The thickness of this floe at its nearest edge was six or seven feet above the sea, and as about six-sevenths are usually immersed, the whole thickness would appear, in the common way of reckoning it, to have been

[1]Arctic Section, Defence Research Board, Canada.

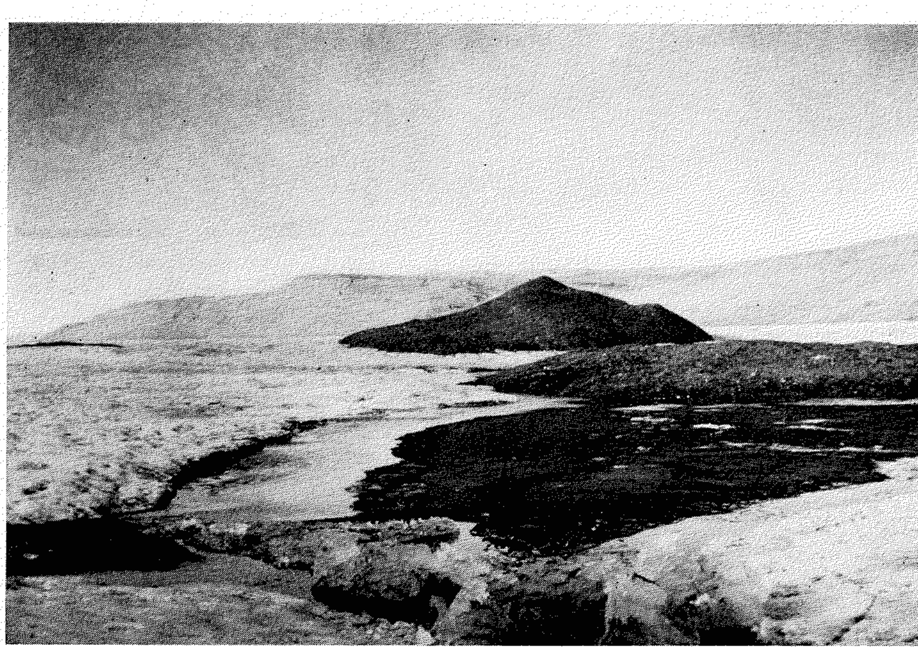

Photo: Topographical Survey of Canada

Fig. 16. Ground level view of the south end of an ice island in Eureka Sound off Stor Island, showing moraines and melt pools, August 1950. Compare the flatness of the ice surface with the rough appearance of Fig. 17.

Photo: R.C.A.F.

Fig. 17. Vertical air photograph of the north end of the island in Fig. 16, July 1950. Stor Island to the left.

from forty to fifty feet. . . But the hummocks were many of them at least from fifteen to twenty-five feet above the sea; so that the solidity and thickness of this enormous floe must have been infinitely greater than any thing we had seen before." (Parry, 1821, p. 240). From the accompanying sketch, however, it seems more likely that this was a large rafted and hummocked old floe, possibly formed on the west coast of Banks or Prince Patrick islands, where the pressure from the arctic pack is very heavy. Similar ice in the same area is described by Robert S. Janes, Second Officer of the D.G.S. *Arctic* on Bernier's voyage of 1910, about thirty miles south of Cape Providence: "Now when I say floe I mean in this case that it was something unusual for I never saw such ice; it must have been 50 to 60 feet thick with hills on it as high as any berg. One saw in coming around this floe it was unbroken, it must have been as old as Adam." (Rep. on Dom. Gov. Exped. (1912?) p. 30). Such references could be quoted indefinitely, especially from travellers off the west coast of Banks Island. But these do not appear to be the ice islands of the air photographs. Isaac Hayes, who sledged across Kane Basin from Etah to Dobbin Bay in 1861, describes "an old field" that he measured as follows: "Its average height was twenty feet above the sea level, and about six by four miles in extent of surface, which was very uneven, rising into rounded hillocks as much as eighty feet in height, and sinking into deep and tortuous valleys." (Hayes, 1867, p. 311). This may well have been one of the flat-topped bergs (Fig. 18) which still break off some of the glaciers in eastern Ellesmere Island.[1] On the other hand it may have been an old arctic floe that had drifted down Robeson Channel, or it may have been an ice island. The chief argument against the likelihood of any of these being ice islands is the apparent roughness and variety of the topography described within a small area.

The expeditions of Nares (1875-6) and Greely (1881-4) did much to add to the general knowledge of both sea and glacier ice and also much to confuse the terminology. This confusion is largely connected with the use of the term "palæocrystic", a word coined by Nares to describe the heavy old pack ice of the Arctic Ocean (Markham, 1878, p. 228). Almost every north polar traveller since then has used this term, but not always to describe the same thing, and as many do not define what they mean by it, the reader is left to make his own interpretations.

Nares's expedition also coined the term "floeberg". By this was meant, as is sufficiently clear from the description and from a photograph which appears in Nares's book, large blocks of polar pack ice which have been thrust up on end by pressure and which commonly mark the junction between the fast ice and the pack; hence the name "Floeberg Beach" which he gave to the *Alert*'s winter quarters because of the line of grounded "floebergs" which protected the ship from the moving pack. He uses the same word to describe the large flat-topped bergs which he saw in Robeson Channel and farther south, which he considered to have the same origin.

[1]And possibly off some of the glaciers of northwestern Greenland.

Greely saw what he thought to be similar "palæocrystic floebergs" in the channels between Ellesmere Island and Greenland and decided that they were of glacial origin and that some of them at any rate came from the east Ellesmere Island glaciers, which produced flat-topped bergs because they had more gradual terminal gradients than the Greenland glaciers south of 80°N. Through his assumption that they were the same as Nares's floebergs he complicated the issue by introducing a suggestion of glacial origin for palæocrystic ice. At the same time he also used the term "palæocrystic" to describe floes in the polar pack which he believed to be ordinary sea ice, and called the whole "palæocrystic pack". From this confusion the term has never recovered. Perhaps the best definition is that of Lauge Koch (1928, pp. 388-92) who follows the usage of Nares and suggests that this ice is formed by rafting, hummocking, and snow accumulation. He limits the area of its occurrence to the seas north of Greenland and the Canadian islands and south of Peary's "Big Lead".[1] The ice north of this lead drifts freely to the open sea east of Greenland, but that to the south is pressed against the land masses and therefore subjected to heavy pressure. It thus attains great thickness and may remain for very many years before melting or escaping to the south through Robeson Channel.

Greely has much that is interesting to say about ice. He divides his "palæocrystic" ice of the channels south of the Lincoln Sea into floes and floebergs, both of which he considered to be of glacial origin, noting their likeness to descriptions of the antarctic shelf ice by the Challenger Expedition. He goes so far as to postulate the existence of an arctic ice cap similar to that of the Antarctic. The floes he describes as ranging from twenty to fifty feet in thickness, and from thirty square yards to as many square miles in area. "On leaving Cape Baird, in August, 1883, my diary records a palæocrystic floe which was fifteen miles long and of unknown width. Another floe, between Cape Beechy and Cape Sumner, was of such extent that a sledge party was nearly two days passing over it. The surface of such a floe resembles closely a piece of rolling country. It is by no means level, but has its hills and dales, its water-courses and lakes; in fact, it is an island where ice replaces earth." (Greely, 1886, Vol. 2, p. 46). This description sounds remarkably like an ice island.

The floebergs are described by Greely as huge, cubical blocks of ice "of a vertical height of from fifty to eight hundred feet, and having sides varying from twenty to a thousand feet in length. The largest one seen by me was about eight hundred feet high, (nearly ninety feet above the sea,) six hundred feet broad, and nine hundred feet wide, nearly a perfect cube." (Vol. 2, p. 47). The ice of these bergs was very clearly stratified, but morainic material was rare. This Greely considered quite natural, as the glaciers of Grinnell Land were also observed to be remarkably free from such matter. He does describe one morainic deposit, however, on the top of a very large floeberg to which he was able to climb over "piles of heaped up ice. Its surface was very

[1]An open lead encountered by Peary on all his polar attempts at about 84°30N. Flights over the Arctic Ocean confirm that a lead is very frequently seen in this area.

Photo: R.C.A.F.

Fig. 18. Dobbin Bay, east Ellesmere Island, showing glaciers and their flat-topped bergs, 24 June 1950. Note the tributary glacier upper left which no longer joins the main one, and the apparently inactive glacier at lower left.

diversified, there being two valleys. . . . This block of ice, six hundred feet thick and nine hundred square, was a floeberg or flat-topped iceberg which had floated from Kennedy Channel with us. In crossing one of the valleys, my foot displacing a thin coat of lately fallen snow, I accidentally discovered a rock. Examining farther I found two rocks and boulders, one in each valley. There were not far from fifty such rocks, and it was evident that they were medial moraines." (Vol. 2, p. 53).

Greely considered that the largest of these floebergs came from the Arctic Ocean, from his supposed arctic ice cap. It is not at all improbable that they were fragments of the northern Ellesmere Island shelf ice. The estimated thickness of six hundred feet is certainly much greater than that of any of the islands known today, but this might be accounted for to a certain extent by wasting in the intervening period. It is also possible that the thickness was over-estimated. It is very hard to estimate vertical distance accurately, and as the visible part of a berg is small compared with the subsurface part a small error would be multiplied considerably in calculating the total thickness. Smaller floebergs, though "of no inconsiderable size", were observed by Greely and others of his party having apparently broken off from glaciers in eastern

Ellesmere Island. Among the places where he mentions seeing them is Dobbin Bay, and a great many are still there today (Fig. 18). As the glaciers of Ellesmere Island were in all probability much more active then than they are now it is not surprising that Greely found these floebergs so common.

Lockwood noticed similar flat-topped bergs coming from the glaciers at the head of Greely Fiord: "Many small icebergs were seen at the head of Greely Fiord in both the bays, as well as an occasional stray one farther down. They were, so far as I could judge, entirely similar to the ordinary floeberg of the straits (Robeson and Kennedy Channels)..." (Greely, 1886, Vol. 2, p. 55). Two of these bergs appear on recent air photographs of Greely Fiord.

G. W. de Long, in 1881, retreating towards the Lena delta after the wreck of the *Jeannette*, came upon "some very old heavy ice, dirty and discolored with mud, with here and there a mussel shell, and with a piece of rock on it, which, as it was similar to that on Henrietta Island, I carried along." (Emma de Long (ed), 1884, p. 613). "I measured one place and found it thirty-two feet nine inches thick, and where it is not mud-stained it is rounded up in hummocks resembling alabaster." (p. 614).

Nansen apparently found nothing with strongly marked ice island characteristics during the *Fram* expedition. The nearest description we find is of "massive high hummocks with . . . square sides, and of great circumference, sometimes quite resembling snow-covered islands. They are of 'palæocrystic ice', as good as any one can wish." (Nansen, 1897, Vol. 2, p. 184).

Otto Sverdrup, whose expedition of 1898-1902 mapped the west coast of Ellesmere Island and added Axel Heiberg and the Ringnes islands to the map, mentions some "old polar ice" in Eureka Sound "with enormously high melted-off ridges and deep dales, where the snow was as loose as sand." (Sverdrup, 1904, Vol. 2, p. 192). Describing Isachsen's journey round Ellef Ringnes Island, he writes: "The most western and north-western parts of 'Isachsen Land' were also low, a land of sandbanks. On its west side the ice was coarse and pressed up in wave-like, more or less parallel, ridges. Violent upheaval must have taken place here, for ridges several yards in height lay pressed right up on land." (Vol. 2, p. 297). Both these descriptions might refer to ice islands.

Storkerson, of the Canadian Arctic Expedition, drifted on an ice floe in the Beaufort Sea with a party of four from April to October 1918. The floe on which they made this drift is one of the most probable ice islands in the literature, as is plain from the following description.

"The floe at the northern edge of which our camp was situated and on which we drifted through the summer of 1918 from the 8th of April to the 9th of October, can best be described as a large island of ice about seven miles wide and at least 15 miles long. This latter estimate is less than the real length of the floe but I say 15 miles because I only explored 15 miles of it. It may have been 30 miles long for all I know. In relation to the smaller surrounding floes it acted exactly as land does. The smaller floes would be more affected by the winds and would drift faster back and forth, depending on the direction of the winds. This fact was of great advantage to us in that with west wind we would have open water to the east. The smaller floes would drift away from the point at which we had our camp. With east wind the small ice on the west side would drift to the west, so we nearly always had open water in which to hunt seals.

"From an elevation close by our camp the panorama presenting itself impressed me exactly as that of a certain kind of land. The colour of course was the bluish white of ice but the contour of the hills, the ridges and the levels in between and in which numerous small lakes and ponds were visible, was exactly like certain stretches of prairie I have seen in the midwestern United States and Canada. This similarity of old ice to land is well known.

"The thickness of the ice at our camp, judging by the amount of it visible above the level of the sea, I should say would be about 50 or 60 feet. This extraordinary thickness was just local and the average of the whole floe naturally would be much less, probably less than 20 feet." (*in* Stefansson, 1921, p. 699).

The statement concerning the well-known resemblance of old ice to land is a timely warning against over-eager diagnosis of ice islands. Nevertheless the size and thickness of this floe combined with its topography strongly suggest an ice island, and the area of the drift was only about 120 miles from the place where T1 was observed in the fall of 1946. It is also interesting to note that Major Koenig reports that T1, T2, and T3 appear to move at a different rate from the surrounding pack and very commonly have open water on one side. This seems to support the suggestion that they are influenced more by current than wind, and certainly their northward track towards the pole is directly against the prevailing winds.

Two interesting references come from the Arctic Ocean sledge journeys of Peary in 1906 and of Frederick Cook in 1908. Peary, somewhere about 86°N., "traversed several large level old floes, which my Eskimos at once remarked, looked as if they did not move even in summer. . . . Several berg-like pieces of ice discoloured with sand were noted during the march, my Eskimos saying that these looked as if we were near land." (Peary, 1907, p. 131). Cook, who, however far he was from the pole, undoubtedly sledged a considerable distance over the Arctic Ocean, provides one of the most likely of all historical references to ice islands: "from the eighty-seventh to the eighty-eighth parallel we passed for two days over old ice without pressure lines or hummocks. There was no discernable line of demarcation to indicate separate fields, and it was quite impossible to determine whether we were on land or sea ice. The barometer indicated no perceptible elevation, but the ice had the hard, wavering surface of glacial ice, with only superficial crevasses." (Cook, 1911, p. 265).

Both these instances are quoted by E. S. Balch in 'The north pole and Bradley Land' as evidence to prove the existence of Bradley Land, seen by Cook in 1908, and Crocker Land, reported by Peary in 1906. These lands turned out to be fictitious and the many flights over the Arctic Ocean leave no possibility of their existence. They apparently belong to the ranks of imaginary polar islands which include the Russian Sannikov Land, Keenan

Photo: R.C.A.F.

Fig. 19. Vertical air photograph of old ice floes in Smith Sound, 24 June 1950. The uneven worn down topography of such floes might easily give rise to descriptions by ground travellers that sound like ice islands.

Land in the Beaufort Sea, and Presidents Land, reported by the *Polaris* party in the Lincoln Sea in 1871. It is pleasant to think that at least some of these might have been ice islands, their height exaggerated by the well known polar mirage effect. The mountainous topography described by Cook makes this improbable in the case of Bradley Land, though an alleged photograph of it in his book looks less dramatic than his description. Peary's "snow-clad summits of a distant land" sounds more likely but this may be simply because the description is less detailed.

Another reported land which appears not to exist is Takpuk Island in the Beaufort Sea, "discovered" in September 1931 by an Eskimo, Takpuk, in his schooner of the same name. This island is well documented, as the discoverers landed on it and took several photographs. As described by Stefansson (1934, p. 104) it was about "half a mile long and of nearly the same width, but with an irregular outline. . . The island was highest at the south-eastern end, sloping towards the northwest. The hill (at the southeastern end of the island) was about as high as the highest land on the shore line near Barrow, which is Cape Smythe, about forty or fifty feet above sea level. The surface was rolling, and there were small ponds." The schooner approached the island through deep water, and with her bows against the beach had a depth off her stern of twenty fathoms. Takpuk is described as being a very fine type of Eskimo with " a most excellent reputation for truthfulness". He had no way of checking the exact position of the island, but had apparently worked well offshore from the coastal fringe of islands. From the available evidence, Stefansson placed its position as near 71°20N., 145°30W. At that time, before aircraft became a familiar means of arctic transportation, there was no reason why a new island should not be found in the Beaufort Sea. Since then there have been many flights over the area and some hydrographic work, and as Takpuk's island has not been reported it may be presumed not to exist.

The evidence in favour of its having been a small ice island is impressive. At first sight the photographs showing the "hill"—a rounded cone of what appears to be coarse unconsolidated material of the boulder clay type—and a quite large area covered all over with earth, seemed to rule out the possibility. A comparison with Eric Fry's photographs of the island in Eureka Sound, however, reveal a quite striking resemblance, particularly in the hill and the ponds (Fig. 16). The soil-covered area is certainly much larger, and grass and mosses were reported on Takpuk's island, but neither of these phenomena seems impossible on an ice island. The description of its surface characteristics and the deep water offshore are strong evidence in favour of the theory. Finally the position is not so very far from the known track of T1.

Stefansson, in 'The friendly Arctic', mentions a small island discovered by Emiu, an Eskimo of his party, "lying . . . perhaps ten miles southeast from the middle of the east coast of Emerald Isle". (p. 492). The air photographs reveal no island in this position. As Stefansson gives no details, the question of its having been an ice island must remain a matter of pure speculation. The area however is one where small ice islands are quite common today.

Edward Shackleton, sledging over the entrance to Dobbin Bay in 1935, "crossed a huge palæocrystic floe, tremendously thick and worn and weathered during countless years, into an undulating country of miniature hills and valleys. On this the snow was packed much harder, and for several hours we made good progress, driving up and down hill until we were nearly half-way across Dobbin Bay." (1936, p. 413). This description might equally well fit an ice island or a very old floe such as is shown in Fig. 19 in much the same area.

The most recent reference to possible ice islands comes from Russia. "In October 1943, three kilometres to the north-northwest of Mys Chelyuskin, a flat-topped iceberg was discovered, 1,500 metres long, 400 metres wide and rising 10 metres high out of the sea. As the fliers informed me, they sighted this unusual ice-mesa off the eastern coast of Severnaya Zemlya during ice reconnaissance flights." (Zubov, 1948). Zubov also reports that icebergs were seen off the east coast of Ostrov Vrangelya in 1946, aground in shoal water, and off the west coast of the island in 1947. No bergs had ever been seen in this area before, and they were assumed to come from northwestern Greenland.

Turning to what Peary called the "glacial fringe" of north Ellesmere Island, we are on much less speculative ground. The first expedition to penetrate the Arctic Ocean by the Smith Sound route was that of Sir George Nares, in 1875–6, in the *Alert* and *Discovery*. The *Alert* wintered on the north coast of Ellesmere Island near Cape Sheridan and from this base Pelham Aldrich sledged west along the coast to Alert Point, over what is almost certainly the source region of the ice islands. He gives a very clear description of the ice, which he calls "ice waves" or "ice rollers".

"Several low ridges from 30 to 40 feet high, and varying from a few hundred yards to about a mile in length, show up in front of the cliffs. . . . I imagine these ridges are composed of hard ice under the snow, though I had no means of penetrating it any depth to find whether or no land lay underneath. . . .

"In passing between the island [Ward Hunt] and the main land, we crossed a ridge about 30 feet high, and ½ a mile in width, which runs quite a mile from about the middle of the south shore of the former. Thinking it was land, I dug down through 2½ feet of snow, and came to ice. Similar looking ridges extend to the eastward and westward of the island." (Parliamentary Paper, 1877, p. 201-2).

"I cannot make out where the land ends and the ice begins. . . There is no crack, but the shelving land appears to blend with the ice, which rises in the form of a roller, with a second roller behind it, exactly as water rolls on a beach after a breeze of wind." (p. 203).

"After lunch we sounded, and came to solid ice, under 4½ feet of snow, but from the height and extent of the ridges, I should imagine land lay beneath." (p. 213).

He mentions these rollers particularly at Disraeli Bay, M'Clintock Bay, Yelverton Bay, and around Cape Alexandra.

Peary, who is the only other man to lead a sledge party over this ice, is equally exact in his description of it. He travelled the whole length of the north coast and first mentions the wavy ice west of Point Moss, which is roughly the eastern limit of it today. ". . . we encountered for the first time, what later became a constant and striking feature of the glacial fringe, the long, prairie-like swells of its surface. . . The swells which we traversed coming from Point Moss, showed up beautifully from here [high land near Cape Columbia] as parallel swells following the main contour of the shore." (Peary, 1907, p. 181). Again, at Cape Alexandra he describes "the series of rolling swells which are a feature of this peculiar ice-foot (?)[1]. . . These swells are on a large scale, and reminded me very strongly of portions of the ice-cap of Greenland. If they are not huge drifts, I do not know how to account for them." (p. 185).

[1]The question mark is Peary's.

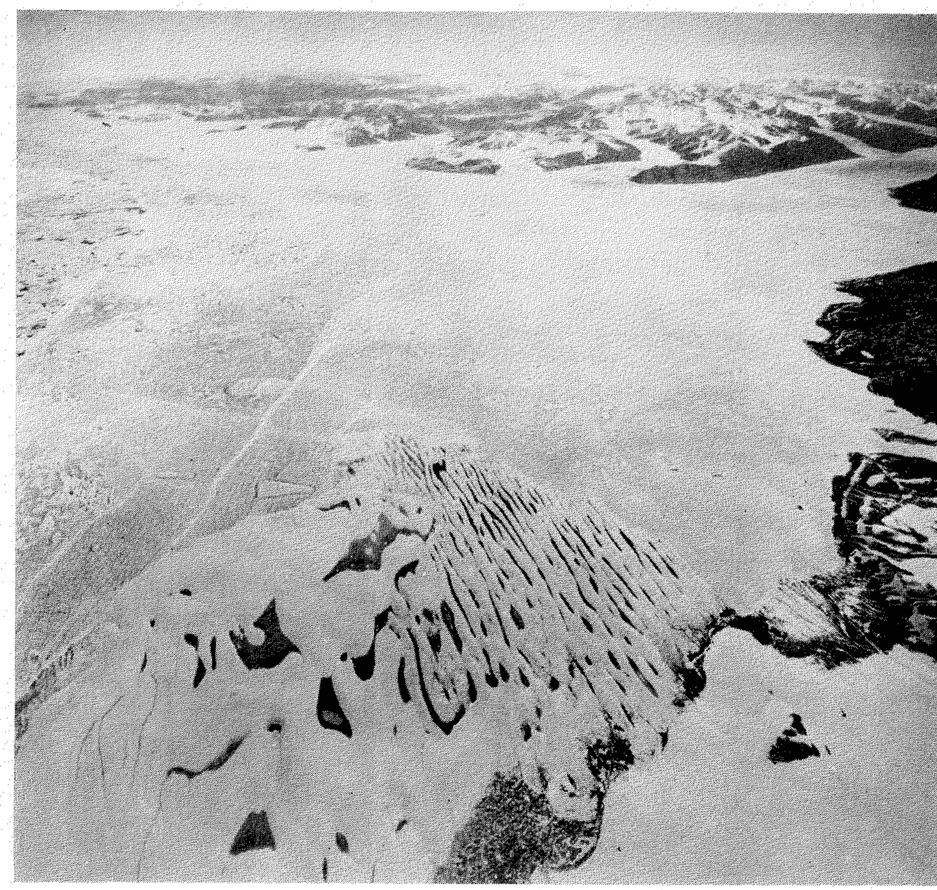

Photo: R.C.A.F.

Fig. 20. Yelverton Bay, north Ellesmere Island, 15 July 1950. Very little of the shelf ice remains in this bay. Note the ice island near the edge of the fast ice at upper left.

On the return journey, in the second half of July, again near Cape Columbia, he says: "Coming back over the bluffs, to our camp the orography of the glacial fringe both east and west was very strongly brought out by the streams and blue lakes which filled every depression and furrow. I took some photos, but was not sanguine as to their success." (p. 231). Apparently he was justified in his lack of sanguinity, because the photos unfortunately do not appear in his book.

Two very interesting points are brought out by comparing these accounts of Aldrich and Peary with the air photographs. Aldrich describes the "rollers" in Disraeli Bay as running approximately SE.–NW., and states that therefore on the east side of the bay they were more or less at right angles to the coast and on the west roughly parallel to it. Peary, speaking of the same area, says "Off Ward Hunt Island and especially the western end, they [the ridges] are particularly marked, and here they blend into drifts formed in the lee of the island." (p. 185). Both these observations are quite strikingly borne out by the air photographs (Fig. 1), showing that this ice has very likely not moved in the last seventy-six years.

In Yelverton Bay, on the other hand, both travellers give the impression that it too was full of rollers, whereas today this is not the case. "Looking back on to the bay [Yelverton], I observed a series of ice rollers, two of which we crossed over yesterday." (Aldrich *in* Parliamentary Paper, 1877, p. 213). "The glacial fringe here has a distinct glacier characteristic in that its surface is undulating, and there is a gradual descent in going away from the land." (Peary, 1907, p. 189).

Peary, who is the only man to have gone beyond Yelverton Bay, describes a similar undulating surface all the way round the coast: "The edge of the ice was still visible [beyond Cape Alfred Ernest], but it was because we were up above sea-level on the undulating surface of the glacial fringe." (p. 190). "The surface of the glacial fringe during this march was intersected with narrow water cracks which seemed to delimit the larger swells, and I observed some hummocks and true crevasses." (p. 191). "The ice traversed in this march was a succession of swells of moderate height. The light and shade after the sun came out, allowed the undulations of this remarkable ice-foot to be very clearly seen, and I was more and more reminded of the ice cap." (p. 201). "I then headed directly across the strait [Nansen Sound] to the northern extremity of the western land [Axel Heiberg Island]. The ice in the Strait was to all appearance a continuation of that forming the glacial fringe of the Grant Land coast." (p. 203).

From these extracts it is quite clear that the "glacial fringe" extended all along the coast and even into Nansen Sound, though it seems more probable that the "continuation" he speaks of may have been a detached portion—in fact an ice island. In any case, the photographs today show only a few broken pieces and a small remnant of fast ice in Yelverton Bay (Fig. 20), and unconnected patches to the west of it. It would appear therefore that there has been a great deal of breaking out of this ice since 1906. These facts, together with the undoubted recession of many of the glaciers on this coast since Peary's time, seem to support the theory that the shelf ice is a relic formation.

Lockwood, of Greely's expedition, makes one or two references to "undulating ice" on the north coast of Greenland, which he followed from Robeson Channel to Cape Washington, but gives no clear description of it (Greely, 1886). It would be interesting to see air photographs of this coast. Koch's photographs taken in 1938 (1940) show only the upper reaches of the fiords, and no undulations are apparent.

It will be seen from these extracts, the result of a fairly extensive but by no means exhaustive study of the literature, that it is at least likely that travellers in the Arctic Ocean and among the Canadian Archipelago have met with ice islands in the past, and that the shelf ice of the north coast of Ellesmere Island has retained its major characteristics over a period of at least seventy-six years. No very definite conclusions can be drawn from these observations as there can be no proof that even the most likely examples were actually ice islands. It is however of some interest to consider the areas involved and compare them with the distribution of ice islands in recent years as shown on Fig. 10.

The most likely descriptions come from three areas. The first is the Arctic Ocean somewhere to the north of Axel Heiberg Island (Cook). This is the general area of the drifts of the three Ts. The second is the Beaufort Sea (Storkerson and Takpuk's island), and is near but well to the south of an area where T1 has been sighted and where T3 may be assumed to have passed. The third area is from Robeson Channel to Smith Sound (Greely). In this area more possible examples have been found than anywhere else, yet a search of the photographs has revealed no ice islands. The photographic coverage is incomplete but it is possible to say with some conviction that there were none on the Canadian side at the time of photographing. This may be coincidental, but it is also possible that in the middle of the last century the shelf ice extended farther east than it does now, just as in Peary's time it extended farther west. Islands from this eastern extension might well have found their outlet through Robeson Channel, and the source being now more or less exhausted they would no longer be so likely to occur in this area.

The other parts of the Canadian Archipelago where possible ice islands were found—Eureka Sound, Isachsen Peninsula, Emerald Island—are all areas where they have been photographed recently. Of the instances off the Siberian coast it is impossible to speak as so little is known, but it seems reasonable to suppose that some islands might escape the northerly current that is presumably responsible for the course of the three Ts from Alaska to the pole, and travel across to the area of the drifts of the *Jeannette*, *Fram*, and *Karluk*.

PART IV. COMMENTS ON THE ORIGIN OF THE ICE ISLANDS. *By Geoffrey Hattersley-Smith*[1]

The great area, thickness, and structural strength of the ice islands, as well as their rolling relief, distinguish them from other forms of ice encountered in the polar sea, and suggest that they originated neither as sea ice, nor by calving from the snouts of valley glaciers. When detailed information on the ice of these islands is available from the work of the U.S. party, who are spending the summer on the island T3, we shall be able to make more definite deductions about the ice of their source area. Preliminary reports mention that seismic soundings have given an average ice thickness of 200 feet, with a maximum thickness of about 250 feet, and a maximum height above sea level of 40 feet. The crests of the "rolls" which characterize the surface are 300 to 1,000 yards apart and about 10 feet in height. In some places the "coast" falls away in a smooth slope to the pack ice; in others there are cliffs up to 30 feet high. Rafted pack ice, standing on edge, flanks some parts of the coast and testifies to the great pressure of the pack, against which the island has maintained its shape for at least the last six years.

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The air photographs of the northern Ellesmere Island coast show that ice formations resembling T3 fill many of the fiords and fringe the coast between them. This ice is continuous between Cape Columbia and Yelverton Bay, with isolated patches to the east and west. This "glacial fringe", the presumed source of the islands, appears to have the characteristics of shelf ice as known from the Antarctic. It connects the ice of the fiords and grows out from the coast for up to about 10 miles, and is presumably afloat for much of this distance. Consideration of the origin of the ice islands therefore resolves into a consideration of how the shelf ice has developed and what is causing it to break up. It is very desirable that this ice should be studied by a glaciologist on the ground; in the absence of definite knowledge the following comments are naturally speculative.

The idea of shelf ice occurring in the Arctic may be unfamiliar, but it is by no means new. Thus Greely (1886, Vol. 2, p. 47) was in no doubt that his "palæocrystic floebergs" originated from ice of the barrier or shelf type, though Nares considered they were old hummocked sea ice. Recently Wordie (1950, p. 416) has drawn attention to the coloured illustration of a "floeberg" in 'Shores of the Polar Sea' (Moss, 1878, Plate 12) as indicating the existence of shelf ice formations. This floeberg, although stratified like the antarctic shelf ice, is described by Moss, one of the doctors on Nares's expedition, as "of salt ice".[1]

Glacial conditions in north Ellesmere Island

The great glaciers at the heads of the large fiords along the north Ellesmere coast draw their supply from the Highland Ice[2] of the mountainous interior. The amounts of snowfall and wasting in this inland region, where the mountains rise to 10,000 feet, are not known. However, it seems likely that the annual snowfall is appreciably greater than the average of 2 inches of water recorded at Alert on the northeastern Ellesmere coast, though scarcely enough to maintain the icefields at their present size.

Near the coast there are very obvious signs of glacial recession. Glaciers have receded from the rock walls of their valleys, tributary glaciers have shrunk back from their former junctions with main glaciers and in some cases have been cut off from their parent snowfields (Fig. 1). It is safe therefore to conclude that the main glaciers, which reach the coast, must be tapping reservoirs of ice accumulated in a period of greater snowfall. The retreat of the smaller tributary glaciers must have caused considerable thinning of the shelf ice in the fiords in recent times, and hence must have contributed to its tendency to break up. The recession apparent in northern Ellesmere is also evident in other parts of the island. In the southwest Schei (*in* Sverdrup, 1904, p. 465) writes of "thin ice-mantles and stationary snow-fields, which are unable even to feed the valley glaciers." According to Bentham (1941, p. 44) most of the glaciers in the southeast appear to be stationary or retreating a little.

[1]Moss noted that some of the larger palæocrystic floebergs "could not be less than two hundred feet deep" (1878, p. 29).

[2]The ice is not thick enough to conceal the underlying topography (see Wright and Priestley, 1922, p. 148).

During the maximum extension of the glaciers and shelf ice of northern Ellesmere it may be supposed that the lower parts of the hilly peninsulas between the fiords were covered by ice, and that this ice continued out to sea and formed a continuous shelf with the ice from the fiords. With the gradual withdrawal of the ice from these peninsulas the outlying parts of the shelf were in many places severed from the glaciers. Emergence of the land, possibly through isostatic recovery, must have had a considerable effect on the coastline and on the course of deglaciation in the immediate coastal region; de Rance and Feilden (*in* Nares, 1878, Vol. 2, pp. 341-2) have shown that the north Ellesmere coast has risen by some 300 feet in recent times. This emergence must have been a factor in determining on which parts of the coast the shelf ice could maintain its hold as conditions became more unfavourable. Recent increases in temperature and salinity of sea water, for which there is evidence from other regions of the Arctic (Ahlmann, 1949, pp. 186-7), may have been most destructive to the ice shelf.

Deglaciation in the coastal region of northern Ellesmere has probably taken place very much on the lines suggested by Flint (1929). With the stagnation of the glaciers and icefields, which accompanies deglaciation, wasting becomes controlled mainly by the topography. As soon as rock surfaces or nunataks make their appearance, the rate of melting of the surrounding ice is greatly accelerated; this is especially noticeable where the rocks are of sedimentary origin—as in northern Ellesmere—rather than of igneous or metamorphic origin. Along the nearby coast of north Greenland, Lauge Koch (*in* Rasmussen, 1921, pp. 310-1) has commented on the rapidity with which the snow disappears in the mountains in comparison with its rate of disappearance at sea level, especially on the sea ice. Doubtless this is in part due to the wind blowing the snow away to low sheltered areas, but Koch implies that it is also due to the very marked rise in air temperature with height above sea level which in turn is related to the insolation at exposed rock surfaces. The shadows cast by the high mountains, the low altitude of the sun, and the northern aspect of these coasts would also assist in preserving the lowland ice.

There is a further factor which favours the persistence of lowland ice—especially shore-fast ice. According to Flint (1929, pp. 259-60), "The difference in rate of disappearance between highland ice and lowland ice is increasingly accentuated by the fact that the meltwater that escapes from the vanishing highland ice necessarily washes the entire débris content of the ice, plus much of the surface débris of the newly exposed highlands, down on to the surface of the lowland ice, where much of it remains as an insulating blanket, sheeting over the glacier remains and materially retarding their rate of melting. Vegetation may gain an extensive foothold on this . . . waste." This blanketing of the ice has certainly taken place along the northern coast of Ellesmere Island. Near shore at Cape Colan late in April Aldrich (*in* Nares, 1878, Vol. 2, p. 12) found beneath the snow "a thin layer or covering of soil or mud lying on top of the hard ice." Nares makes the comment that this discovery was to be expected from the amount of soil and gravel which he saw deposited on the ice by the summer torrents later in the season.

Outwash and morainic material are therefore to be expected on ice islands which have broken away from that part of the ice shelf nearest to the shore. The U.S. party have found morainic boulders on T3, and Eric Fry's photographs of the ice island near Stor Island in Eureka Sound in 1950 show large amounts of outwash and morainic deposits 40 to 50 feet high (Fig. 16).

Glacial regime on the ice shelf

There is very little information on nourishment and wasting on the ice shelf itself from the records of Nares's and Peary's journeys along the north Ellesmere coast. In spite of the low precipitation large depths of drift snow were encountered. Nares (Parliamentary Paper, 1877, p. 19) reports that only 6 to 8 inches of snow fell during the winter, yet in the following months of April and May Aldrich (*in* Nares, 1878, Vol. 2, p. 12) found depths of from 1 to 4½ feet of snow resting on a thin layer of soil or mud above hard ice near Cape Colan. The U.S. party on T3 also reports finding snow resting on a few inches of dirty, porous ice which may contain volcanic ash and cosmic dust; immediately below the dirty ice there is clear glacier ice. In neither of these records is there any mention of firn or "snow-ice".

On the assumption that T3 has broken away from the shelf ice of northern Ellesmere Island, it would seem that during recent decades at least no increment to the surface of the shelf ice has been taking place by firn formation, except possibly in a few places close to the shore where unusually large amounts of drift snow may accumulate. Peary records that on 15 July 1906 most of the snow had melted on the shelf ice of Disraeli Bay (1907, p. 228). There is still the possibility of a small annual increment through refreezing of meltwater at the surface of the ice, as occurs on the Barnes Icecap (Baird, 1952). Summer meltwater naturally tends to concentrate in the troughs of the rolls, as is shown in the air photographs and as Peary (1907, p. 231) has recorded. If refreezing greatly exceeded wasting the rolls would in time become levelled off unless the forces which produced the rolls are still acting. The writer suggests that the rolls for the most part reflect actual folding of the ice due to pressures which, in some parts of the ice shelf, have acted in the past but which are no longer acting (see pp. 100–1). If this is so, it would mean that present summer wasting at the surface of the ice shelf from whatever cause is equal to or exceeds the annual accumulation.

It is unlikely that any increment is now taking place at the under-surface of the ice shelf because of the high temperatures caused by the large amounts of summer meltwater from the land which drain down beneath the ice. Thus Markham (*in* Nares, 1878, Vol. 2, pp. 64-5) reports a temperature of 31.8°F at a depth of 9 feet and 29.0°F between 12 feet and the bottom in 12 fathoms; he concludes that "The very marked change . . . [in temperature] between the water at a depth of nine and that at twelve feet is evidently due to the meeting of the freshwater running off the melting ice and the sea water." Moss (*in* Nares, 1878, Vol. 2, pp. 61) expressed the opinion that "waste exceeds growth near shores."

Formation of the shelf ice

Off the north Ellesmere coast it is probable that both the normal processes by which a sheet of shelf ice may be formed have been important. These are:

1. By the floating ice tongues of separate glaciers pushing out to sea and coalescing. (Sea ice may form in the interstices and become incorporated in the main mass. However, "the characteristics of Shelf-Ice . . do not appear until the contours of the original glacier ice and sea ice have been swamped beneath a heavy accumulation of snow." (Wright and Priestley, 1922, p. 164)).
2. By the accumulation of snow upon sea ice which has persisted for several seasons.

In the inner parts of the fiords, where the ice appears to be very thick, the main glaciers and their tributary glaciers seem to have been the chief sources of supply; in the outer parts of the fiords and along the coast between the fiords the shelf ice seems to have grown mainly through the accumulation of snow on sea ice. Lauge Koch (1923, p. 54-5) in his classification of the glaciers of northwestern Greenland describes the ice conditions in certain fiords, and it may well be that the shelf ice along the north Ellesmere coast originated in much the same way. "On account of the climatic conditions at the inner end of deep fjords, the sea ice as well as the projecting tongue of the glacier increase in height, the annual precipitation finding no outlet. For this reason no line of demarcation can be drawn between the sea ice and the glacier. The sea ice in the fjord moves with the glacier almost as far as to the mouth of the fjord, forms fissures, and pushes moraines over projecting headlands or islands in the fjord." In north Greenland this old fiord ice is referred to as "floating inland-ice", and Koch (*in* Rasmussen, 1921, p. 331) adds that: "The Eskimos call it 'Sikussaq'—*i.e.,* ice which resembles the ocean-ice."

Calving from the shelf ice

Calving from an ice shelf is at its greatest either at the maximum glaciation when the shelf is pushing actively forward, or when the supply is cut off and the shelf is slowly disintegrating *in situ.* There is no information on the rate of movement of the Ellesmere shelf ice in the fiords, nor on the proportion which is afloat. In view of the low snowfall and the general recession of the tributary glaciers, the guess may be hazarded that in most of the fiords the forward movement of the main glaciers is largely dissipated before the sea is reached. The seaward movement of the shelf ice near the mouths of the fiords is probably very small indeed. Those parts of the shelf which form a coastal fringe between fiords presumably can have no outward movement at all; their periodic calvings to form ice islands show that their present hold on the coast is precarious. They may well be relic portions of a former more extensive sheet of shelf ice along this coast.

"Relic glacial forms" of probably similar origin on the west coast of Graham Land in the Antarctic have been described by Fleming (1940), who concludes that: "The island ice-caps and the fringing glaciers . . . are unstable and ephemeral glacial features. The shelf-ice with which they formed a continuous sheet and to which they owed their development must have broken away from the coast quite recently." (p. 100).

It is possible that the fringe of shelf ice on the north coast of Ellesmere Island is only able to maintain its present hold through the presence of small off-shore islands, which it has swamped and to which it is firmly anchored. In some of the air photographs small islands can actually be seen in the process of emerging through the shelf ice. In the Antarctic small off-shore islands and shoals are thought to be important factors in the development and maintenance of the Larsen Ice Shelf, east Graham Land (Reece, 1951, p. 408; Mason, 1951, p. 514), and of the Shackleton Ice Shelf, King George V Land (Mawson, 1942, p. 324).

Wind action, tide action, and pressure from the pack may cause cracks to develop in the ice shelf, and so hasten the ultimate calving of ice islands. With the presumed increase in the temperature of the polar sea in recent times these cracks may remain open longer. Near the shore meltwater streams cause decay of the shelf ice, thus hastening disintegration in which wedge-shaped islands may be produced. T2 and T3 each have one end markedly higher than the other which suggests that they may have come from a shore-fast part of the shelf.

That the break-up of the Ellesmere shelf ice has been fairly rapid in recent years is suggested by Peary's description of the extent of this ice in Yelverton Bay in which only isolated fragments remain today (Peary, 1907, p. 189). It may be that the production of ice islands is now at a maximum.

Formation of the rolls

Rolls are characteristic of shelf ice in the Antarctic, and it is therefore not surprising that they occur in the Ellesmere ice shelf. The rolls may be due to a number of causes: these include movement of the glaciers, movement of the shelf ice, pressure of the pack ice, temperature changes, tidal action, and wind action.

The rolls in the inner parts of the large fiords must be regarded as pressure ridges caused by the seaward movement of the main glaciers, modified by lateral pressures exerted by tributary glaciers. This force could scarcely be affecting the outer parts of the fiords today where movement of the shelf is either very small or non-existent.

In certain small bays and inlets it is difficult to explain forces of sufficient strength to produce rolls in ice of such evident thickness. The rolls may therefore result from the weathering of ice folded at an earlier date through glacier or shelf ice movement. Stratified ice contains layers of various hardnesses and porosities, and it may be expected that weathering, as in sedimentary rock, will bring out secondary structures in folded ice. If this is in fact occurring it would seem to support the view that the present state of the ice shelf is one of surface waste and not of growth. On the other hand, on a portion of the ice shelf which has broken away to form an ice island, it may be that growth will occur by refreezing of meltwater or firn formation as the islands drift to a colder region or one of higher precipitation. Miller (quoted on p. 73) suggests that this may partly account for the smoothing out of the rolls on the ice islands T1 and T2. Those islands which drift to a warmer region will naturally weather through increased melting, which would also cause smoothing out of the rolls.

In the outer parts of the fiords and along the exposed parts of the coast between fiords the rolls are generally parallel to the coast. It may be that here their persistence and origin are largely due to the great pressure of the pack ice on the edge of the shelf. A bay to the west of Phillips Bay shows a system of low, closely spaced rolls in the outer part of bay-fast ice of moderate thickness. A little way back from the mouth of the bay the ice is smooth, showing that these rolls are recent and due to pressure of the pack. Although this ice may persist long enough to be called semi-permanent fast ice, it is unlikely under present conditions that it can reach sufficient thickness to justify being called shelf ice. It does, however, point to the possibility that the outer parts of the northern Ellesmere shelf ice may have been formed from semi-permanent fast ice.

Rolls may also be partly due to pressure induced by temperature changes, which would also account for their parallelism to the shore. Wright and Priestley (1922, p. 344) give this explanation for ridges and troughs parallel to the shore in bays on the east side of McMurdo Sound in the Antarctic: "a rise of temperature, acting over a very large area, causes expansion in the ice-sheet, especially when the latter is thick. This, in its turn, sets up considerable pressure which is usually concentrated along shorelines, or against immovable objects such as islands and stranded bergs."

In the Antarctic tidal action has also been suggested as a possible cause of parallel rolls near the seaward edge of shelf ice, notably on the Ross Barrier (Poulter, 1947, pp. 377–9 and 382–3; Debenham, 1949, pp. 210–1). These features are attributed to fracture throughout the depth of the ice caused by the rise and fall of the tide on the seaward side of a portion of the barrier which is grounded on moraine. The fractures become filled with frozen sea water from below and with drift snow from above (see Siple, 1945, Fig. 38, p. 57). The tidal range off the northern Ellesmere coast is small, but it is also small in the Ross Sea area. Therefore, in the present state of knowledge tidal action as a possible cause of rolls should not be discounted, although in the Arctic the effect of the tide is greatly reduced by the density and persistence of the pack ice, even in summer.

Wind action is unlikely to be the main cause of rolls, although it may influence their development. In general wind-driven snow would be expected to fill up the troughs between rolls and so obliterate them. That this does not seem to happen is another reason for believing that summer wasting exceeds the preceding winter's snowfall.

In the light of all the known facts it is difficult to reconcile the development of an ice sheet of considerable thickness with present conditions along the northern Ellesmere coast. The development probably took place before the post-glacial climatic optimum in a period of greater precipitation, lower summer temperatures, and lower sea temperatures. Accumulation of drift snow at the foot of the coastal mountains may have been a more important factor than at present, and may have influenced the growth of the shelf ice, as has been suggested for the Larsen Ice Shelf in the Antarctic (Mason, 1951, pp. 513-4). In the outer parts of the fiords and along the coast between the fiords the ice shelf should be regarded as a relic glacial feature. It is the periodic breaking-off of large areas of this shelf which has formed the ice islands at present drifting in the Arctic Ocean and channels of the Canadian Archipelago.

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*Consulted in translation only.