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Report COO-1473-3

GLACIOLOGICAL INVESTIGATIONS ON THE CASEMENT GLACIER, ALASKA

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Institute of Polar Studies

U. S. Atomic Energy Commission
Chicago Operations Office
Argonne, Illinois

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INSTITUTE OF POLAR STUDIES
THE OHIO STATE UNIVERSITY
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TECHNICAL PROGRESS

REPORT

By

THE OHIO STATE UNIVERSITY
RESEARCH FOUNDATION

1314 KINNEAR RD.
COLUMBUS, OHIO 43212

To U. S. ATOMIC ENERGY COMMISSION
Chicago Operations Office
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On GLACIOLOGICAL INVESTIGATIONS ON THE CASEMENT GLACIER, ALASKA

For the period May 1, 1967 - January 31, 1968

Submitted by Donald N. Peterson
Institute of Polar Studies

Date January 31, 1968

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GLACIOLOGICAL INVESTIGATIONS ON THE CASEMENT GLACIER, ALASKA

INTRODUCTION

The Casement Glacier (58° 57' N, 135° 57' W) is located in Glacier Bay National Monument in southeast Alaska. It is a complex valley glacier formed by the merging of at least seven smaller tributaries with the main ice stream. The entire system has an area of 125 to 150 km^2 with névé basins at elevations between 1200 and 1700 m (4000 and 5000 ft). The terminus is now located about 6.7 km northeast of Muir Inlet, where it joined with the Muir Glacier at the beginning of the present century (Fig. 1).

The U.S. National Park Service has greatly assisted this project by transporting the party and its equipment and supplies from Juneau to the Casement Glacier outwash aboard the National Park Service vessel Nunatak. The party was moved by helicopter from the outwash to the selected campsite.

During the first year, 1965, only one camp was established, at an elevation of 300 m (1000 ft). From this camp it was possible to do intensive work in the lower portion of the ablation zone of the glacier. The main camp for the 1966 season was located farther upglacier, 32 km from Muir Inlet and at an elevation of 1050 m (3400 ft) so as to provide access to both the upper reaches of the ablation zone and the accumulation zone. In addition, tent camps were set up at the 1965 campsite and at the location of the tunnel dug during the 1966 season. The camp organization for the 1967 season was the same as during the 1966 season. During all three seasons, daily radio contact was maintained with the U.S. National Park Service at Bartlett Cove through which arrangements were made for the delivery of mail and supplies. The first two seasons, 1965 and 1966, were each ten weeks long and the 1967 season was extended to twelve weeks (until mid-September) in order to make the final mass balance measurements as late in the ablation season as possible.

MASS BALANCE STUDIES

During the 1965 season seven rows of movement-ablation stakes were installed in the lower portion of the ablation zone. In 1966 nine new rows of stakes were drilled into the ice and stakes from five of the seven lines from 1965 were located and reset. During the 1967 season, three more rows of movement-ablation stakes were added to the network to make a total of more than 165 stakes in the ice (Fig. 2).

An extensive triangulation network was established so that all the movement data can be related to a single system. All the stakes were

Fig. 1 - Map of Muir Inlet area showing the retreat of the ice front of the Muir, Casement, and associated glaciers since 1880.

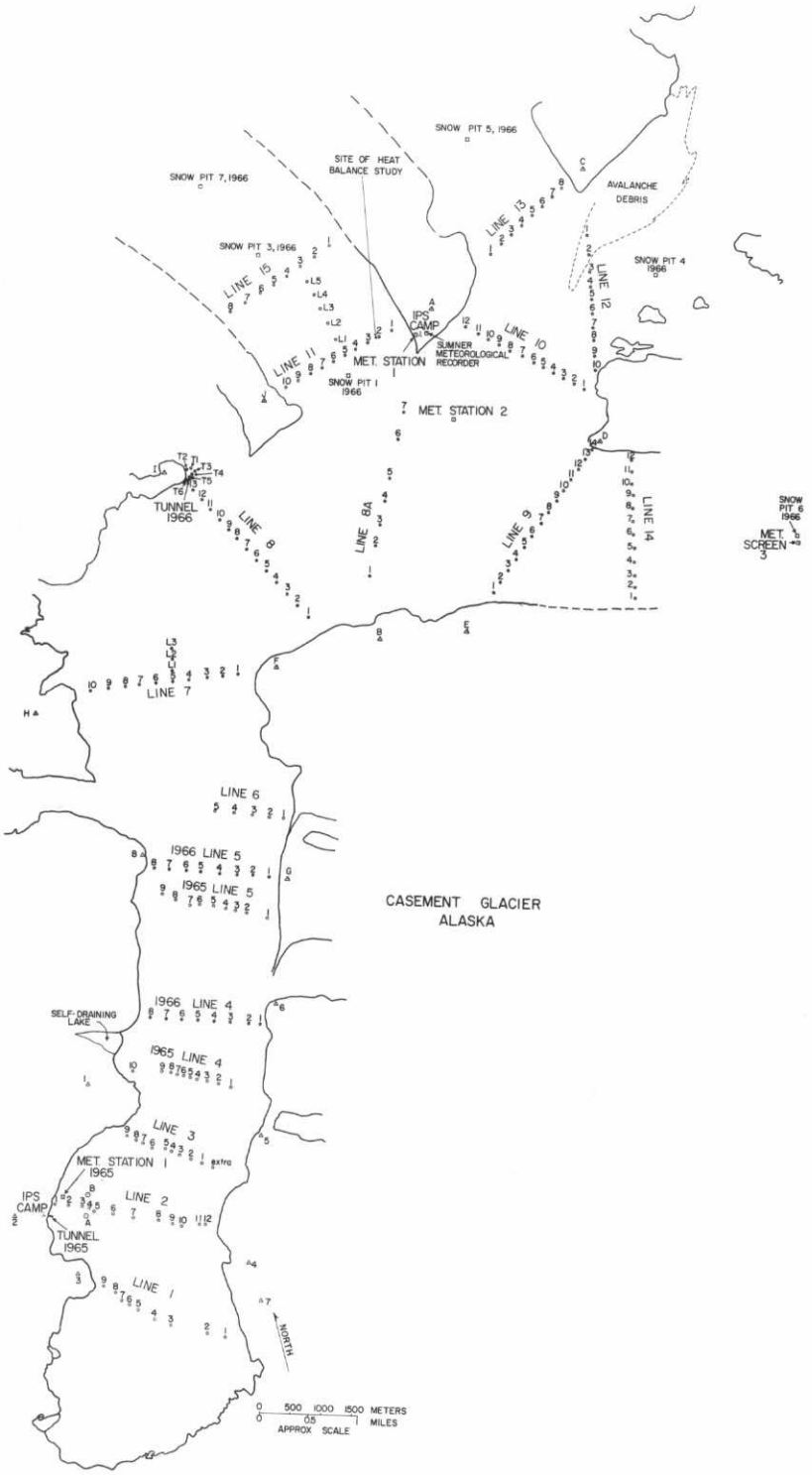

Fig. 2 - Map of Casement Glacier showing the location of the camps, survey stations, rows of movement-ablation stakes, the met stations and the ice tunnels.

surveyed twice during the 1965 season, but five weeks of bad weather at the end of the 1966 season prevented a complete resurvey of all the stakes in the ice at that time. The survey work in the 1967 season was carried out with the use of two theodolites. The entire initial survey was completed satisfactorily and the final survey was completed in three days, except for the second set of angles on one row of stakes. Bad weather prevented this last set of angles from being measured; however, the survey data already collected are adequate for the movement studies.

Ablation was measured as often as possible during all three seasons. Mass balance studies show, from July 1, 1966 to July 1, 1967, an average net loss of 143 cm water equivalent on line 4 at an elevation of 750 m (2400 ft), an an average net loss of 175 cm water equivalent on line 11 at an elevation of 1050 m (3400 ft). There is normally a decrease in ablation with increase in elevation. These anomalous results have yet to be explained.

In addition to the annual ablation studies, short-term ablation was measured during the 1967 season at a location on the glacier near the base camp (Fig. 2) by averaging the measured daily ablation from a set of ten stakes in the ice. The daily fluctuations in ablation reflect changes in the meteorological conditions and so the results are presented with the meteorological data (Fig. 21).

Snow pits were dug in the accumulation zones of four of the main tributaries at the end of the 1967 season (Fig. 2). In addition, longitudinal and transverse snowdepth-sounding profiles were made from the beginning of the snow to the site of the snow pit and across the glacier at that point. The results of these studies are shown in Figs. 3-5. As can be seen from the profiles, very little new snow was left at the end of the 1967 summer, and over more than half of the accumulation area the snow then exposed at the surface was older than the 1966-67 winter. The older snow can be distinguished from the newer on the basis of color, the newer snow being much cleaner. This observation indicates that the 1967 summer was particularly warm with respect to previous summers. The Casement Glacier, as evidenced by the observations over the past summers of 1965 through 1967 and its rapid retreat from the shores of Muir Inlet, has an extremely negative budget.

ICE TUNNEL STUDIES

During the summer of 1967 the tunnel which had been excavated in 1966 was re-excavated and observations were made at an ice-bedrock contact on the rate and manner of basal slip (Figs. 6, 7, and 8). The slip rate at this location as determined during the 1966 season was 2.9 cm/day. Measurements made at the beginning of the 1967 summer, when the tunnel was re-opened, show that the basal slip rate over the 1966-67 winter was 2.3 cm/day, departing from the summer average and

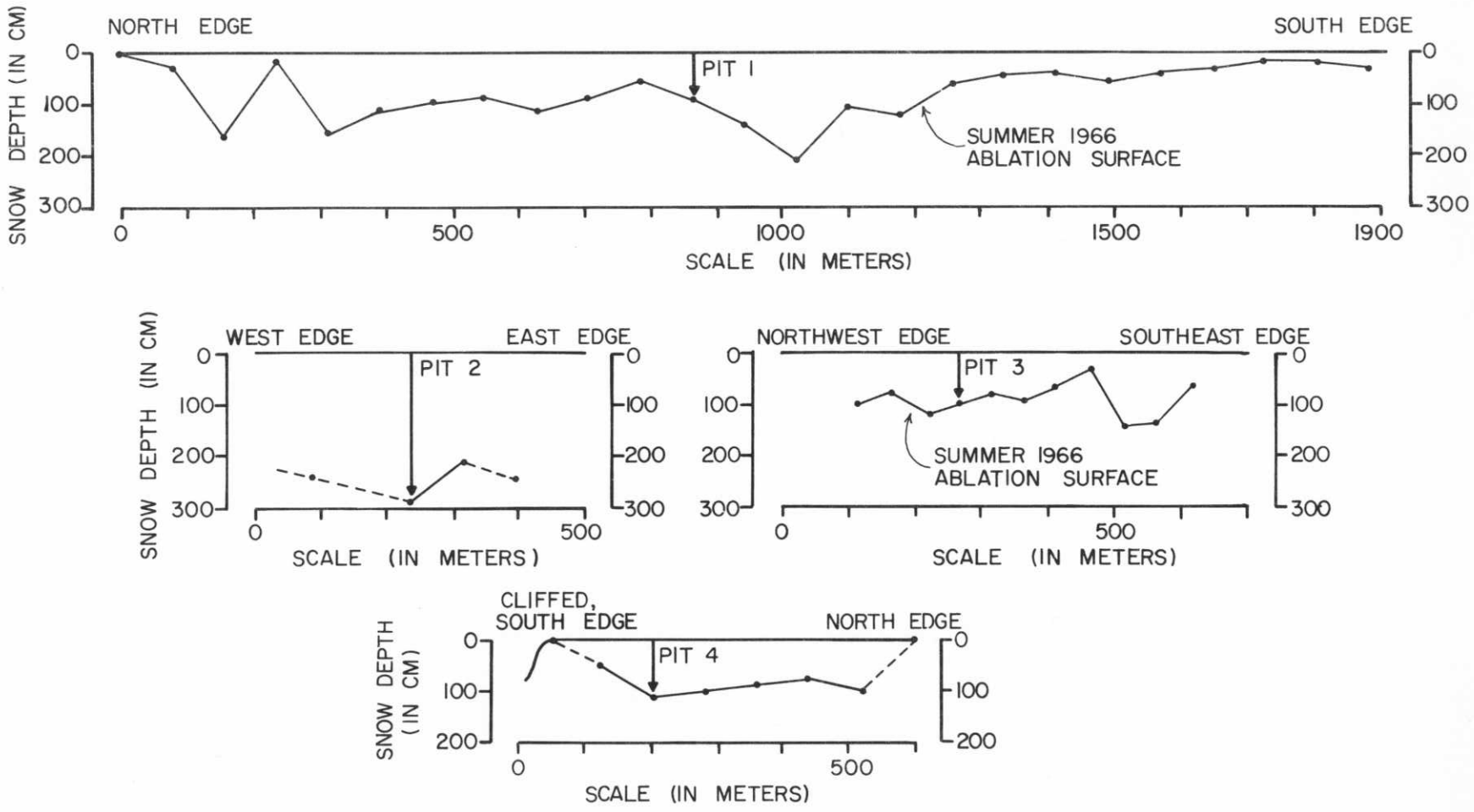

Fig. 3 - Transverse snow-depth profiles made at the site of the 1967 snow pits, Casement Glacier, Alaska. See Figure 4 for longitudinal profiles.

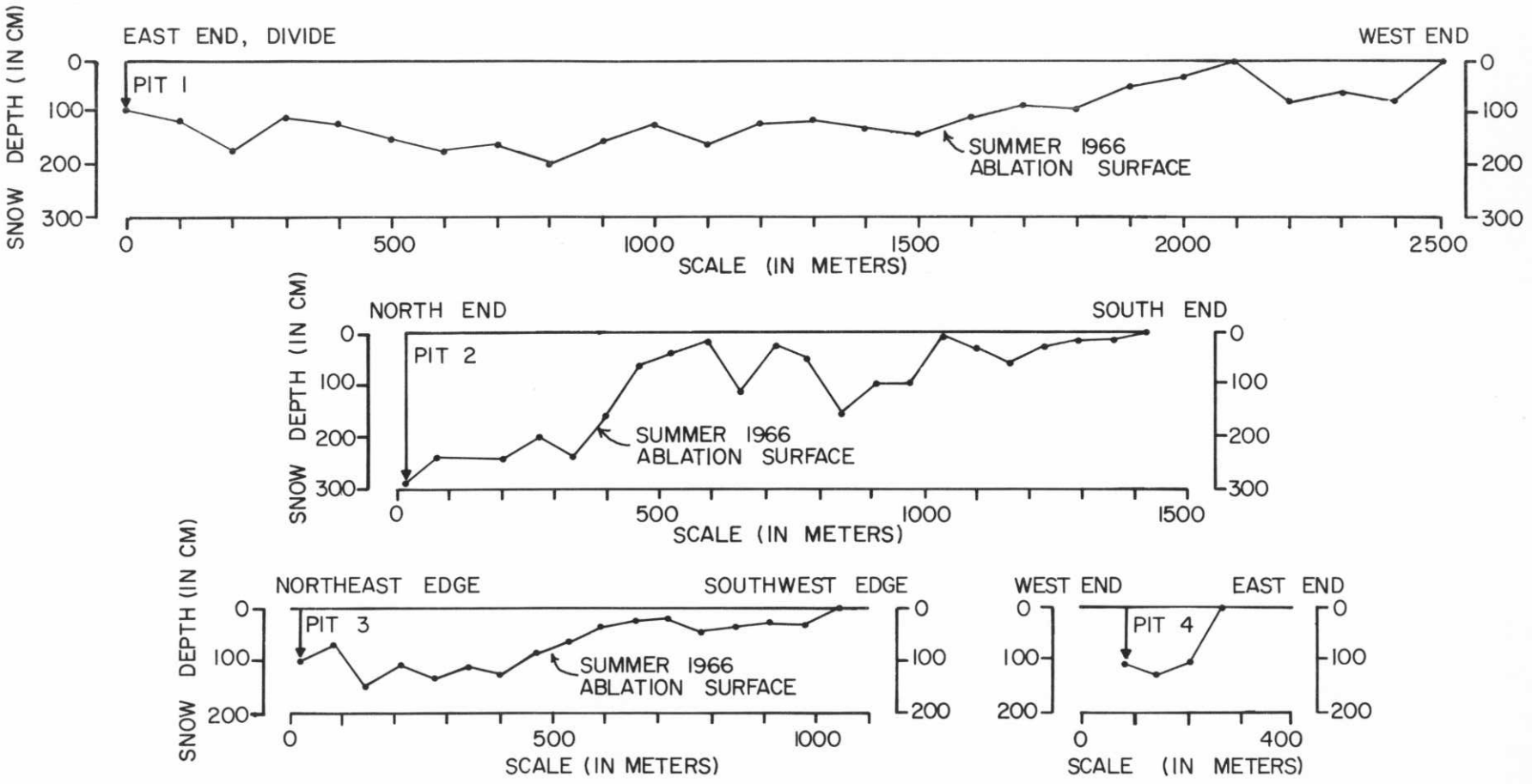

Fig. 4 - Longitudinal snow-depth profiles from site of snow pit to firn line, 1967 season, Casement Glacier, Alaska.

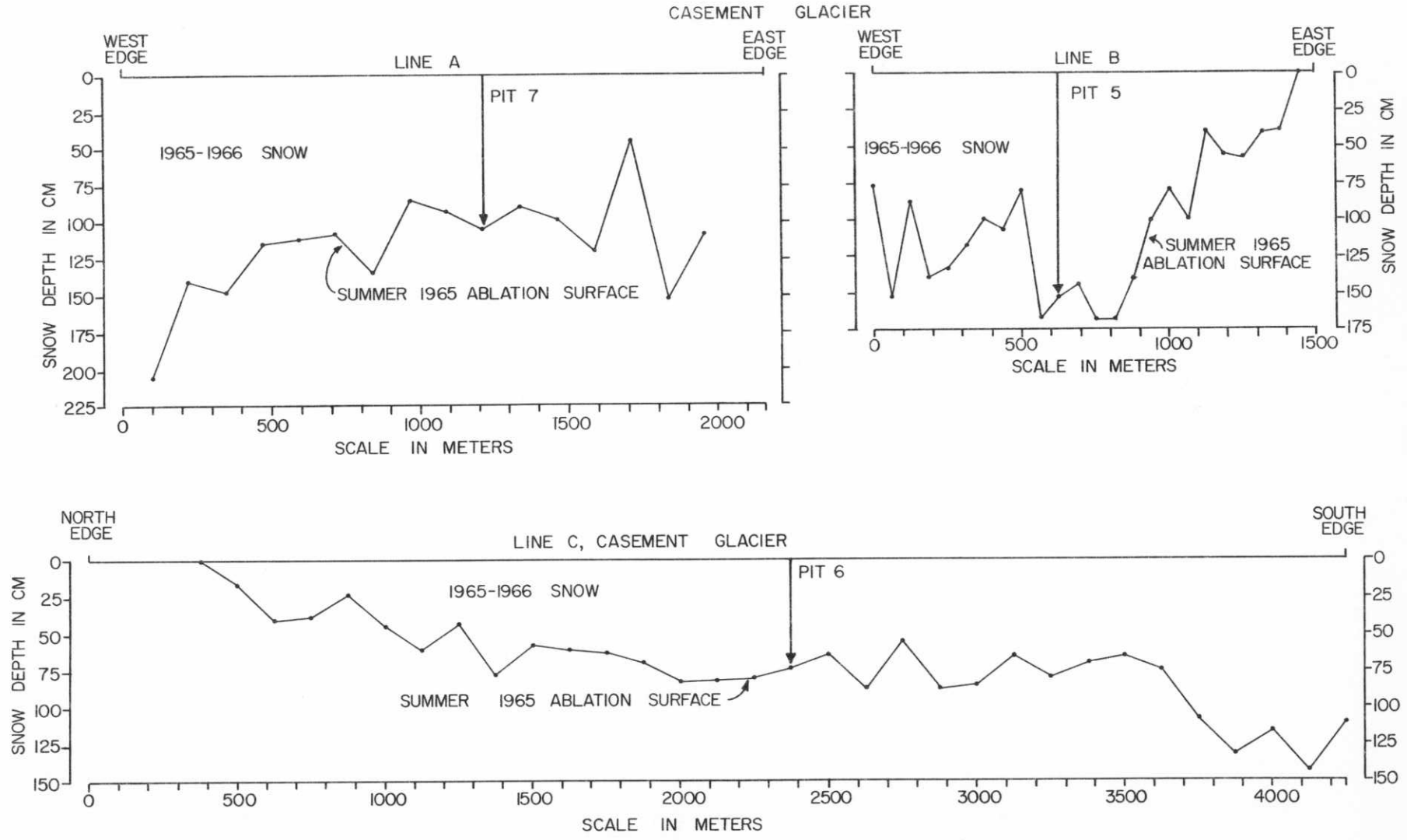

Fig. 5 - Transverse snow-depth profiles along lines A, B and C, Casement Glacier, Alaska, 1966.

Fig. 6 - Entrance to 1966 and 1967 tunnel in upper Casement Glacier showing ice-bedrock contact.

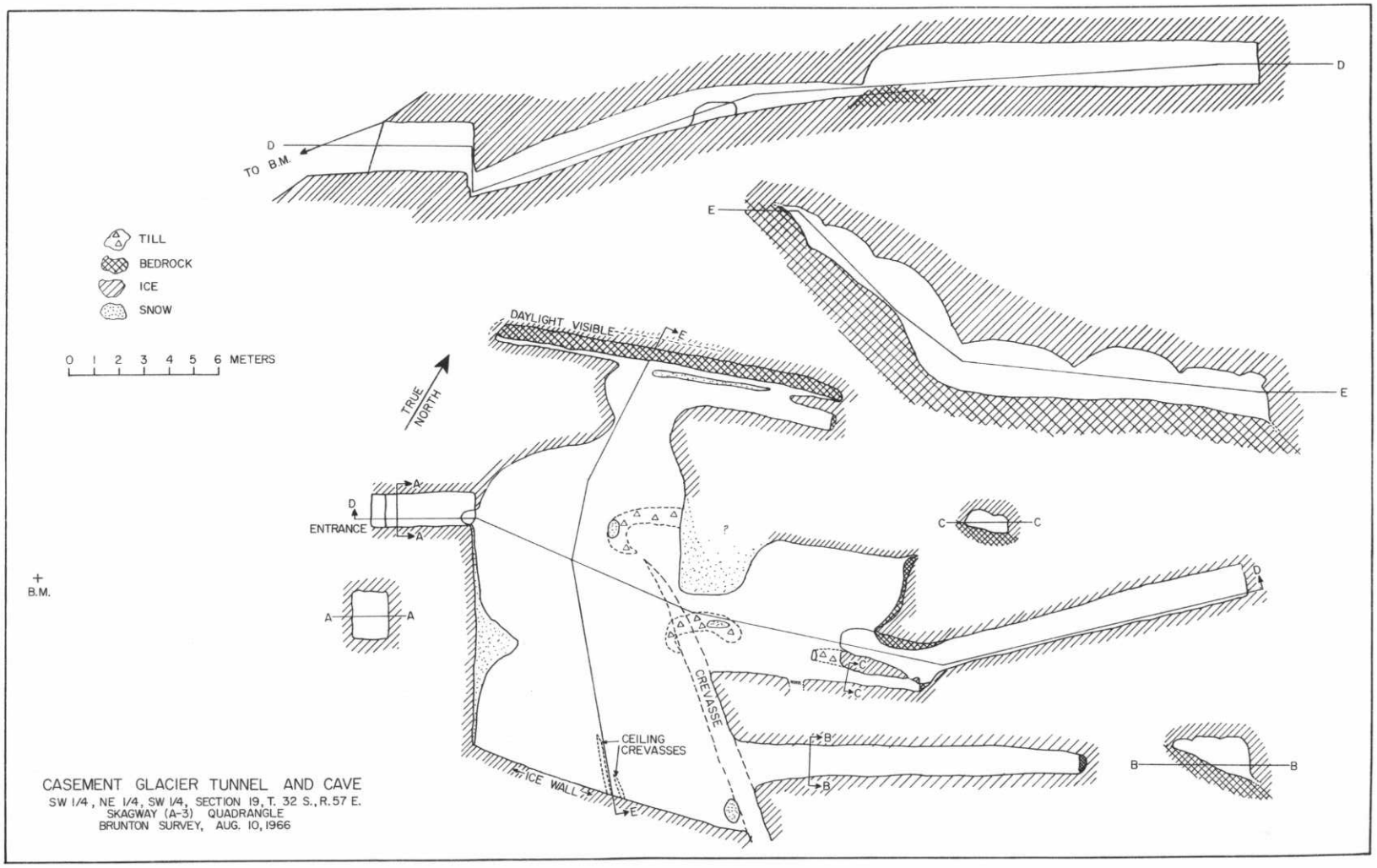

Fig. 7 - Plan and cross-section 1966 tunnel and associated glacier cave, Casement Glacier, Alaska.

indicating that the slip rate might be controlled, at least partially, by the quantity of meltwater, acting as a lubricant, present at the bottom of the glacier.

The tunnel study had three main objectives during the 1967 season: (1) to determine whether basal slip is continuous or intermittent, (2) to determine if there is any diurnal variation in slip rate and any distinction between the rates on sunny and cloudy days, and (3) to emplace obstacles on the bedrock knobs and observe the mode of flow of ice around them.

INSTRUMENTATION

In order to measure short-term variations in slip rate, two Starrett dial gauge micrometers were used. These instruments (Fig. 9) are calibrated to 0.001 inch and can be read to the nearest 0.0002 inch. Gauge I was mounted on a wooden stand which could be moved along a 2" x 2" wooden beam which eas securely fastened to bedrock with rockbolts (Fig. 10). It was possible, therefore, to keep the piston, which is connected to the rack operating the gauge, in contact with a $\frac{1}{2}$" dowel emplaced in the ice 20 cm above the ice-bedrock contact. Gauge II (Fig. 9) was fastened directly onto a rock bolt with its piston in contact with a small piece of wood nailed to the end of a dowel which had been drilled into the ice 20 cm above bedrock.

RESULTS

1. Dial strain gauge results

Washburn and Goldthwait (1937) on the Crillon Glacier in Alaska determined that the glacier flows in a series of discrete jumps, with a period of stress build-up preceding each movement. Although that work was done on the surface of the glacier, Goldthwait (personal communication) thought this type of movement would exist at the bottom of the glacier as well. However, during the period of observation with the dial strain gauges in the Casement Glacier, there was no discontinuous movement which could be attributed to a sudden advance of the glacier. The gauges were read every minute for a $1\frac{1}{2}$-hour period. A plot of the data shows that the points fall almost perfectly into a straight line (Fig. 11), giving a slip rate of 2.243 (0.883 inch) cm/day.

Two studies were made in order to determine if there is any diurnal variation in slip rate which might be related to surface ablation and runoff causing increased bottom lubrication. The first study was for 24 hours, with the gauges being read every five minutes. The second period of observation was 48 hours, with the gauges being read every half hour. There was precipitation during the first hours of the first study. During this period the slip rate was 2.14 (0.844 inch) cm/day. A definite break in slope occurs in the plot of dial readings

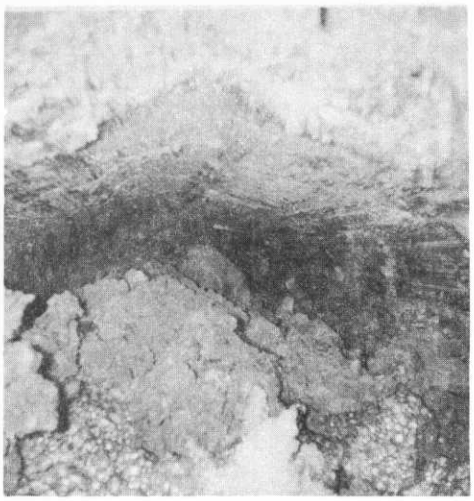

Fig. 8 - View of ice-cave roof showing part of large groove that is produced in the ice at the bottom of the Casement Glacier as the ice flows over a bedrock knob. The flow is towards the viewer. The material in the left background is till-covered bedrock. Width of view is about 4 m.

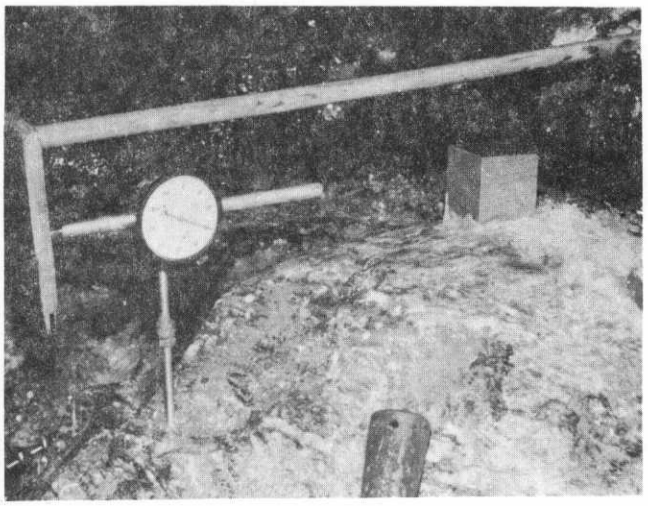

Fig. 9 - Photo of dial gauge micrometer II mounted on rock bolt placed in bedrock knob. The numbers on the dial are .01 in. and the marked intervals are .001 in. The dowel is drilled .5 m into the ice parallel to the flow vector which is right to left. Note the polished surface on the bedrock knob and the plucked, more steeply dipping portion into which the rock bolt is drilled. The cubes on the bedrock surface are 5.0 and 2.5 cm on a side.

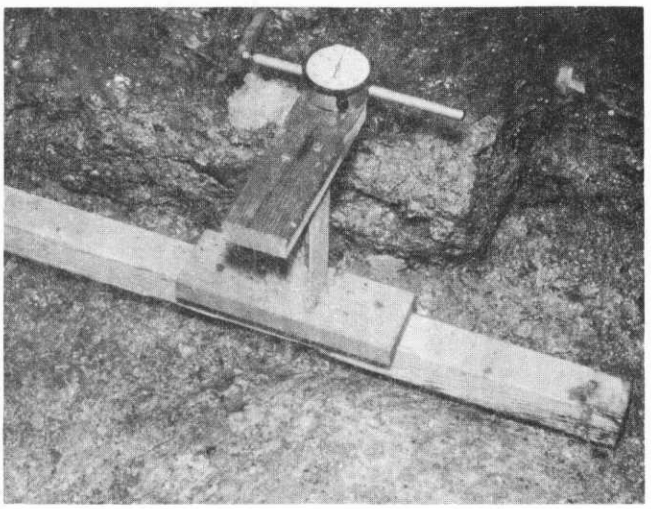

Fig. 10 - Photo of Gauge I. The piston from the gauge is placed in a hole drilled into a wooden dowel which is perpendicular to bedrock with rock bolts and so the support stand can be moved along the beam so that the piston can be kept in contact with the dowel as the glacier moves.

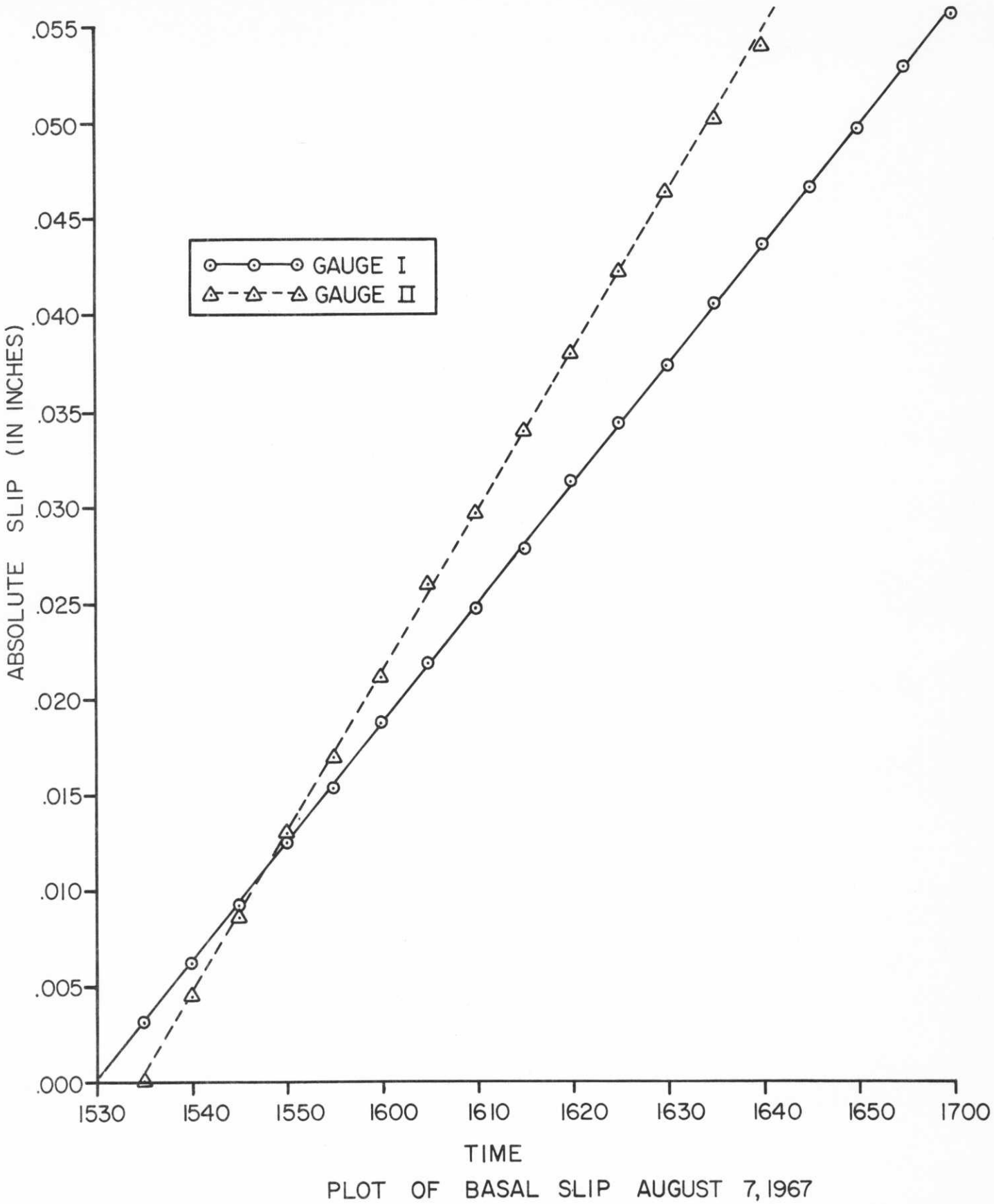

Fig. 11 - Plot of movement observed at Gauges I and II in $1\frac{1}{2}$ hour study. Note that the points fall in a straight line indicating that the slip was continuous with no short-period fluctuations.

versus time (Fig. 12). The velocity decrease probably results from the decrease in water available for bottom lubrication. A plot of the data for the 48-hour study (Fig. 13) is irregular and is probably a result of the intermittent precipitation during that period of observation.

2. Results from emplacement of obstacles on bedrock

Weertman (1957, 1964) and Kamb and LaChapelle (1964) state that the size of a protuberance on the bedrock surface determines the mode of flow of ice around it, with plastic flow predominating for larger obstacles and regelation slip prevailing for obstacles smaller that a critical size. The investigators differ in their estimates of the critical size, Weertman suggesting that it is 1 cm, while Kamb and LaChapelle believe it is 10 cm.

To test these ideas, limestone cubes of different sizes were fastened to one of the exposed bedrock knobs (Fig. 14) with rock bolts and epoxy glue. Because of the high debris content of the basal layer of ice, only two of the cubes, one 2.5 cm and one 1 cm remained intact and fastened to the bedrock after the ice came into contact with them. The rest of the cubes were smashed by the debris-laden ice (Fig. 15).

The 2.5 cm cube which did survive temporarily had been placed with a corner upglacier (Fig. 16) so as to reduce the stress on the upglacier face of the block. The flow of the ice around this cube produced a groove in the sole of the glacier (Fig. 17). A careful examination of this groove showed that the cavity in the ice on the lee side of the block was 0.5 cm narrower than the block itself and that this cavity was lined with a layer of clear regelation ice 2 mm thick (Fig. 18). Thus, both of the basal slip processes as suggested by Weertman (1957, 1964)--regelation slip and plastic flow--were operative in the movement of the ice over the 2.5 cm obstacle. The 1 cm cube, which had been anchored to bedrock with epoxy, also produced a groove lined with regelation ice in the bottom of the glacier; however, this cavity exhibited no closure over a distance of 21 cm.

Plastic flow around a bedrock knob 1 m high and 3 m wide was observed in both 1966 and 1967. The ice which flows around the side of this knob has a "ropy" appearance (Fig. 19). This ice also exhibits closure on the downstream side of the knob, but, in this case, the closure is on the order of 10 cm. This ice also had a thin layer of regelation ice, as was present on the surface of the ice which flowed around the 2.5 cm cube.

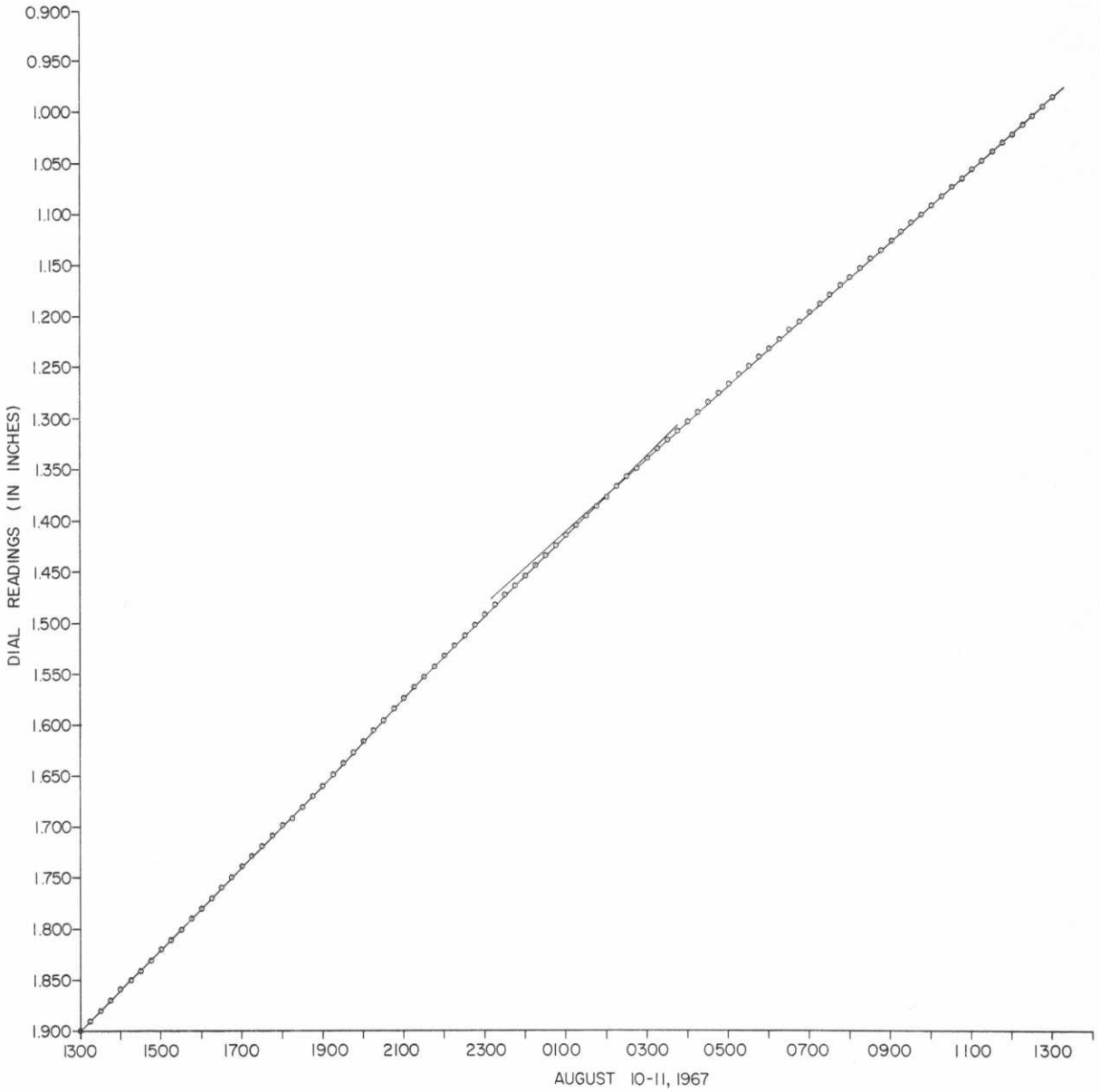

Fig. 12 - Plot of movement observed in 24 hour study. Note that the break in slope which indicates a decrease in basal slip rate occurs at approximately the same time that precipitation halted.

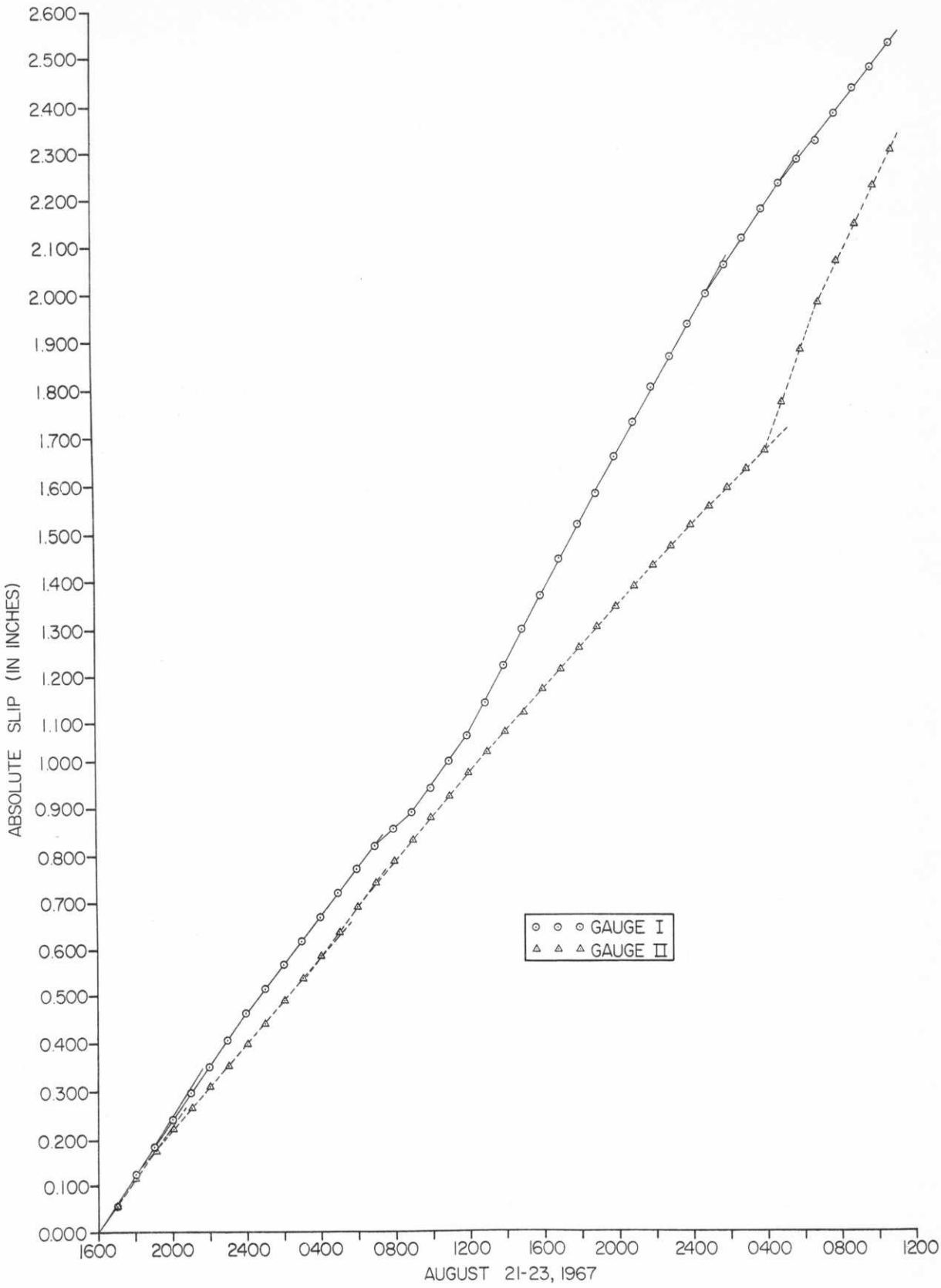

Fig. 13 - Plot of movement observed in 48 hour study. The changes in slope are thought to be a result of changes in slip rate produced by intermittent precipitation.

Fig. 14 - Photo of limestone cube 5 cm on side fastened to bedrock knob with rock bolts and epoxy. Flow of the glacier is toward the viewer, parallel to the diagonal of the cube.

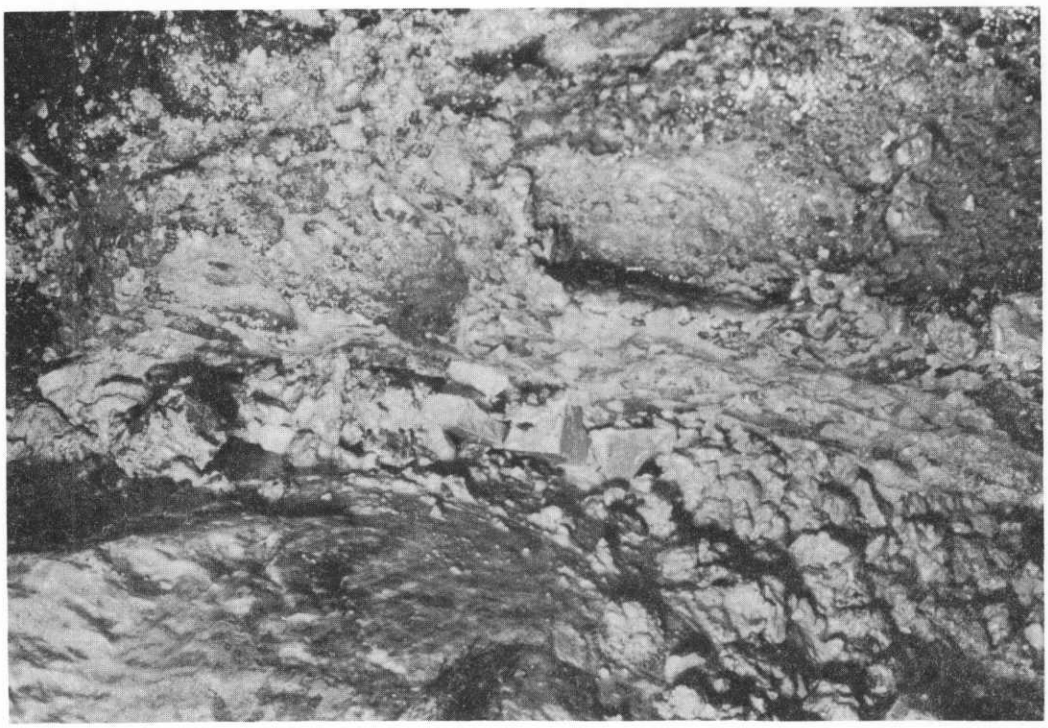

Fig. 15 - Photo of cube smashed by englacial debris. Note polished, striated bedrock surface in left foreground.

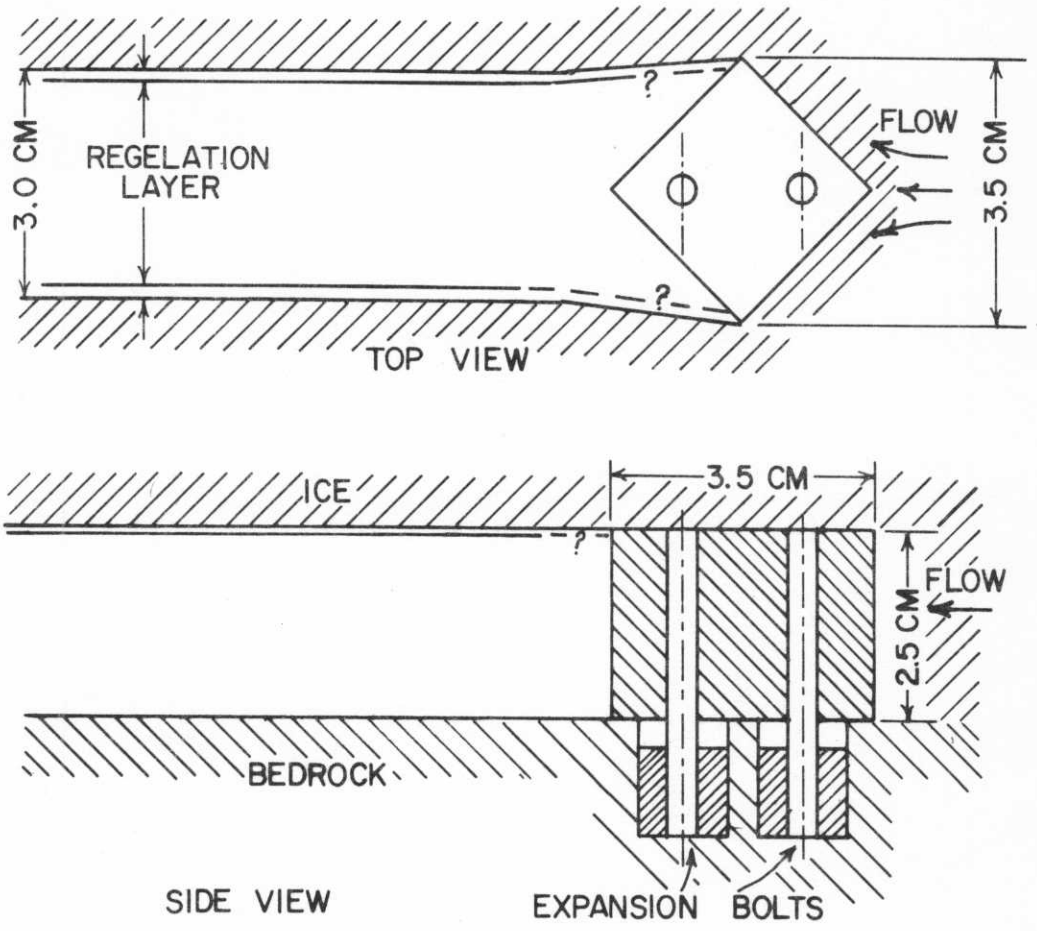

Fig. 16 - Diagram of the ice flowing around a 2.5 cm cube. Note the plastic closure and the regelation layer on the lee side of the cube.

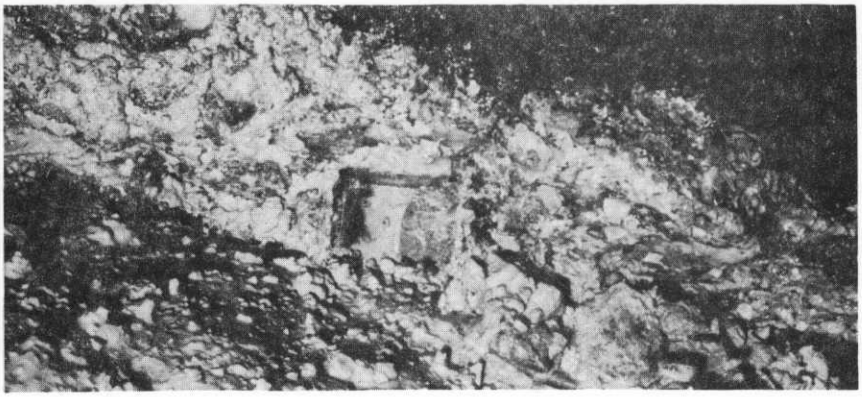

Fig. 17 - Photo of cavity formed on the lee side of the cube as the ice flowed around it. Debris in foreground has been melted from the englacial load which is the broad lighter band across the photo from the upper left to the lower right.

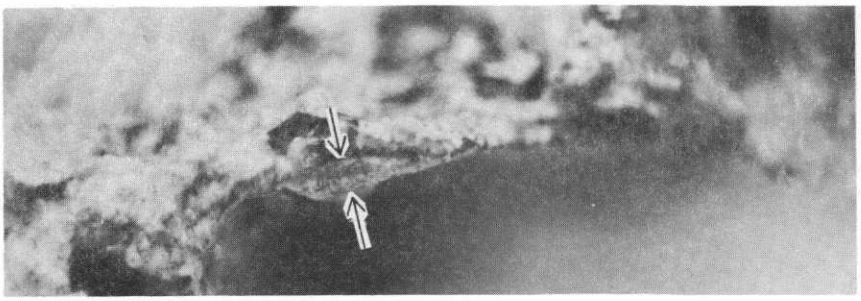

Fig. 18 - Close-up photo of fragment of ice which has flowed around the 2.5 cm cube. Note the remainder of the regelation layer. (The rest had melted).

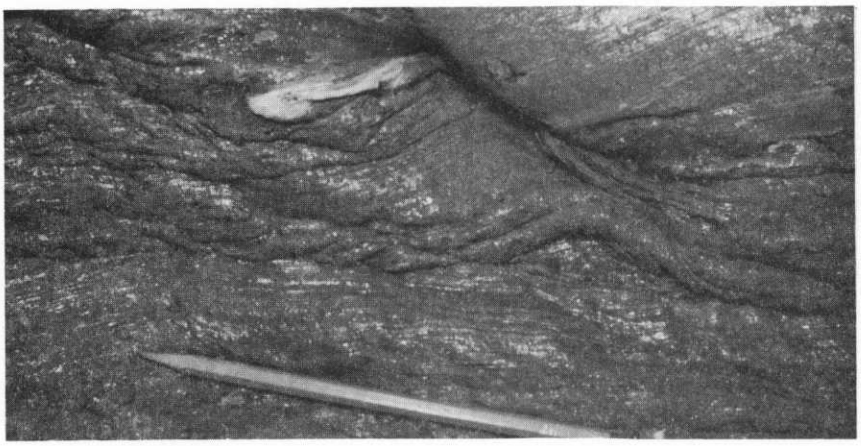

Fig. 19 - Feature in glacier-cave wall about 20 m inside the Casement Glacier, showing "turbulent flow" of the basal ice layer as it is squeezed around a bedrock knob (1 m high x 3 m wide). Flow is from right to left. The shiny appearance of the wall is a result of the camera flash reflective off a thin layer of clear regelation ice.

VELOCITY PROFILES

The deep-drilling program for the Casement Glacier as originally proposed has been plagued with difficulties since its inception and the 1967 field season was no exception. The original plan was to drill a set of holes through the glacier and to determine the velocity profile by repeated measurements of the inclination of these holes. The initial steam-type hot point drill, which was field tested in 1965, was found to be effective to depths of only 7-9 m. Investigation into other deep-drilling programs led to correspondence with Dr. R. Shreve, of the Department of Geology, University of California, Los Angeles. Using plans drawn by Shreve, three electrical hot points were built in Columbus for use in the field during the 1966 season. Two of these drills burned out in trying to drill the first hole and the third could not be removed from the hole once it had been drilled successfully to a depth of 50 m (see report of 1966 field results).

The three drills for the 1967 field season were built under the close supervision of Dr. Shreve and were tested and found to be satisfactory. The field plan was to place two or three holes in each of two rows of stakes (rows 11 and 15) so that the mass balance for a given volume of the glacier could be obtained (Fig. 2 for location and Fig. 20 for planned program). The first hole was drilled successfully

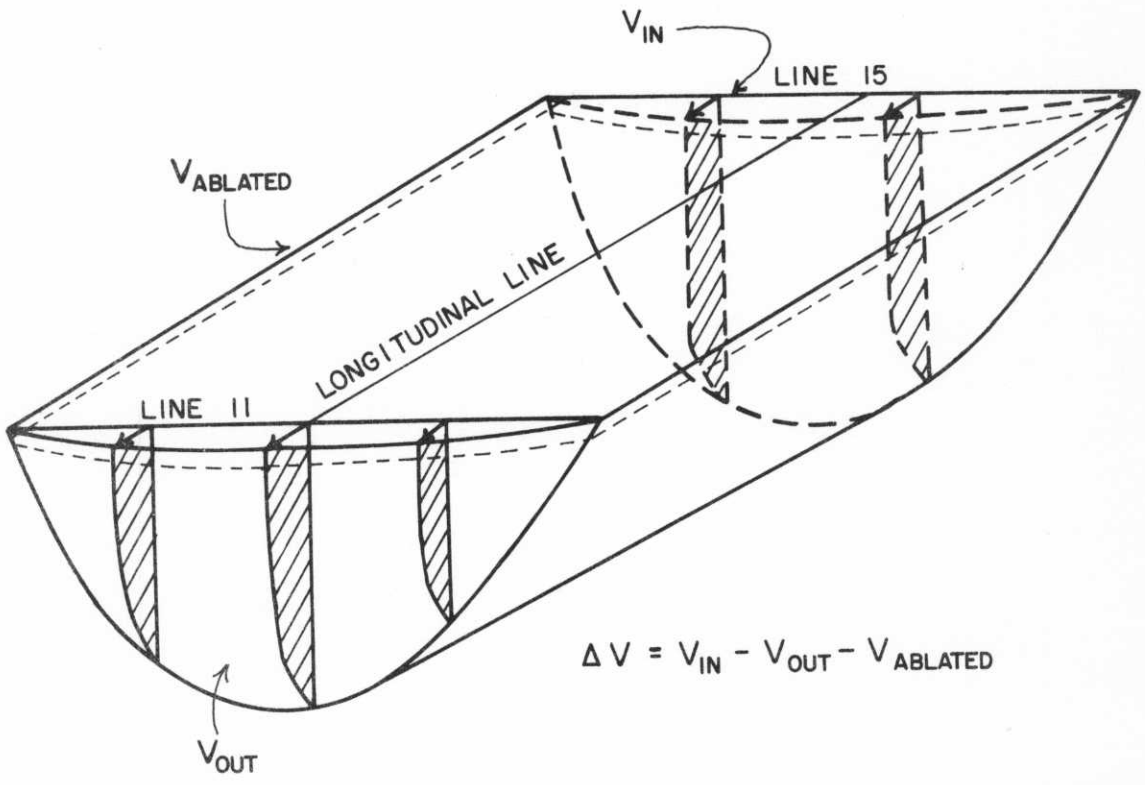

Fig. 20 - Diagram of proposed study of mass balance of a segment of the Casement Glacier in which the net ice gain or loss could be measured by determining the inflow, the outflow, and the surface oblation.

at stake 2 of line 11 to a depth of 44 m. The hole was surveyed on July 14 and found to be vertical within the limit of measurement of the inclinometer (±1°). The second hole was started on July 15 at flag 6, line 11. One of the drill points was burned out in drilling this hole when the water in the hole drained out (presumably into an open crevasse or another cavity) leaving the hole dry to 28 m. Without the presence of water to conduct the heat away from the point, the resistance wire overheated and burned out the drill. The burned-out point was replaced and the drilling continued to a total depth of 51.6 m until the drill made no further progress. This is probably not the bottom; the drill probably encountered some englacial debris which it could not bypass. The inclinometer survey was conducted on July 19 showing this hole to be vertical also. The third hole was started at flag 4, line 15, and had reached a depth of more than 100 m when the electrical cable pulled apart from its own weight at a connection between two lengths, dropping the hot point and cable irretrievably into the hole. Faced with the choice of continuing the initial drilling plan with the last hot point, or of saving it for re-opening the holes for the final inclinometer survey, the writer chose to be cautious and keep the one remaining drill for the end of the season. Unfortunately, the last drill burned out in trying to re-open the second hole for the final inclinometer survey and, consequently, nothing was achieved.

The purpose of the velocity profiles which would have been obtained from the inclinometer data in the deep holes, was to provide control for the calculations of the trajectories of points initially on the surface of the glacier as they move through the glacier. The calculations are based on the flow law of ice determined in laboratory studies, and require a knowledge of the glacier's surface velocity, slope of the upper and lower surfaces, and thickness. These parameters have been determined at the movement stakes and, despite the lack of control, it is believed that reasonable estimates of the trajectories will be obtained.

METEOROLOGICAL RESULTS

The 1967 meteorological program was to re-establish the three stations from the 1966 season and also to carry out heat balance studies at a site on the glacier near the main camp.

The program was not as extensive as had been planned because of the unexpected illness of the meteorologist, who was forced to leave the party after only one week in the field. However, the meteorological station at the base camp (station 1 from 1966, Fig. 2) was maintained from 29 June to 8 September with synoptic observations at 0700, 1300, and 1900, Alaska Standard Time. In addition to the observations at camp, two 96-hour heat balance studies were conducted, July 31-Aug. 3 and Aug. 26-29. These meteorological results, together with those from the previous two summers, will be used in making the final

TABLE I. Meteorological Shelters, Locations, Instrumentation, and Dates of Operation
(See Figure 3 for Location)

Year	Station	Elevation	Terrain-surface material	Instrumentation	Period of Operation
1965	1	300 m (1000 ft.)	Ice	Barograph Hygrothermograph Pyrheliograph Recording anemometer Campbell-Stokes sunshine recorder Assmann psychrometer Precipitation totalizer Max and min thermometers	30 June - 25 August 1965 with three times daily observations at 0700, 1200, and 2100 hrs. Cloud cover in 10's noted at time of observations.
	2	100 m (325 ft.)	Outwash gravel	Hygrothermograph Pyrheliograph Recording anemometer Precipitation totalizer	1 July - 25 August 1965
1966 and 1967	1, base camp	1050 m (3400 ft.)	Moraine	Barograph Thermograph Assmann psychrometer Rain gauge and totalizer Hand anemometer Max and min thermometers Campbell-Stokes sunshine recorder	23 June - 26 August 1966 with three times daily observations at 0700, 1300, and 2100 hrs. Cloud cover in 10's noted at time of observations.
				(Pyrheliography, 1967)	29 June - 7 Sept. 1967 with observations at 0700, 1300, and 1900 hrs.
1966	2	1030 m (3350 ft.)	snow/ice	Hygrothermograph Pyrheliograph Max and min thermometers Precipitation totalizer Recording anemometer	22 June - 22 August 1966
	3	1170 m (3800 ft.)		Hygrothermograph Pyrheliograph Max and min thermometers Precipitation totalizer	4 July - 22 August 1966

analysis of the mass balance of the glacier. The relative importance of radiation, sensible heat, and latent heat in supplying energy at the glacier surface will be calculated for the oblation period.

SUMMARY OF SYNOPTIC DATA

1. Sunshine and cloudiness

The weather during the 1967 season can best be described with one word--miserable. A comparison of the average daily sunshine for the three field seasons is given in Table II. The average daily sunshine during the 1967 field season was minimum for every one of the observation periods except for the interval 16-31 Aug. when the average of 2.3 hr day exceeded the 1966 average of 1.3 hr day, but fell far below the 1965 average of 6.4 hr day. During the nine days of observation in the month of September the sun did not shine.

2. Temperatures

Although there was less sunshine during the 1967 season, the air temperatures as observed at meteorological station 1 were higher than for the same period in 1966. Table III presents a summary of the mean temperatures for the periods of observation.

3. Relative humidity

The mean relative humidities at station 1 for the 1966 and 1967 seasons are summarized in Table IV.

4. Precipitation

The 1967 season was the wettest of the three summers, with measurable precipitation falling on 80 per cent of the days in the field. The precipitation data for the three seasons are summarized in Table V.

HEAT BALANCE STUDY

The principal sources of heat energy at the surface of a glacier are radiation from the sun and sky, conduction and convection from the overlying air mass, condensation of water vapor on the surface releasing the latent heat of condensation, and conduction from warmer ice below the surface. This energy is used in a variety of ways. Among them are the reflection of incident radiation back to the sky, conduction downward into the glacier, sublimation of the ice on snow, and melting of the surface snow and ice.

During the 1967 field season two 96-hour heat balance studies were made at a station on the glacier near the main camp (Fig. 2).

TABLE II. Total Sunshine in Hours Per Day and Mean Cloud Cover

	22-30 June	1-15 July	16-31 July	1-15 Aug.	1-15 Aug.	1-9 Sept.
Maximum possible hours of sunshine per day	18.25	17.75	17.00	16.00	15.00	
Mean daily sunshine, 1965		5.5	4.5			
Mean daily sunshine, 1966	4.9	5.8	5.1	3.6	1.3 6.4	
Mean cloud cover, 1965		70%	70%	63%	42%	
Mean cloud cover, 1966	88%	65%	71%	76%	90%	
Mean daily sunshine, 1967	3.5 (23-30 June)	3.0	2.8	3.1	2.3 (16-31 Aug.)	0
Mean cloud cover, 1967	80%	82%	84%	80%	85%	100%

TABLE III. Mean Temperatures and Mean Extremes (°F)

	Time	30 June - 18 July		19-31 July		1-25 Aug.
Station 1, 1965	0700	41.9		42.1		43.5
	1200	42.3		42.8		44.6
	2100	42.6		43.2		44.8
	Max.	50.2		49.8		51.4
	Min.	40.1		39.9		39.4
	Time	**23-30 June**	**1-15 July**	**16-31 July**	**1-15 Aug.**	**16-26 Aug.**
Station 1, 1966	0700	38.5	39.9	46.3	42.8	40.2
	1300	45.0	42.7	50.9	43.0	42.4
	2100	38.5	41.8	47.3	42.6	42.0
	Max.	54.1	52.3	55.2	48.8	45.5
	Min.	32.1	33.4	39.7	36.2	34.5
Sta.2 1966	Max.	46.7	48.7	48.5	43.0	39.8
	Min.	29.6	32.4	35.0	32.2	32.0
Sta.3 1966	Max.		47	44	39	40
	Min.		28	30	30	30
	Time	**1-15 July**	**16-31 July**	**1-15 Aug.**	**16-31 Aug.**	**1-8 Sept.**
Station 1, 1967	0700	41.0	40.4	43.8	44.6	40.4
	1300	45.4	46.2	47.4	48.8	41.2
	1900	43.4	47.5	45.6	45.3	41.4
	Max.	50.0	49.9	50.0	50.7	43.9
	Min.	37.7	39.3	40.5	40.7	37.6

TABLE IV. Mean Relative Humidities at Meteorological Station 1, 1966 and 1967

Time	23-30 June	1-15 July		16-31 July		1-15 Aug.		16-31 Aug.		1-7 Sept.
	1966	1966	1967	1966	1967	1966	1967	16-26 1966	16-31 1967	1967
0700	49	59	86	66	82	79	82	86	85	88
1300	59	55	70	69	72	80	81	89	86	96
2100 (1966 only)	53	54		70		82		80		
1900 (1967 only)			79		82		84		86	92

TABLE V. Precipitation Data, 1965-1967

Year	Station	Precipitation (cm water equivalent)	Period of observ.	No. of days	No. of days w/measurable precipitation
1965	2	20	15 June - 25 Aug.	69	30
1966	1	29.8	9 July - 27 Aug.	49	33
	2	27.4	9 July - 22 Aug.	44	30
	3	25.8	4 July - 22 Aug.	49	32
1967	1	59.7	25 June - 8 Sept.	76	61

During these two periods observations of the profiles were made every half-hour from the surface to 2 m of air temperature, vapor pressure, and wind speed. At the same time measurements were made of the in coming short-wave radiation, the net radiation and the precipitation. The elements in the heat balance equation for the two periods will be calculated and related to seasonal changes in ablation.

LANDSLIDE STUDY

Because of the interest of the Institute of Polar Studies personnel in the effect of landslide material on the rate of ablation of the underlying ice, an examination was made of the effects of the rock slide on the Casement Glacier (Fig. 21). Oblique aerial photos taken on Oct. 8, 1935, shows that the material was on the ice at the time discounting the possibility that it could have been loosened by the Good Friday earthquake in 1964 which caused the emplacement of a large debris slide on much of the ablation zone at the Sherman Glacier, near Cordova, S. Alaska (Fig. 22).

The Casement Glacier landslide, which has a area of about 2 km^2, is composed of angular rock fragments up to 10 m across. There is much less fine material than on the Sherman Glacier, and ice is exposed between many of the fragments. The deficiency of fine debris is probably because it has been at least 32 years since the slide occurred, and the annual precipitation in this region is quite high, so that much of the fine material has been washed away. The result of this lack of fine material is that the debris-covered area does not rest on a platform of ice as does the landslide on the Sherman Glacier. Instead, the surface is slightly lower than the adjacent clear glacier surface. The effect of the isolated boulders is to increase the average ablation; the exposed ice ablates at mearly the same rate as the adjacent ice with no debris cover, and the ice near the rock fragments is ablated more, because of the increased absorption of insolation by the rock. In the portion of the slide area that still have a mantle of fine material, the surface is raised slightly above that of the adjacent boulder-covered area from which most of the fines have been removed.

ICE-DAMMED SELF-DRAINING LAKE

During the 1967 field season, as in the previous two years (Lindsay, 1966), some observations were made on a small ice-dammed self-draining lake (Fig. 23). This lake exists along the west side of the Casement Glacier at an elevation of 550 m (1800 ft), at which point the trunk glacier forms a dam directly across a deglaciated, right-angled tributary valley. Meltwater from the glacier and surface runoff from the surrounding mountain slopes are thus impounded in this ice-free tributary valley to form a small lake. Because of the lake's location with

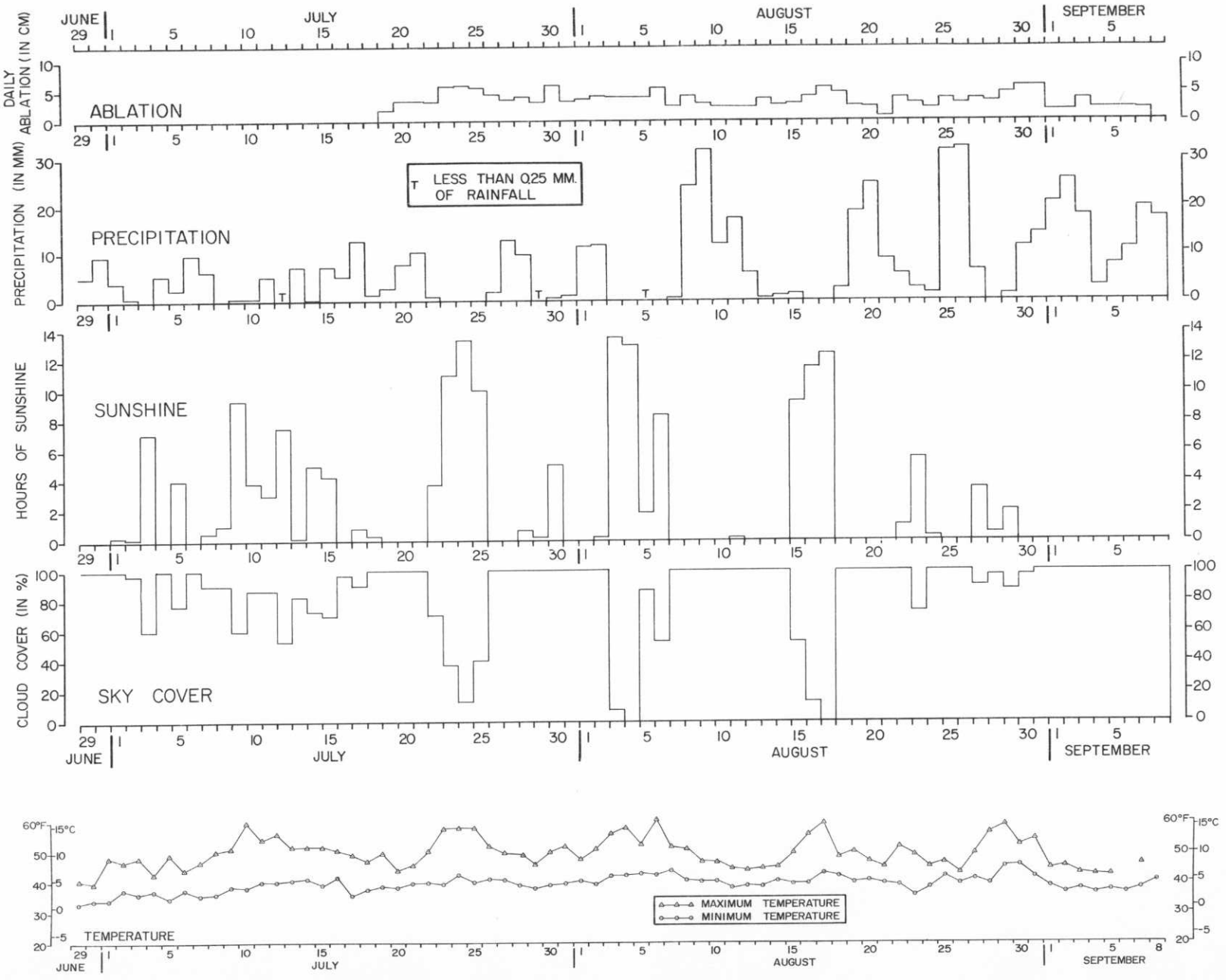

Fig. 21 - Temperature, sky cover, sunshine duration and daily ablation at Station 1, Casement Glacier, 1967.

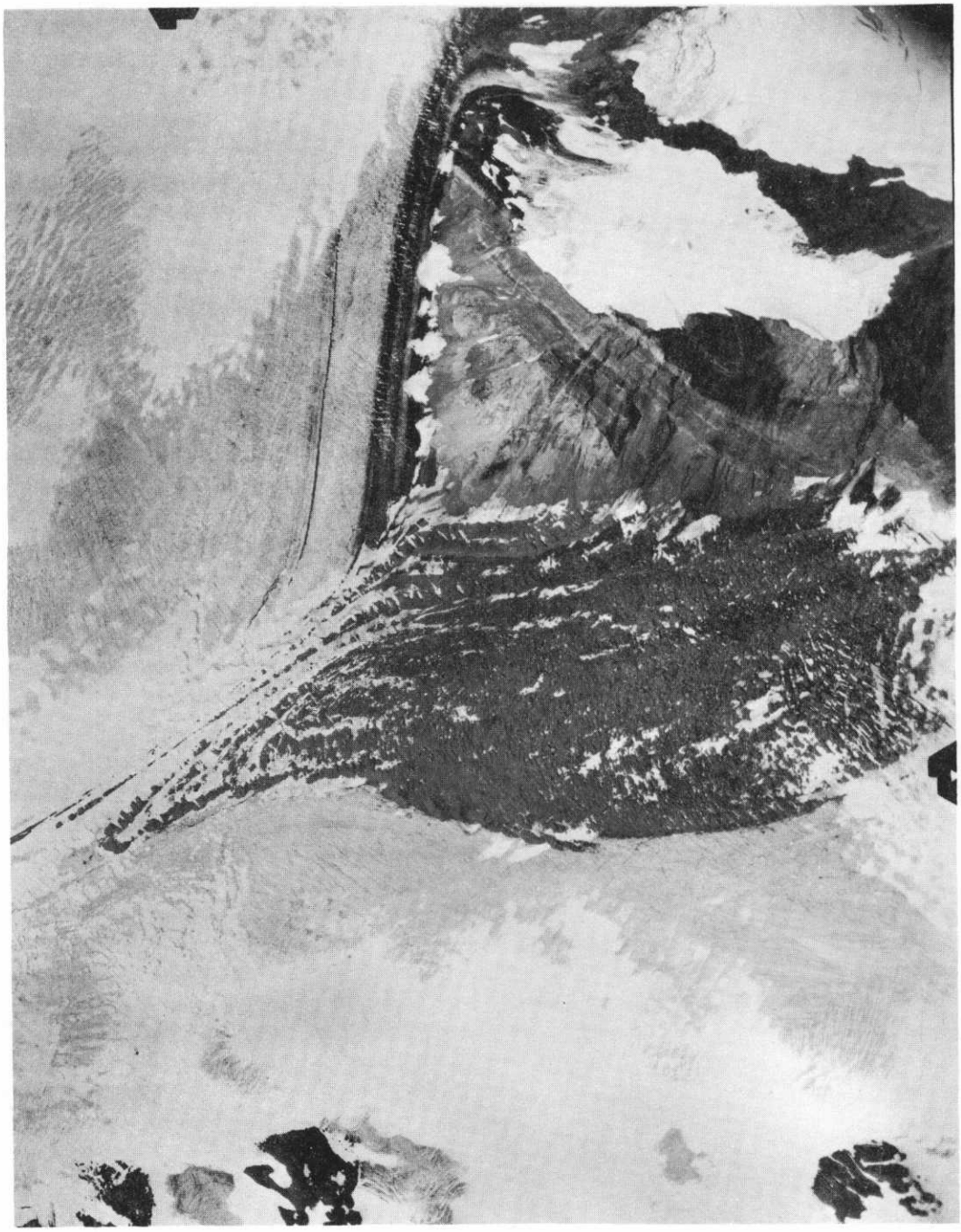

Fig. 22 - View of landslide on Casement Glacier, Alaska. (Photo by Austin Post, US Geological Survey)

Fig. 23 - View of landslide on Sherman Glacier, near Cordova, Alaska. Note that the landslide is now resting on a thick pedestal of ice. (Photo by Austin Post, US Geological Survey)

respect to the main camp, which was some 20 km upglacier, opportunities to observe the lake's behavior were infrequent. This situation was very unfortunate because daily observations would have provided a much more complete and precise record of the chronology of events; consequently, greater insight into the problem might have been gained.

During the 1967 field season, observations of the lake were first made from the air on 18 June, at which time the lake appeared to be nearly full. The lake was next seen on 27 June, at which time only general observations were made. The water level appeared to have remained constant or to have risen slight. By 6 July the water level had risen slightly from the 27 June level. There was no evidence of drainage at this time, but the retaining ice barrier showed evidence of having been somewhat uplifted as it was arched in the center.

As members of the party were working in the immediate vicinity of the lake between 6 July and 15 July, the lake was seen almost daily during this period. The water level continued to rise daily. Measurements taken on 11 July showed a 40 cm rise in the lake level during the preceding 24 hours. By 15 July arching of the ice-dam front was much more pronounced than it had been on 6 July. This change seemed to indicate that the barrier was definitely being uplifted as the water level rose (Fig. 24).

The lake was not seen again until 22 July. By this date drainage had occurred, supposedly very suddenly. The drainage mechanism appeared to the one first purported by Thorarinsson (1939) to explain the drainage of such lakes in Iceland; i.e., the water level continues to rise until it reaches nine-tenths of the height of the ice barrier, at which time the ice dam is buoyed up, thereby permitting the initial rapid release of previously impounded water. In the case of this lake, drainage was not complete. The actual amount that the water level had dropped was not measured until 27 July; at that time measurements revealed a drop in water level of some 32 m from the 15 July level.

The retaining ice dam which was definitely uplifted during the period when the lake was filling up had been dropped, thereby preventing further drainage. On 22 July it was noticed that the water level had more or less stabilized at its new lower level. Because the lake level did not rise from its 22 July level during the remaining seven weeks of the field season, it was concluded that water was escaping through crevasses or other fractures in the recently lowered retaining lobe at a somewhat constant rate and that a rough balance was achieved between drainage and the inflow of meltwater and surface runoff from the surrounding mountain slopes.

Additional evidence in support of the "dam flotation" theory was revealed throughout and immediately behind the retaining barrier on 22 July. As stated above, contrary to its pre-drainage arched shape, the ice dam had been dropped, and it actually sagged from either end

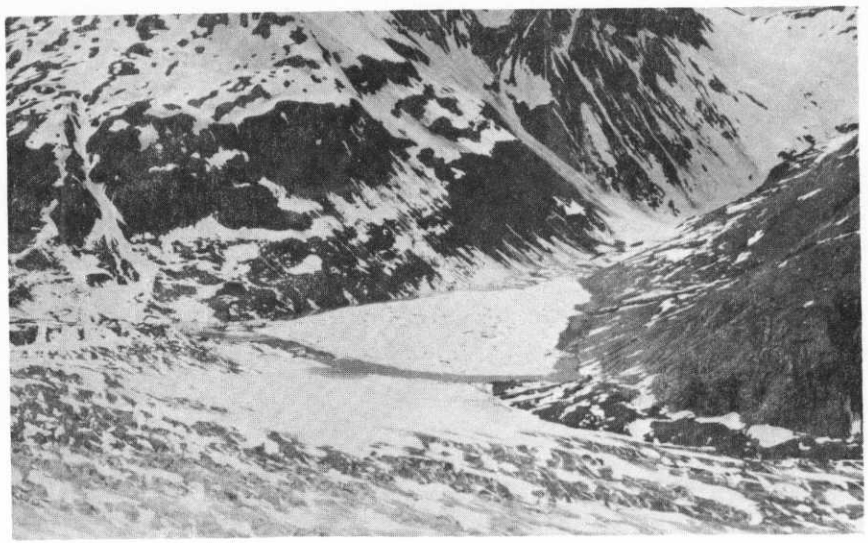

Fig. 24 - Aerial view of self-draining lake along the side of the Casement Glacier at full stage. Photo taken 12 June 1966. On 18 June 1967 lake was in similar state.

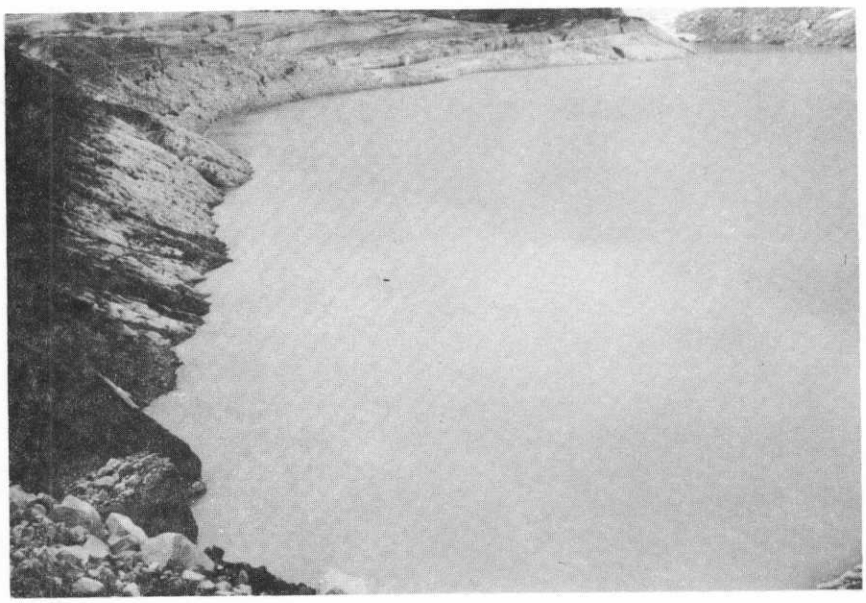

Fig. 25 - View of ice cliff damming the valley which produces the lake. Note that the water is no longer above the edge of the cliff and that there is a "shore line" of washed ice which is highest in the middle. Note also the presence of a marked slumping ice cliff in background in step-like fashion, but as yet ther were no icebergs floating in the lake.

toward the center. Furthermore, in the wake of drainage, the entire dam had slumped forward in addition to having been lowered. As consequence of these events a maze of fractures throughout the barrier was created. Extensive breakup was everywhere evident. Numerous small icebergs were now floating about the lake.

The lake was next observed on 9 August. By this time the entire dam and immediate vicinity had become so unstable as to render it unsafe for any close-up study. However, reference points established on 27 July were in view. It appeared as though the water level was much the same on this date as it had been on 27 July. No significant change had occurred.

On 17 August the water level had dropped from its 9 August level. A small delta at the lake's head was now exposed. This fact constitutes proof of further drainage. The conclusion was drawn that water was escaping through crevasses and other points of egress in the barrier lobe at a more rapid rate than water was flowing into the lake. The balance between inflow and drainage discussed above no longer existed. This unbalance is to be expected as the amount of ablation decreases in late summer. If water continued to escape at approximately a constant rate following the initial rapid discharge, the rate of drainage should exceed inflow in late summer as the rate and daily amount of ablation decline rapidly. Perhaps it was this negative balance in the lake's "budget" which accounted for the observed drop in water level. No other drainage mechanism seems to offer a satisfactory explanation.

The final observation of the lake was made from a helicopter on 10 September. Although some water still remained in the lake, the level had dropped since 27 August. Much more of the delta at the lake's head was now exposed. That further disintegration of the ice cliff had occurred was revelaed by the amount of ice now floating in the lake. Numerous bergs were also perched on recently emerged lake terraces. Whether the lake ever did drain completely before the onset of winter is not known.

ICE WORMS

(modified from a preliminary report by D. Goodman, Department of Zoology, Ohio State University, who was employed during the 1967 field season, primarily as a meteorological observer.)

Considerable interest among biologist had been generated by the reports after the 1965 and 1966 field seasons, of the presence of large numbers of "ice worms" on the surface of the Casement Glacier. Because so few studies have been made on these animals in the past, the opportunity was taken during the 1967 season, to devote such spare time as was available to observations of their ecology. Although this work is

outside the scope of the original glaciology program, this short report is included because of its inherent interest and because it indicates a field of future profitable research. Most of the observations were made on the ice worm, which has been tentatively identified as Mesenchytraeus solifugus.

During the first 96-hour heat balance study, a census was taken of the worm's abundance at the snow surface was taken at half-hour intervals. Although the worms disappeared completely from the surface during the day, during the evening they became increasingly abundant until as many as 75 could be counted in an area 40 cm^2 on a side. An analysis will be made to determine if there is any correlation between the worm abundance and the parameters such as air temperature, humidity, and incident shortwave and net radiation. In addition to their activity on the glacier surface, ice worms were often seen on the bottom of cryoconite holes and on the walls of water-filled crevasses.

A Hach water engineer's field kit was employed for some rudimentary chemical analyses of the water in a crevasse. The kit was not especially well-suited for this task despite its compactness and usual simplicity of operation, for some of the reagents were difficult to dissolve at low temperatures, and many of the determinations were at the lower limit of the equipment's range of sensitivity.

Samples of ice and snow from different locations on the glacier were melted and filtered with a Millepore vacuum filter apparatus. Permanent mounts, suitable for microscopic examination, were prepared from the cleared filter membranes. Subsequent study of these slides has provided data on the relative local abundance of several species of algae, including the Chlamydomonas responsible for "red snow." These red algal cells were seen in preparations of mashed ice worms, which lends credence to the suggestion that the worms feed on algae.

Dissection of a snow bunting, Plectrophenax nivalis, shot over the glacier revealed that the ice worms are in turn eaten by these birds. The snow bunting's stomach also contained fragments of snow fleas or springtails, order Collembola, the only other metazonans besides the ice worms that were common in the glacier ice and snow.

Several collections of ice worms were preserved in alcohol, as were a few of the Collembola. Serial sections are now being made of the preserved worms and examination of these should ascertain the worms' identity and provide a more precise account of their gut contents.

At the end of the season a number of live ice worms were brought to The Ohio State University in an ice chest because they disintegrate at normal room temperatures. The live worms have been maintained at 0°C in an incobater. Their motions remained normal for 3 months. At the present writing, (January 1968) except for victims of various experiments, the worms are still alive though their activity has diminished.

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In the laboratory the metabolic rate of the ice worm has been determined at several temperatures. An electron microscopical study of the worm is being undertaken in collaboration with Dr. Wayne B. Parrish, of the Department of Zoology. The ice worms' body musculature has thus been found to be of the oblique-striated type. Currently a study of the curious ultrastructure of the cuticle is in progress.

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