ELLESMERE ICE SHELF PROGRAM

ELLESMERE ICE SHELF INVESTIGATIONS*

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The overall purpose of the expedition to Ellesmere Ice Shelf during 1959 was to observe and study physical changes on the central portion of the shelf during the thaw and freeze-up periods. Investigations were made of the composition, heat budget and wastage of the shelf.

Glaciological and Geophysical Investigations

It is unfortunate that Mr. Paul Walker, the glaciologist, and Mr. Frank Crowley, geophysicist and scientific leader, could not be here to describe their investigations; however, a brief review of their work will be presented. The glaciological investigations were conducted by Mr. Paul Walker until he became seriously ill early in August and was removed for hospitalization on 10 August. The glaciological program proceeded as planned until that time and the program was continued by other members of the party after that date. Other glaciological investigations which had been planned were cancelled or postponed depending upon available time of personnel remaining at the site.

A rectangular grid composed of 70 twelve-foot aluminum poles set about 10 feet into the ice was established about 3 miles north of Ward Hunt Island near the end of May to study ablation and changes in ice form as the melt season progressed. These poles were set approximately 600 feet apart in 5 rows of 14 poles each, to form a grid about one-half miles wide and two miles long oriented approximately in a north-south direction. About two thirds of the grid area was on the ice rise and the remainder was on the shelf.

This grid provided fixed points for measuring ablation of both the snow and ice surfaces. About 1000 snow depths and numerous snow densities were measured systematically over the entire grid immediately after its establishment to determine the mean snow depth and also the distribution of the snow cover. Further analysis of the large sample of snow depths can be made by dividing the grid into north and south facing slopes or by dividing the grid into depths on the rise and on the shelf to learn how the snow was distributed. Ablation was measured frequently at both the snow and ice surfaces at the 70 poles and densities were determined throughout the melt and following accumulation. The foregoing observations should provide a fairly reliable indication of the snow coverage and provide information on changes to the snow and ice.

The grid was used to position 19 pre-melt and 14 melt period pits which were

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dug to provide data for studies of the snow and ice stratigraphy.

Thermopiles were systematically set at 18 sites on the grid to provide temperature data in the vertical profile from the surface to a depth of 10 feet. These thermopiles were read at weekly intervals.

Two sites within the grid were marked by wood poles set in the ice where surface snow elevations and depths to ice were obtained at one-foot intervals to record the surface form. Changes in surface form can be studied by repeating the survey in future years. One site was located on the rise and another on the shelf.

A topographic survey was made of the grid, and the elevation and location of each of the 70 ablation poles were obtained. As a part of this survey one north-south and two east-west lines of grid poles were accurately chained so that lateral movements may be detected when those lines are measured again. The grid was positioned by shooting several series of bearings to mountain peaks, and a survey line was extended from the grid to a bedrock point on Ward Hunt Island. This line was later tied to mean sea level datum.

A survey line was run normal to the ridge-trough system of the ice shelf about 10 miles west of Ward Hunt Island to study the surface form of the ice shelf at an arbitrary location. This line extended from Ellesmere Island to the pack ice about 11 miles away. Snow-surface elevations and snow depths were obtained at critical and intermediate points along the entire line. Three reaches along this profile were more carefully studied by obtaining snow-surface elevations and depths every 10 feet over two or more ridge-trough systems. These data provide an additional 800 snow depths. The range in depth of snow on both grid and survey line varies from about 2 inches to 5 feet and the distribution is skewed toward the greater depth. The survey line was established by setting reference marks on Ellesmere Island; the line was semi-permanently fixed by installing 35 aluminum poles and seven thermopiles about eight feet west of the original line. An aluminum pole and thermopile of the foregoing were set on each side of an ice crack which is about two miles off shore. This was done to check possible movement and differences in ice temperatures across that crack.

Transportation to the survey line was a problem during the melt season; however, three complete sequences of observations were obtained. In addition to observations already mentioned, the survey line was used to locate seismic observations, some of the poles were used to reference water surface elevations and depths, and the location of several water samples were referenced by position on the line.

Data from thermopiles set deep in the ice were desired, and one of those set by members of the 1954 expedition was located and temperatures in the vertical profile were read. Also, an attempt was made to set a thermistor cable 60 feet deep using a thermal drill; but a short circuit developed in the line at 40 feet, and the drill froze into the ice and was lost.

A trip was made to the re-entrant area near the northeast section of the shelf where a line of four wood ablation poles and a thermopile was installed. This was done early in August, and, therefore, the data obtained are not complete for the season.

A Piper Supercub aircraft was obtained by contract with Bradley Air Services, Ottawa, Canada; during July landings were made at four glaciers to measure between a point fixed on the snout of each glacier and a point fixed on land. Future measurements will indicate glacial movement. The aircraft was also used for reconaissance by the glaciologist and hydrologist.

The geophysical investigations were somewhat curtailed during the summer. Mr. Frank Crowley, the scientific leader, was required to supervise the establishment of scientific programs. He was flown out on 14 June because of a very serious illness in his family, and after his return transportation difficulties seriously curtailed his investigations. In spite of these troubles seismic data were obtained along the survey line 10 miles west of Ward Hunt Island. Mr. Crowley mentioned that the ocean floor was deep until coming within about two miles off shore when an abrupt rise in bottom was encountered. The collection of seismic data is being continued by Mr. Crowley and is the explanation for his absence at this meeting. He expects to obtain additional data along the survey line, the grid, Disraeli Bay, and elsewhere depending upon time available before his return in November. A survey of the earth's magnetic field was made at sites on Ward Hunt Island, on the grid and along the survey line.

Hydrologic Investigations

The main purpose in making hydrologic investigations was to determine the quantity and nature of the water that melts and flows off the ice rise and ice shelf. More specifically this was to be accomplished by determining mean daily discharges from two drainage basins on the ice rise and one drainage basin on the ice shelf, installing staff gauges at four or more additional sites and obtaining periodic readings therefrom, installing a type of crest-stage gauge measuring device at each of the foregoing sites, surveying drainage areas of streams studied, and sampling water for chemical analysis.

A brief description of the snow cover during the pre-thaw, thaw, and freeze-up periods will be given before relating how the hydrologic investigations were conducted. Air and snow temperatures increased during the pre-melt period until the surface snow reached 32°F. On 1 July sixteen holes were dug to ice for the purpose of installing hydrologic equipment, and water was observed on the ice at three of these holes. The first ponded water above the snow surface was observed on 3 July; the melt season was progressing rapidly. Rather heavy and continuous melting occurred until 18 July when temperatures became cooler and enough drifting snow fell to choke off most of the flow in the small rivulets. The cold snap lasted until 23 July when another warming period commenced. Streamflow increased but did not reach the high discharges experienced before the cold snap. After this period there seemed to be alternate warm and cold periods lasting about four or five days each, indicating an autocorrelation of meteorological conditions. Streamflow had ceased by 16 August except for delayed runoff from ponded water on the ice shelf. The actual hydrologic observations covered a six-week period in which most of the runoff occurred during the first two weeks.

Three water-stage recorders were used to obtain continuous records of water-surface elevation. Portable stilling wells to house the recorders were designed,

Fig. 1. Inflow channel to Alpha Lake. Note the water flowing over the snow forming a dune-type regime on the channel bottom. The small ice crystals are similar to dunes in a sand channel. The stream is flowing on snow and ice crystals which are about two feet deep.

Fig. 2. Bill Mattox measuring streamflow in outlet channel to Alpha Lake. Note cryoconite in channel bottom and melting effects on ice. Location is on ice rise one mile north of Ward Hunt Island.

constructed and placed, but not installed, at selected sites prior to the melt period. The sites selected were in lakes where it was believed that there was less danger of losing the recording equipment because there would be essentially no velocity and the station would not be affected by channel migration. There was some fear that waves and wind would knock down the gauge structures, but this was not believed to be a serious threat.

The task of making the hydrologic observations was complicated by unstable channel conditions. The original plan was to install the gauges in the lakes when the lake outlet channels somewhat stabilized. It had been presupposed that water flowing over snow would scour the channel down to ice in a period of hours, but this was not true. The largest inflow channel investigated, in which 49 discharge measurements were made, flowed over snow for about 10 days before scouring down to ice. This condition was believed to be caused by a lack of heat in the water over that of the heat of fusion; in fact, small crystals were observed to be flowing in the stream and the snow bottom developed a snow-dune regime analagous to dunes in a sand channel. This flow collected in a pond which was termed Alpha Lake for purposes of these investigations, although the lake has no official name. The surface of this lake rose nearly two feet a day from 3 July until 8 July when water first flowed downstream. It took several additional days for the water to scour down through the snow to the old channel at the lake outflow. In fact, about 1,000 feet downstream from the outlet the water flowed under the snow. This situation of snow bridging the channel subsequently caused difficulty because the snow occasionally caved, causing a backwater condition in the lake. Otherwise, the water-surface elevation in the lake decreased about a foot a day until 18 July, the start of a cold period. During a warm, clear, and sunny 24-hour period on 25 July the bottom of the outlet channel melted out about seven tenths of a foot. There are probably several reasons for this surprising melt. First, the temperature of water on the channel bottom may be slightly over 32°F, although water temperature at the surface was always found to be 32°F; secondly, cryoconite was present in depressions on the channel bottom and absorbed considerable incoming solar radiation; and thirdly, the weather was sunny and clear with heavy incoming radiation. Stabilized channels immediately below all lakes inspected had very flat gradients and velocities of less than one foot per second. Noting the melt condition of lake outlets, it became obvious that lakes are not particularly desirable sites in which to work.

On 26 July it was decided to install the gauge on the inflow channel rather than in the lake itself. This operation was completed on 27 July, and the gauge operated for a week during which cold weather persisted. The record obtained was of questionable value, and it was decided that the recorder would perform a more valuable function if operated as a tidal station around Ward Hunt Island. Therefore, the gauge was removed, but discharge measurements were continued.

The foregoing description is somewhat analagous to observations made at the other two recorder sites, so only a very brief summary of those sites will be given. The investigations of the lake on the shelf were discontinued after about 10 days of operation because a strand crack developed across the lake and most of the water ran out. The second lake (called Beta Lake) investigated on the ice rise did not overflow at the outlet until 29 July. It took several days for that water to flow out of the lake sufficiently for discharge measurement data to represent natural runoff from the

Fig. 3. Tidal gauge stilling well at west end of Ward Hunt Island. The stilling well was anchored by attaching cables from the well to boxes filled with rocks. Total tidal variation was about 18 inches (taken 17 August 1959).

Fig. 4. Close-up of tidal gauge.

drainage basin. Observed and recorded elevations were obtained at Beta Lake, and daily streamflow for that basin will be computed by volumetric differences in ponded water based on a completed survey of lake volume and daily stage observations.

Sufficient data have been obtained to compute daily discharge values with reasonable accuracy for the two drainage basins on the ice rise for which drainage areas were surveyed. A total of 101 discharge measurements were made during the six-week period.

It was hoped that three ponds and drainage basins on the ice shelf in which the water had not flowed out could be located and volume and drainage area surveyed for comparison with those data obtained on the rise. Two such ponds were located about five miles east of base camp; but the heavy snows after the first of September, shortage of personnel available at that time, and other work loads precluded making surveys of those lakes.

Staff gauge plates were mounted on a 2 x 4 board set in a hole which had been drilled about eight feet into the ice at the three lake sites investigated and also at each of the four other lakes between the main and satellite meteorological stations to provide a reference datum for the lake and ice-surface elevations. Three of the lakes developed strand cracks, and those stations were discontinued. Valuable data on both water and ice elevations were obtained periodically at the others. A special crest-stage gauge device made out of plastic garden hose cut and attached vertically to the boards set in the ice proved to be of little value.

It is necessary to determine the quantity of snow and ice that has changed from solid to liquid or simply a mass balance to evaluate the natural processes that occurred during the melt period. There are two methods of determining this quantity of melt; first, measurements of ablation and density are sampled and the results extrapolated over the entire drainage area; second, the melt water leaving the area via stream channels can be measured, and these values can be compared, as in the following general model:

$$\text{Melted snow and ice} + \text{melted precipitation} = \text{runoff} + \text{infiltration and retention} + \text{losses} \pm \text{sampling errors.}$$

This equation can be reduced further since negligible infiltration occurs because of the impervious ice, retention appears as an ice accumulation or increase in snow density, evaporation is small because of low temperatures and short melt season and can be estimated, and melted precipitation such as rain can be measured. The equation can then be reduced to its simplest form, or approximately:

$$\text{Melted snow and ice} = \text{runoff} \pm \text{sampling errors}$$

Based upon the two-week record obtained at Beta Lake and daily information obtained at Alpha Lake, diurnal runoff fluctuations are believed to be very small. The reasons for the small diurnal variation are the small diurnal temperature variations, high angle of incidence of the sun at night, relatively flat topography, and the sponge-like nature of rotten ice and snow which tend to retain the water.

Several samples were obtained of water, melted snow, and melted ice to determine the chemical constituents of those waters. Those samples have not yet been analyzed.

Shortly after the first of August it was decided that the three water-stage recorders should be used to collect tidal data around Ward Hunt Island. One recorder was located in Disraeli Bay at the south edge of Ward Hunt Island, another was placed in the moat at the north edge of the island, and the third recorder was operated for about two weeks at the west edge of the island and then maintained for about two weeks at the east edge of the island. The data provided by these recorders on the character of tidal fluctuations at those points will be used to assist in the determination of an approximate sea level datum. The word "approximate" is used because of the undetermined influence of the ice shelf in trapping fresh water underneath. The fresh water, being of lower density, floats on sea water near shore and is unable to pass out to sea because of the thickness of the ice shelf. If this is true our indicated sea level will be higher than true sea level. The data obtained in the moat are referenced to bedrock and are available for further study. The tides in the moat have smaller fluctuations and lag the other sites by about three hours, indicating that the moat is partially blocked from the sea. The information obtained on the west end of Ward Hunt Island indicates a 20-minute lag from that on the east end and Disraeli Bay. This lag may have been a local condition caused by ice being attached to the ground, thereby blocking direct flow from the south. Tidal stations in Disraeli Bay and at the east end of Ward Hunt produced identical fluctuations in time and amplitude, showing that there is a large opening between the ocean and Disraeli Bay to the east of Ward Hunt. The tidal amplitude may generally be considered to be about 18 inches. If additional tidal information is obtained along the Ellesmere Island mainland we should be able to know more about the tidal currents.

Summarizing, systematic observations have been obtained on the ice shelf and ice rise to study the surface form and the physical changes acting thereon during the thaw and freeze-up periods. The program established was one of vision toward future investigations. It requires measurements and time to study surface changes. Semi-permanent measuring points have been established, and their full value can only be realized by performing similar future investigations. The hydrologic program provides daily and total volumetric runoff for two basins on the ice rise and their drainage areas, tidal information, miscellaneous lake elevations, and water samples.

Proposed Hydrologic Investigations for 1960

The following suggestions for an Ellesmere Ice Shelf hydrologic program for 1960 will be very general and brief. A report will soon be prepared in greater detail for the benefit of the one who will make the hydrologic investigations for 1960, assuming the hydrologic investigations are continued.

The hydrologic investigations should include collection of daily volumetric data throughout the entire melt season on the two drainage basins studied during 1959 to determine a mass balance and also a comparative analysis between 1959 and 1960. From meager information available, it seems that the ice shelf is in a delicate climatic balance, and relatively small climatic differences probably can cause a considerable variation in runoff; therefore, it is believed that continuing the hydrologic program at least another year will not duplicate the efforts of 1959. It is believed that the experience gained in 1959 will enable the investigator to conduct a more substantial program in 1960.

Perhaps the most important need is for photogrammetric surveys which would lead to topographic maps having two-foot contour intervals. Most of the ice shelf has a variation in elevation between 5 and 20 feet, and a topographic map using anything larger than two-foot intervals would not be of much value except on the ice rise where 5-foot intervals could be used. By knowing the topography, one can outline and compute all drainage basin areas, choose locations where ice dams can be constructed so that water can be stored for later pumping operations, compute the available storage, and also compute the expected runoff. By building ice dams, one can visualize changing the entire surface of the ice shelf to suit any military purpose that may be desirable. This can easily be done at a small cost, but good topographic maps must be available to plan such an operation properly. Caution is advised in the distant future use of the topographic maps, because the surface of the ice shelf and ice rise are highly subject to change due to ablation and accumulation. Changes since 1947 are indicated by comparing photographs taken during that year, and conditions existing in 1959; however, topographic maps should be good for several years, and if the surveys are repeated, say every five years, perhaps much can be learned about changes of surface form.

The topographic maps would be very useful to determine drainage area boundaries, and if it is feasible to contour lake bottoms one could easily determine the total volumetric catch in lakes if the areal photography is taken late in the season--about August 5 to 10. Runoff after those dates would probably comprise only about 5% or less of the total yearly runoff, and that portion could be quite accurately estimated.

Much valuable information could be obtained by studying the formation of channel meanders and their migration on ice. The formation of meanders was observed in 1959, but this writer was not aware of what was to come later and missed an excellent opportunity to study the mechanisms associated with the formation of a meander. The processes involved can be described but there were no physical measurements made in 1959 of this phenomenon.

The hydrologist should also plan to collect tidal data in the moat, Disraeli Bay, along Ellesmere Island proper, and in the Arctic Ocean if possible. The latter would be to determine the difference in water surface elevation between the ocean and in Disraeli Bay caused by fresh water floating on salt water. A light aircraft probably would be necessary to install and service this equipment and a survey line would have to be run between the gauge in the ocean and the gauge in Disraeli Bay. The program concerning ocean tides, if feasible, would determine the effects of fresh water over the salt water and also indicate the drag effects caused by the ice shelf on the movement of tidal waters. The latter could only be obtained if the depth of fresh water over salt water is determined by other methods. A program to collect water samples should be considered, based upon results of the analysis of samples collected in 1959.

The runoff season can probably be expected to occur between July 1 and August 20. The hydrologist would not need to spend the entire season at the site; but if a light aircraft is available, he could arrive about June 10 and have ample time to set up his program.