CATASTROPHIC ADVANCE OF THE STEELE GLACIER, YUKON, CANADA

by

L. A. Bayrock

A preliminary report on surveys conducted on the Steele Glacier from August 20th to August 23rd, 1966

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PREFACE

This report represents preliminary results of the studies conducted on the Steele Glacier, Yukon, between August 20th and 23rd, 1966. The final report of this investigation will be published by the Boreal Institute, University of Alberta, during the spring of 1967. Only 15 copies of this report are prepared in this manner and are distributed only to persons interested in following up the research on the Steele Glacier during the summer of 1967. This report does not constitute the final form, and any comments for its improvement will be appreciated by the author.

Acknowledgments

The author gratefully acknowledges the support of the Boreal Institute, University of Alberta, for supplying most of the field funds for the project. The Research Council of Alberta carried all the costs involved in compilation of the report.

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Introduction

The Steele Glacier is located on the north side of Mt. Steele, St. Elias Mountain Range, Yukon. It flows in a narrow valley which is from one to ~~one and~~ one half miles wide. About 5 miles from the end the glacier makes a sharp turn to the right, as of August 23, 1966.

In the upper reaches the Steele glacier is fed by many small tributary glaciers which helped it to attain a length of about 10 miles (or 16 km) before the advance. Canada National Topographic Sheet 115G and 115F (E 1/2) (Klaune Lake) (Fig. 1) to a scale of 1:250,000 shows the Steele glacier to be stagnant, as judged on the basis of V and U shaped contours pointing upstream when crossing the glacier. The first point at which the contours cross the glacier in a straight line is taken as the position of the terminus. The topographic map was prepared from air photographs taken from 1947 to 1951. The advance of the Steele glacier from that position until August 23, 1966 is approximately 7.5 miles or 12 km.

The author and his assistant, Mr. Thomas Reimchen, Edmonton, were able to study the Steele glacier for four days, Aug. 20th to Aug. 23, 1966 inclusive. As the author did not have the time or a helicopter available, most of the study was concentrated at the left terminus of the glacier and along the left side to a point two miles upstream from the toe. Aided by good weather (cool and mostly cloudy, but no rain) it was possible to conduct a number of surveys of some processes of erosion and transportation and some flow characteristics of this spectacular natural phenomenon.

TABLE I

ANGLES FROM BASELINE TO POINTS ON THE GLACIER

POINT	TIME	ANGLE	VALUE
CAVE	Aug. 21, 7:45 pm	ABC	87°57'
		BAC	86°28'
	Aug. 22, 8:00 pm	ABC	86°57' *
		BAC	87°33'
	Aug. 23, 12 Noon	ABC	86°05'
		BAC	88°20'
PILLAR	Aug. 21, 7:45 pm	ABP	82°54' *
		BAP	87°35'
	Aug. 22, 8:00 pm	ABP	79°40'
		BAP	89°48'
	Aug. 23, 12 Noon	ABP	78°6'
		BAP	91°22'
BOULDER I	Aug. 21, 7:45 pm	ABBI	67°51' *
		BABI	97°0'
	Aug. 22, 8:00 pm	ABBI	64°51'
		BABI	100°22'
	Aug. 23, 12 Noon	ABBI	62°49'
		BABI	102°43'
BOULDER II	Aug. 22, 8:00 pm	ABB III	117°37'
		BAB II	52°36'
	Aug. 23, 12 Noon	ABB II	116°12'
		BAB II	52°42' *
PINNACLE	Aug. 22, 8:00 pm	ABPL	92°22'
		BAPL	84°52'
	Aug. 23, 12 Noon	ABPL	92°5'
		BAPL	85°11'

* Denotes error in measurement

TABLE II

RATES OF FLOW OF CERTAIN POINTS ON THE GLACIER AND DISTANCES FROM THE SOUTH EDGE

POINT		DISTANCE	RATE OF FLOW in feet per 24 hrs
I	Pinn	4300	22
II	Cave	1650	41
III	Pill	650	46.5
IV	B I	250	46.5
V	B/II	400	40
VI	Edge	0	37

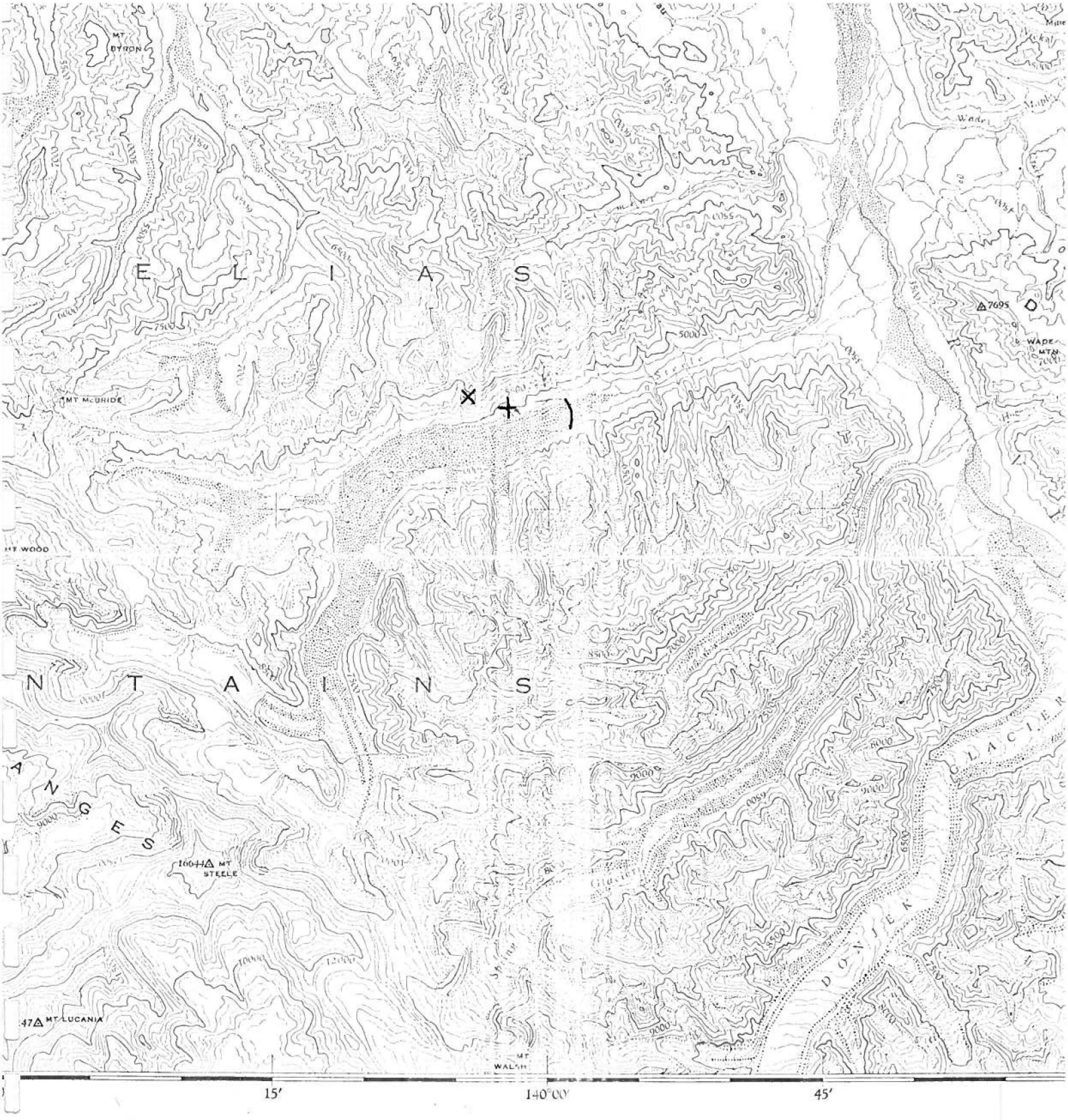


Figure 1

\ - Terminus of glacier, Aug. 23

\+ - Camp

X - Panoramic view camera location

Road — Route

hard surface, all weather ... payée, toute saison

loose surface, all weather ... de gravier, toute saison

wagon, cart track ... chemin de terre

trail or portage ... sentier ou portage

Railway, normal gauge ... Chemin de fer, écartement normal

Depression contours ... Courbes de cuvette

Spot elevation, in feet ... Repère de nivellement en pieds

KLUAN

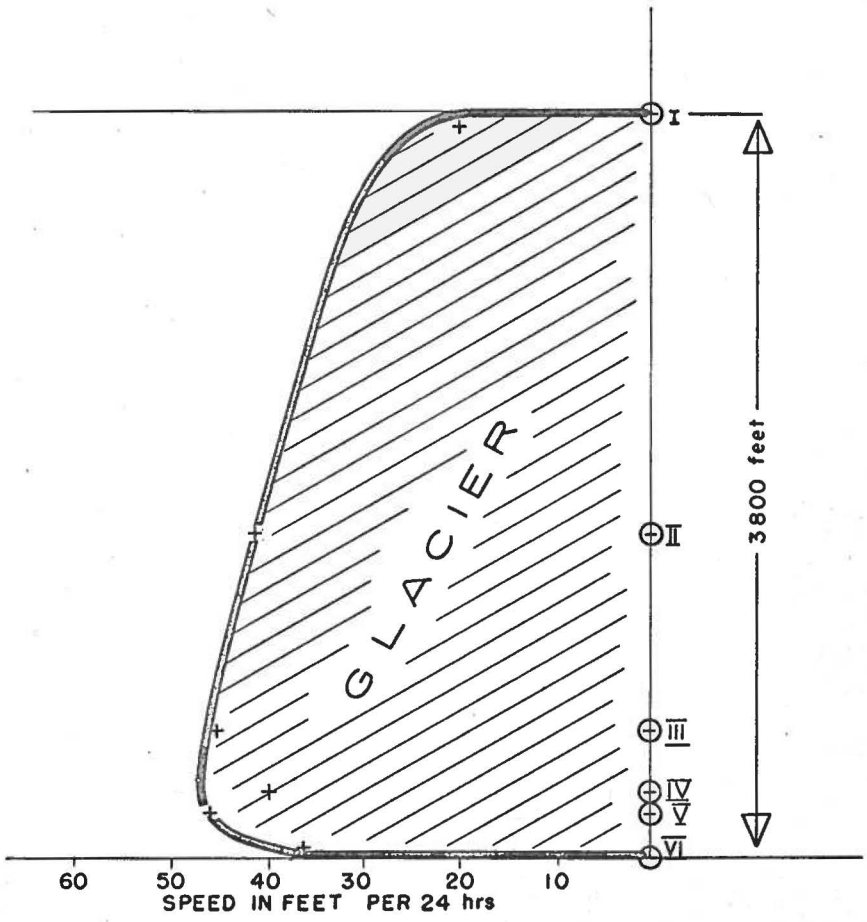
YUKON

Scale 1:

Miles 5 0 5

Kilometres 5 0 5 10

FIG. Ia: VELOCITY DISTRIBUTION



On Figure 1 are indicated positions of the terminus of the advancing glacier as of August 23, 1966, the position of the camp, and the position from which a panoramic view of the terminal portion of the glacier was taken.

A general panoramic view of the glacier is shown on Plate I. The photographs were taken from the location marked by X on Figure 1, which is about one mile north of the glacier and about 3000 feet above the glacier. The distant part of the glacier is about 6 miles away from the camera location and the toe about 3 miles away.

Motion

The motion of the glacier was measured by triangulation from a baseline 206.10 feet long constructed on an old moraine. The location of the baseline is shown on Plate I. The baseline was close to being parallel to the edge of the glacier, about two miles from the toe, 460 feet south of the edge of the glacier and about 170 feet above it. Four points were measured on the glacier from the baseline and the angles set out in Table I. The endpoints of the baseline are marked with capital letters A and B (A being the downstream point).

Distances and rates of flow were calculated from the angles given in Table I and the motion at the edge of the glacier was calculated from photographs of camera Stations II and III. Table II gives the distances from the edge of the glacier to the points measured and their rates of flow. The distribution of rates of flow across the glacier are set out in Figure 1a. The maximum rate of flow of the glacier is close to the left margin of the glacier. This abnormal flow rate distribution is thought to be

TABLE III

Station Number	Time photographs were taken	Location of Station
I	Aug. 20, 12 Noon Aug. 21, 4:00 pm Aug. 23, 12:30 pm	On the survey baseline
II	Aug. 20, 2:00 pm Aug. 21, 4:30 pm Aug. 22, 7:00 pm Aug. 23, 1:00 pm	At edge of glacier, below the survey baseline, 450' upstream and 250' towards the glacier from point B
III	Aug. 22, 12 Noon Aug. 22, 7:00 pm Aug. 23, 2:00 pm	About 180' from the glacier and 400' upstream from station II
IV	Aug. 21, 1:00 pm Aug. 22, 1:00 pm	At the toe of the glacier
V	Aug. 21, 1:30 pm Aug. 22, 1:00 pm	At the toe of the glacier

caused by the flow of the glacier around a sharp turn some 5 miles upstream rather than irregularity of bedrock surface. The bedrock surface seems to be quite uniform as determined from the topographic map (Figure 1).

The average of the flow of the glacier is 37 feet per day at the location of flow survey.

Camera stations

Five camera stations for time lapse photography were set up. Three stations were in the vicinity of the survey baseline and two at the toe of the glacier. The camera was set on a large rock and the outlines of the camera were drawn on it so as to ensure the same setting on consecutive days. In front of each station a stick was set up and its distance to the camera was measured. Whenever possible distances from the stick to the glacier or other objects were also measured. The height of the stick as visible from the camera position was also recorded.

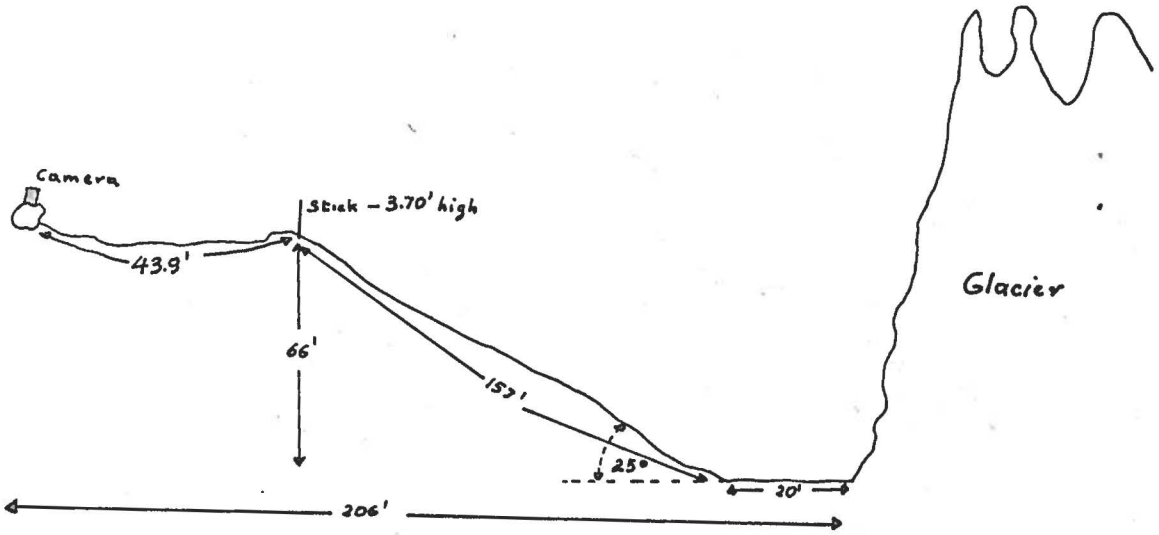
Table III gives times and dates on which photographs were taken at the stations. Positions of Stations 1, 2 and 3 are shown on Plate 1. Position of stations 4 and 5 are not shown, as they were not visible from camera location of Plate 1.

STATION 1

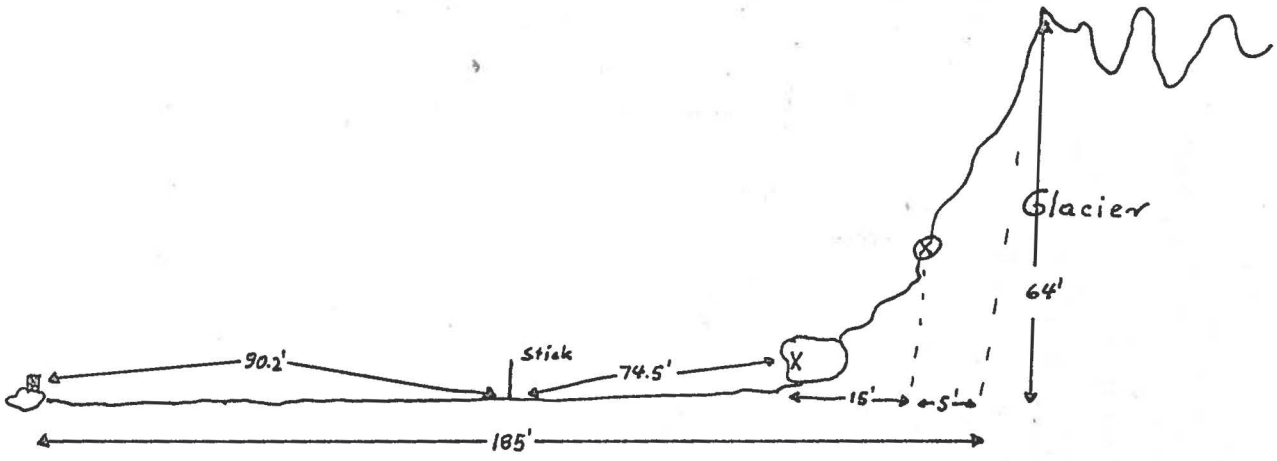
The location of the station was unfortunate in that the photographs do not lend themselves for exact calculation of the motion of the glacier. The camera was pointed upstream at a sharp angle and the flow rate survey points do not show up on it.

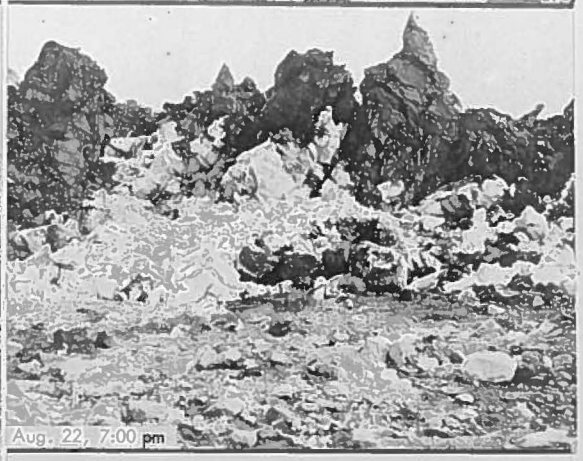
FIGURE II

(a) Position of camera at Station II (diagramatic)



(b) Position of camera at Station III (diagramatic)





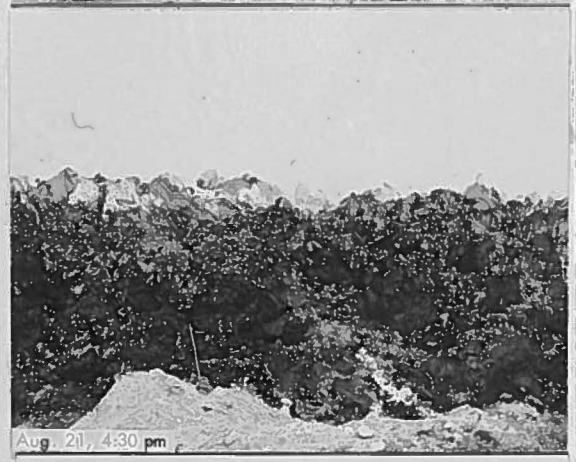


PLATE III

Camera Station 3, photographs taken during a 24 hour period showing the motion of the edge of the glacier (see Figure 2(b) for distances)

PLATE II

Camera Station 2, photographs taken on consecutive days showing the motion of the edge of the glacier (see Figure 2(a) for distances)

STATION II

This station was set up on a small moraine ridge near the edge of the glacier. Figure II shows in a diagramatic form the position of the camera with respect to the glacier. From the analyses of the photographs it was possible to calculate the motion of the glacier. Unfortunately, at this station the base of the edge is not visible.

Plate II shows photographs taken from the station and also the motions as calculated. The edge of the glacier was flowing at 25 feet per day. The large boulder on top of the glacier was moving at 40 feet per day.

STATION III

Station III was set up about 400 feet from Station II. Fig. 2(b) shows in a diagramatic form the position of the camera. The stick shown in the photograph has been marked with a 6 inch wide black band exactly 2 feet below the upper end. The angle from horizontal from the camera position to the top on an ice pinnacle (marked by X on Plate III) is 19° which gives the height of the pinnacle as 64 feet.

Using the stick as a marker calculations for the rate of motion of the glacier near the edge were performed. Plate III shows the results of the measurements. Maximum flow rate of flow measured on the photographs is about 37 feet per day. In the center of the photograph is a block of ice which is moving at about 20 feet per day and to the right a block of ice is moving at about 26 feet per day. The different motions result in compression of the block moving 20 feet per day and as seen from the successive photographs, the relatively slow moving block was crushed and it disappeared.

In photograph (a) the marginal shear is well marked by a bend of dirty groundup ice. In front of this shear the material does not move but behind it it does.

PLATE IV

Camera Station 4, photography taken 24 hours apart showing the advance of the large push moraine. The stick is 2.8 feet high ans is 32 feet from camera. The outer margin of the push moraine is 225 feet from camera.

PLATE V

Camera Station 5, panoramic photographs showing the advance of the toe of the glacier. The stick is 2.5 feet high.

This shear is obscured in photograph (b) by debris of the slow moving ice block but in photograph (c) it is visible again in the left portion of the photograph.

At this point the glacier was not only moving forward (to the left) but also it was moving slowly towards the camera. This is evident from the fact that in photograph (a) some exposed large ice blocks in front of the glacier are completely covered up by ice debris in the last (c) photograph. Such a motion is to be expected if the glacier were expanding laterally.

STATION IV

Station IV was situated at the toe of the glacier showing a side view of the large frontal push moraine and is shown diagramatically on Figure 3. The glacier is only visible partly behind the moraine. Only two photographs were taken from the location - on August 21 at 1 pm and on August 22 also at 1 pm (Plate IV).

Close examination of the glacier behind the push moraine shows that it has undergone only very little change although it has advanced about 20 feet. All of the crevasses and the individual ice blocks produced by the crevasses are very much the same. The only conclusion that can be drawn from the fact is that at this location the glacier motion was predominantly by basal slippage. A similar situation may be observed on Plates 5, 7, 8, and 9.

The push moraine also has not undergone much change, especially in the upper portion as is evidenced by the distribution and relative position of individual boulders on it. The major movement of the moraine was also by basal slippage.

PLATE VI

Stereoscopic view of the edge of the glacier near camera station 3. Note human

The stick is 2.80' high and is about 32 feet from the camera. The outer margin of the push moraine is about 225 feet from the camera.

STATION V

The stick visible in the photographs is the same one as that of Station IV (Plate V). The position of the station is shown diagramatically on Figure 3. The visible portion of the stick is 2.50" and the stick was about 60' from the edge of the glacier on August 21 at 1:30 pm. On August 22 at 1:00 pm this stick was only 24' from the toe of the glacier. The total advance of the bulging front was about 36' in 24 hrs.

Again here as at Station IV the glacier did not change its appearance with the motion and consequently maximum shear was on the base.

Other photographs

A large number of photographs were taken to show different features of the glacier but they were not taken from exactly the same position on successive days. Also the photographs were taken to show the same features of the glacier in stereo. This was accomplished by taking a second photograph of a feature from a position 5 to 10 feet laterally.

Plate VI shows in stereoscopic view the edge of the glacier as looking from Station II towards Station III. Note in the center of the photographs a human figure. The ice pinnacles at the edge were from 60 to 120 feet high and were moving at rates from 20 to 37 feet per day, or from about one to one and a half feet per hour. The movement was so rapid that it actually could be seen.

FIGURE III

Rates of advance of the toe of The Steele Glacier

Diagramatic presentation

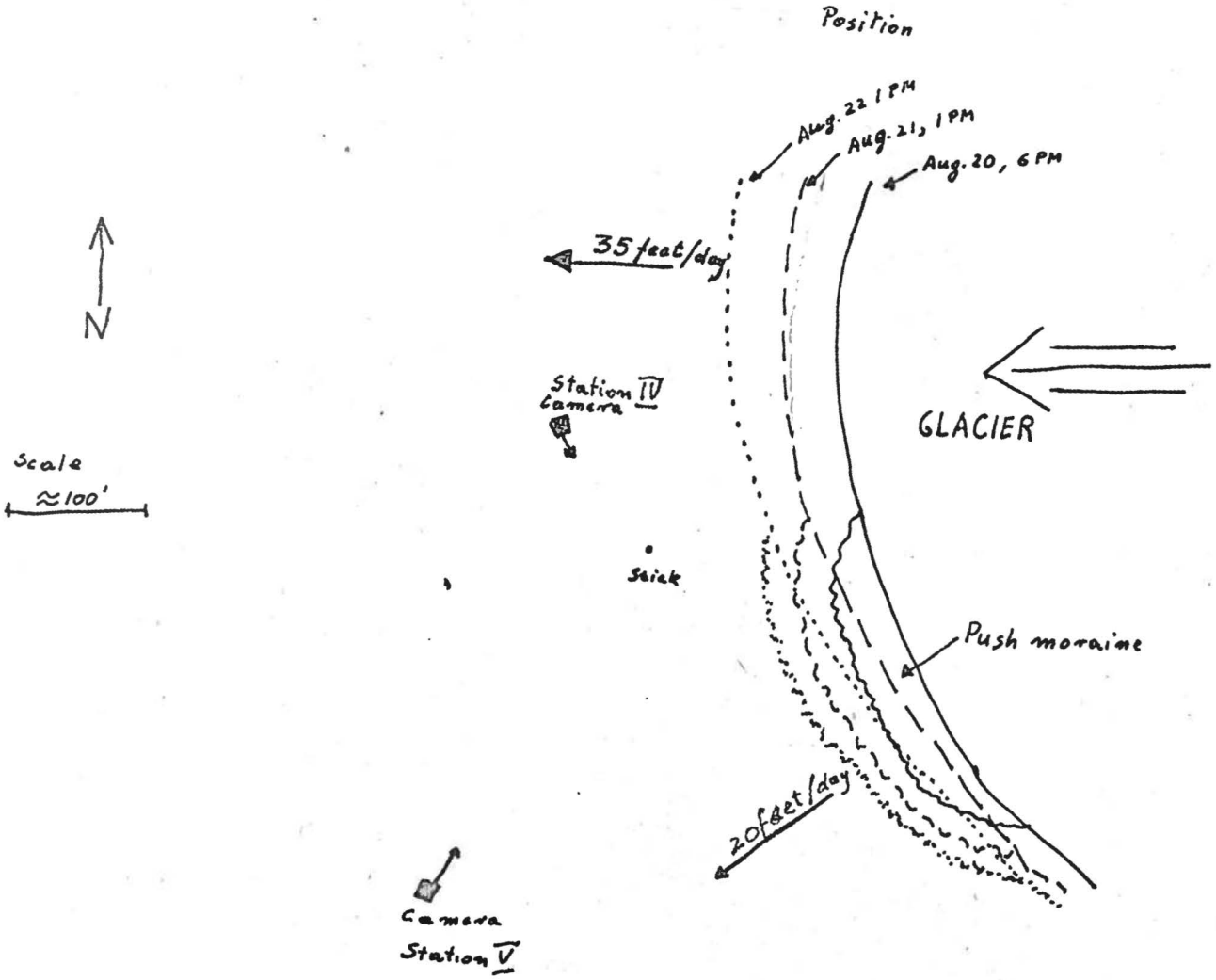


PLATE VII

Panoramic view of the toe of the glacier taken on two consecutive days, August 21, 2:00 pm and August 22, 2:00 pm. The large push moraine in center of photographs

It was noticed that the movement of the glacier was not uniform, but was variable over short time periods. The highest ice pinnacle shown on Plate VI would be moving rapidly and then practically stop over periods of 5 to 15 minutes. A similar finding was reported by Washburn and Goldthwait (1937) on the South Crillon Glacier, Alaska.

Panoramic views of the toe of the glacier were taken on two consecutive days, Aug. 21, 2:45 pm, and Aug. 22, 2:00 pm, Plate VII. For scale may serve the large push moraine in right center which is 30 feet in height.

The whole of the ice front advanced over 30 feet between the taking of the photographs, yet only very small changes in the appearance of the glacier can be seen. This confirms the above conclusion that maximum shear of the glacier is at its base.

Of interest on Plate VII is the left portion of the photographs. There a block of dead-ice is pushed by the glacier and the dead-ice reactivated. The right half of the photographs show the glacier advancing over ice free terraine.

Advance of the Toe of the Glacier

Rates of advance

The toe of the glacier was found to advance at different rates. Figure III shows in a diagramatic form the advance of the toe over a two day period - Aug. 20 to Aug. 22. As no detailed surveys of the front were made all the distances are only approximate.

The discrepancy between the rate of advance of the toe and the rate of flow of the glacier cannot be resolved on the basis of the data available.

The rate of flow of the glacier determined by triangulation was variable (Fig. I), the average being about 37 feet per day across the whole width of the glacier near the survey baseline or about 2 miles upstream from the toe. The rate of advance of the toe was from 20 to 35 feet per day as determined by the advance of the front.

Formation of push moraines

Small and large push moraines were present along most of the toe of the glacier where dead-ice was absent. Most of the push moraines were quite small in height - 1 to 3 feet, but at the very front one push moraine was about 30 feet high.

The large push moraine was examined 3 times - on August 20 at about 6 pm, on August 21 at about 1 pm and on August 22 at about 1 pm. On the first day of examination a line of sticks was set up on the moraine and in front of it to determine the rate of advance. On August 21 camera Stations (IV and V) were set up to record the advance of the glacier and the push moraine. On August 22 the push moraine was again photographed from the Stations and from other points to show the advance and its features (See also Plates 4, 7, 8, 9).

The large push moraine was 24 feet high on August 20, and 30 feet high on August 21st and 22nd. From August 20, 6 pm to August 21, 1 pm the push moraine advanced 22 feet at an average rate of 1.16 feet per hour or 28 feet per day.

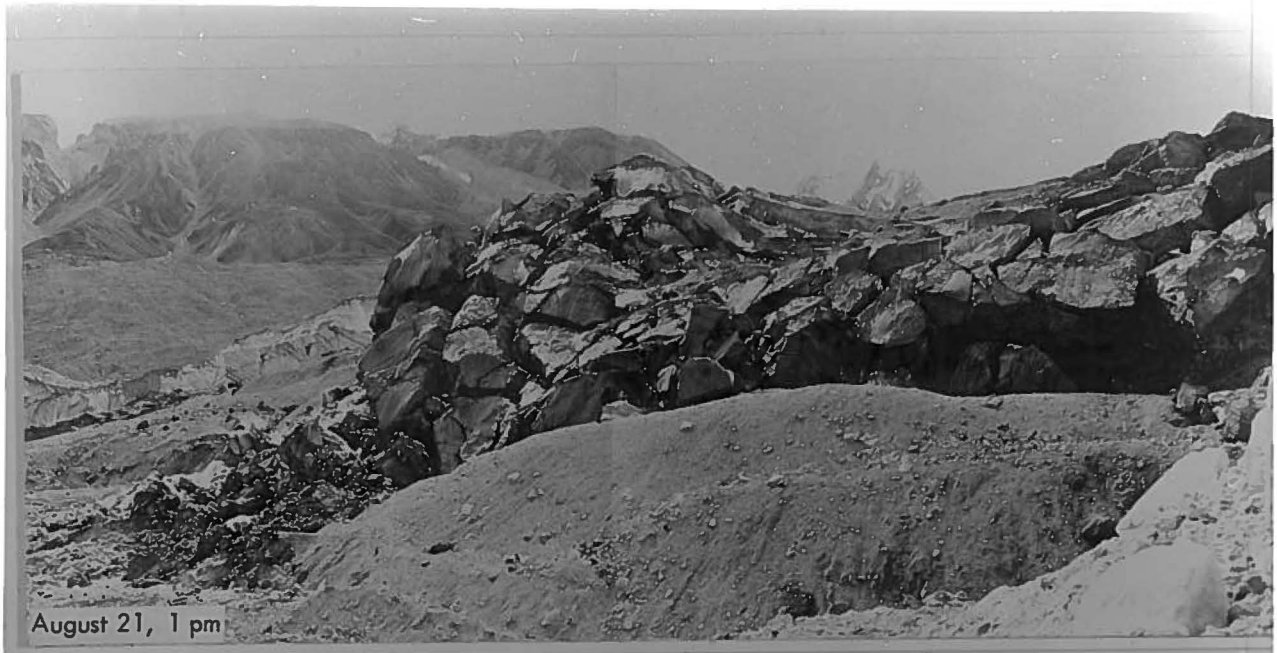


PLATE VIII

Close up panoramic views of large push moraine taken on August 20, 6:00 pm, and August 21, 1:00 pm.

PLATE IX

Close up views of large push moraine taken on August 21, 1:00 pm, and August 22, 1:00 pm.

From August 21, 1 pm to August 22, 1 pm the push moraine advanced 18 feet. But from August 20 to August 22 the push moraine changed its attitude. Originally the line of stakes to measure the advance of the push moraine was set up nearly perpendicularly to the front of the moraine and on August 22 the front changed by an angle of 35°. That is to say that on August 22 at 1 pm the front of the push moraine made an angle of 55° to the line of stakes. From this it is concluded that the portion of the push moraine nearer the center of the glacier advanced much farther.

On August 20 and on August 21 photographs were taken of the large push moraine from approximately the same position (Plate VIII). Detail examination of the photographs reveals a surprising fact that although the push moraine advanced 22 feet between the taking of the pictures the upper part of the moraine looks undisturbed. Specifically many of the small and large rocks making up the push moraine are in the same position. This gives the impression that the push moraine did not advance at all, but examination of the foreground shows the significant change in position. Most of the change has taken place in the lower part of the moraine.

The changes in the appearance of the push moraine were greater from August 21st to August 22nd. Plate IX shows 2 photographs taken from approximately the same position. Detailed examination of the positions of the rocks comprising the moraine shows that the lower part is distrubed and that the upper part of it has remained unchanged.

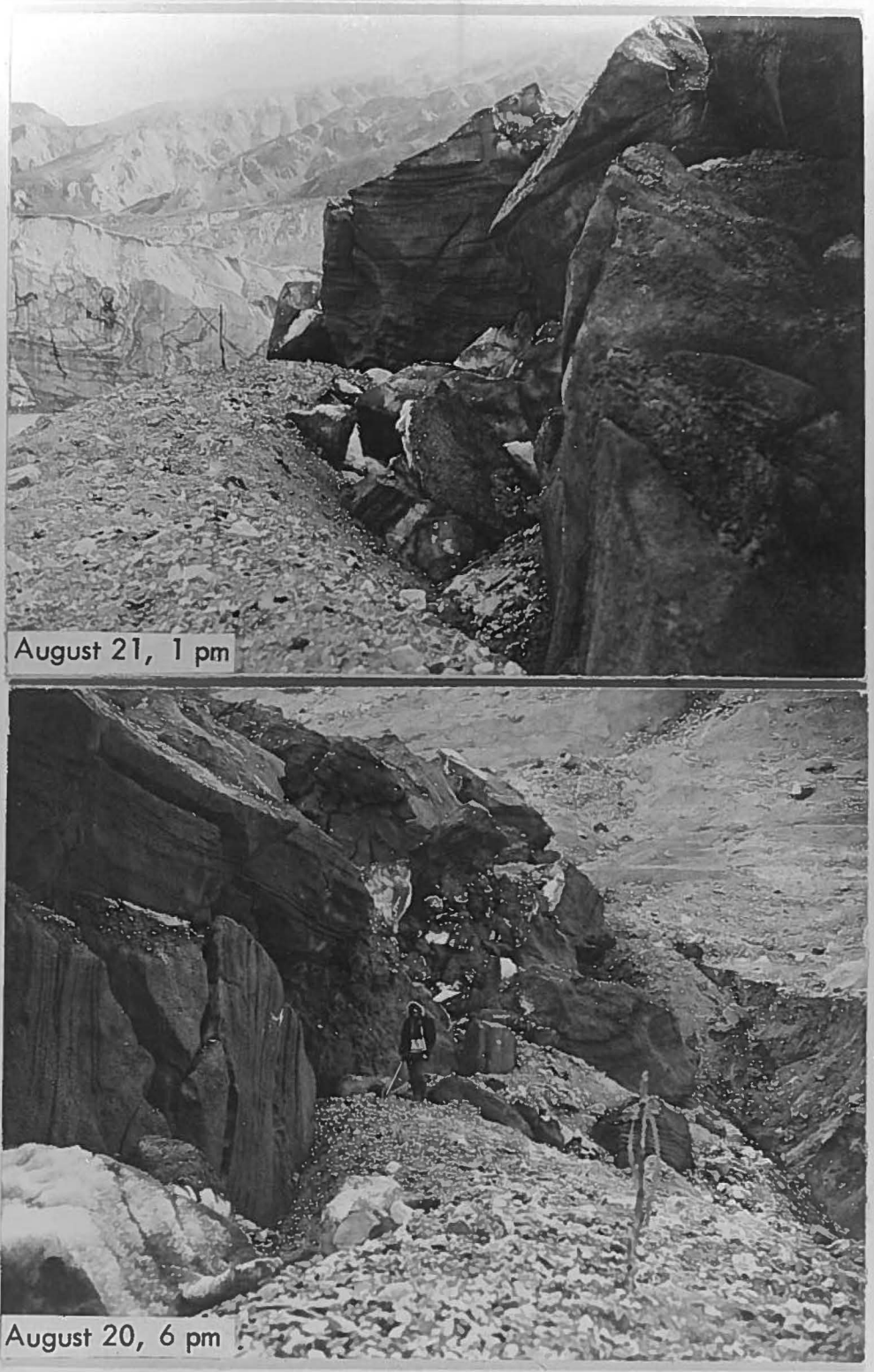


PLATE X

Photographs of the top of the large push moraine showing a stick which remained in undisturbed position with advance (August 20, 6:00 pm and August 21, 1:00 pm).

PLATE XI

Advancing push moraine abutting against an old moraine. Arrow points out boulder shown in photo 12.

PLATE XII

Push moraine (left) advancing against an old moraine (right) with a boulder (arrow) being pushed and overridden by boulders behind it. Photographs were taken about one hour apart.

The highest point of the moraine was marked with a stake placed vertically on August 20. On August 22 the stake remained in the ground nearly undisturbed. Plate X (photos 6-1 and 3-3) show the top of the push moraine and the stake on August 20 and 21 respectively, during which time the push moraine advanced 22 feet.

The advance of the push moraine was so rapid that by watching the base of it one could see the changes taking place. The most obvious, although not the most significant, was the slumping of dirt and pebbles near the base. Every minute or so small trickles or slumps came down from the moraine to the front. These small slumps did not involve more than 1/10 to 1/2 cubic feet and did not originate higher than 6 feet above the base of the push moraine.

On the other hand bodily pushing of the whole moraine was observed by the movement of large boulders at or near the base of the moraine.

On August 20 the left portion of the push moraine was abutting against a very small old moraine with a near vertical face (Plate XI). A large boulder projecting from the base of the moraine was touching the vertical face of the old moraine. Strange dull thumping sounds were coming from the boulder and standing on it the boulder was felt quivering and moving. After one hour of observation it was noted that this boulder was being pushed straight into the old moraine face. Two photographs (Plate XII) were taken one hour apart and show that beside the boulder being pushed in a few inches into the face of the old moraine it was also being overridden by large boulders from behind. The two photographs also show changes produced by the above mentioned slumping.

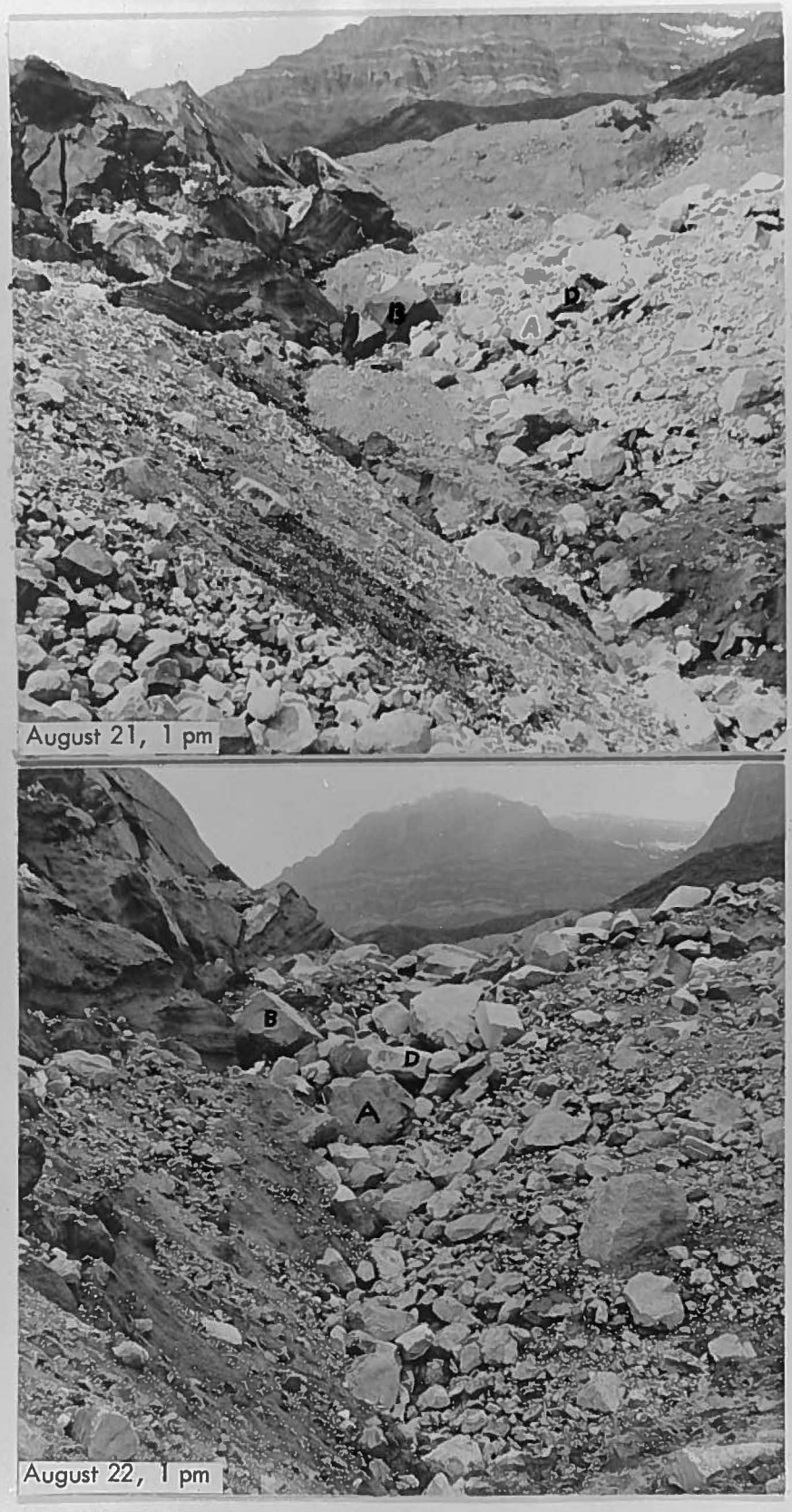


PLATE XIII

Push moraine advancing with boulders in front being rotated.

The large push moraine advanced over the vertical face of the old moraine and beyond it from August 20 to August 22. On August 21 the push moraine was barely over the face and on August 22 it advanced some 20 feet further. Photographs were taken of this portion of the push moraine on all of the days but were not taken from the same locations. Plate XIII shows the left hand portion of the push moraine on August 21 and August 22. During this time the advance of the moraine was about 20 feet as determined on the photographs using the human figure for scale (6 feet).

Of significance in the photographs (Plate XIII) is the relative position of boulders. Boulder A has been pushed forewards about 2 feet and has been rotated about 30°. Boulder B has been pushed foreward about 5 feet and has been rotated considerably. Boulder D has been rotated about 30°.

From the above it is evident that the major thrust plane of the large push moraine is positioned at its base or very close to it. The rotation and pushing of large boulders in front of the moraine and the retention of relative positions of the boulders on the moraine and the very small change in the appearance of the surface of the moraine from day to day signify for the postulate.

The small slumping at the lower portion of the push moraine evidently are not significant in the over-all mechanism of the formation of the large push moraine.

Small push moraines

Small push moraines made of gravel were present all along the front of the glacier examined. They ranged in ehight from one to three feet. The lifetime

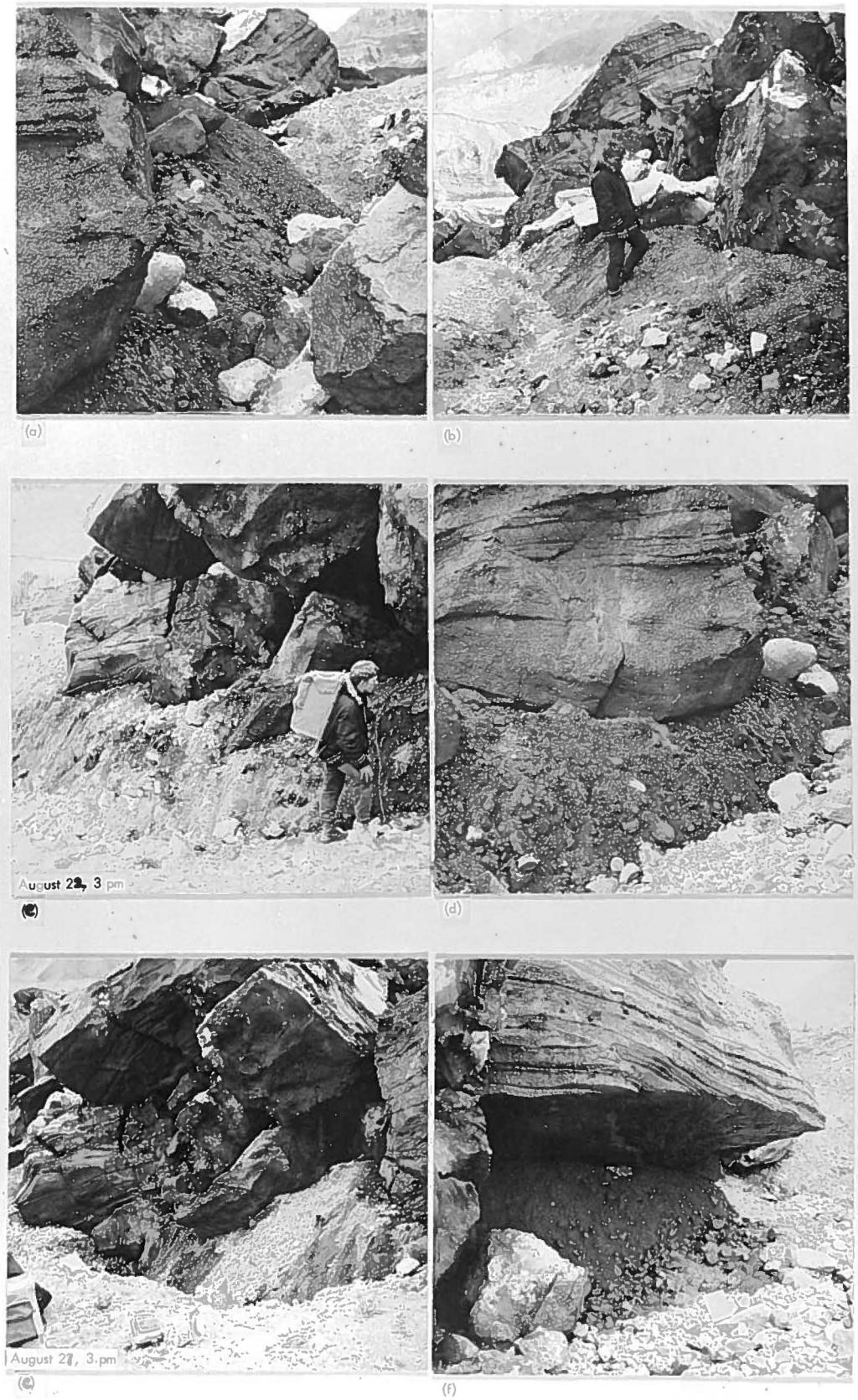


PLATE XIV

Views of small push moraines at the left edge of the glacier near the toe: (a) and (b) small push moraines; (c) small push moraine, August 21, 3:00 pm; (e) same as (c), August 22, 3:00 pm; (d) and (f) small push moraines being overridden.

PLATE XV

Back slopes of the large push moraine in front of the glacier.

of the individual push moraine was short. The ice front was overriding the moraines rapidly. The overriding took place by two methods. In one case large ice blocks fell or rolled from the glacier onto the moraine and thus covered it. On further pushing the fallen ice blocks were incorporated into the glacier together with the small push moraines. In the second process the small push moraines were bodily overriden by ice behind it as the glacier was advancing up slope at this location.

The material of the small push moraines was also incorporated directly into the glacier by being squeezed into crevasses and cracks in the glacier toe or into spaces between individual ice blocks.

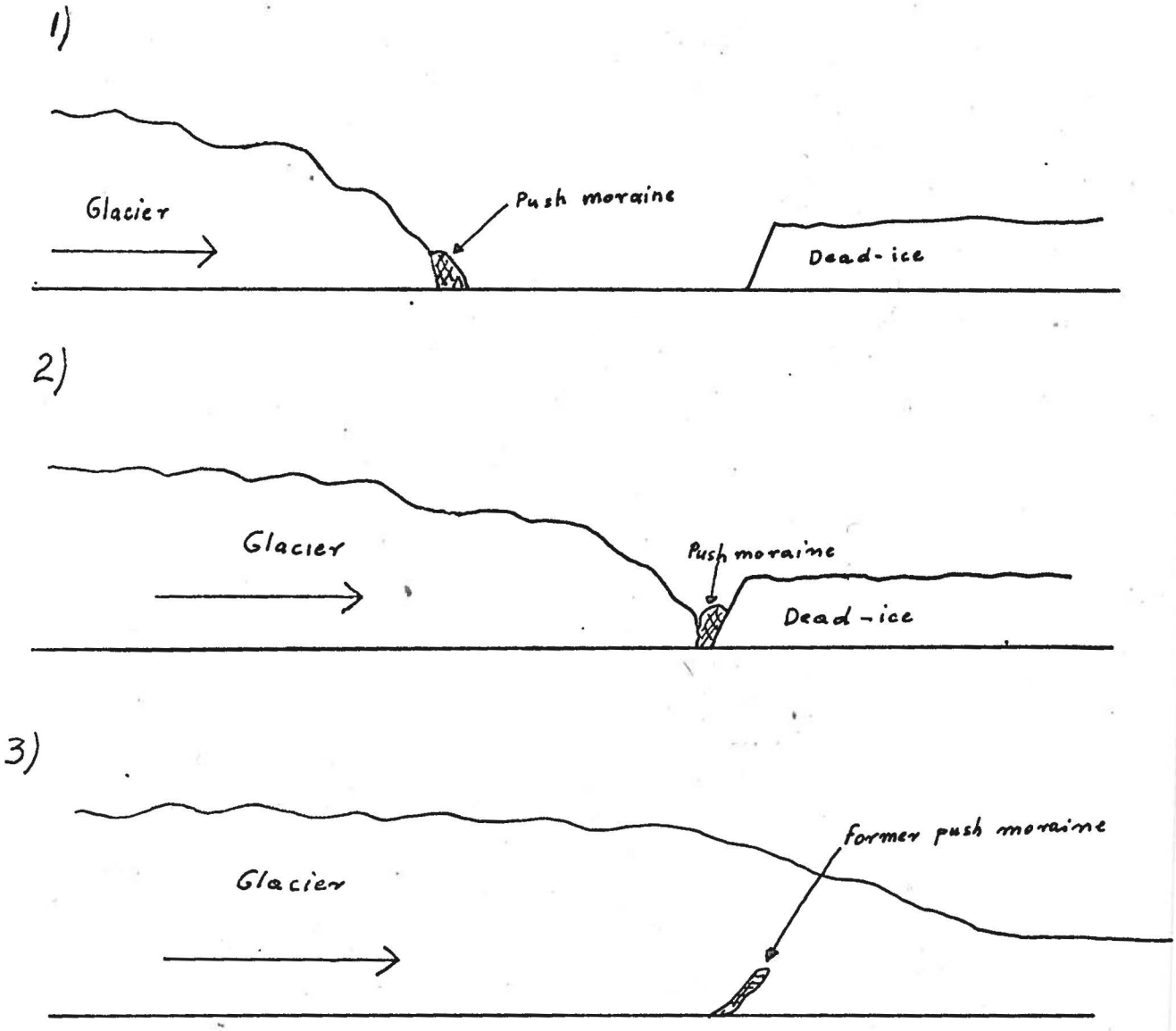
Plate XIV shows push moraines being formed, overriden and incorporated into the glacier.

The importance of the push moraines is in the fact that as they were being incorporated into the moving glacier directly, they thus were part of the mechanism of incorporation of debris into the basal portions of the glacier.

The incorporation of debris into the glacier from the large push moraine was very much the same as the second process dexcribed. The glacier behind the large push moraine contained very numerous open crevasses. The dirt or gravel from the large push moraine trickled, or was squeezed directly into these crevasses from the stoss side of the push moraine. Plate XV shows the back side of the large push moraine sloping into crevasses of the glacier (See also Plate X).

The final results of these two processes was that the glacier ice

FIGURE IV


1)
Glacier
Push moraine
Dead-ice
2)
Glacier
Push moraine
Dead-ice
3)
Glacier
Former push moraine

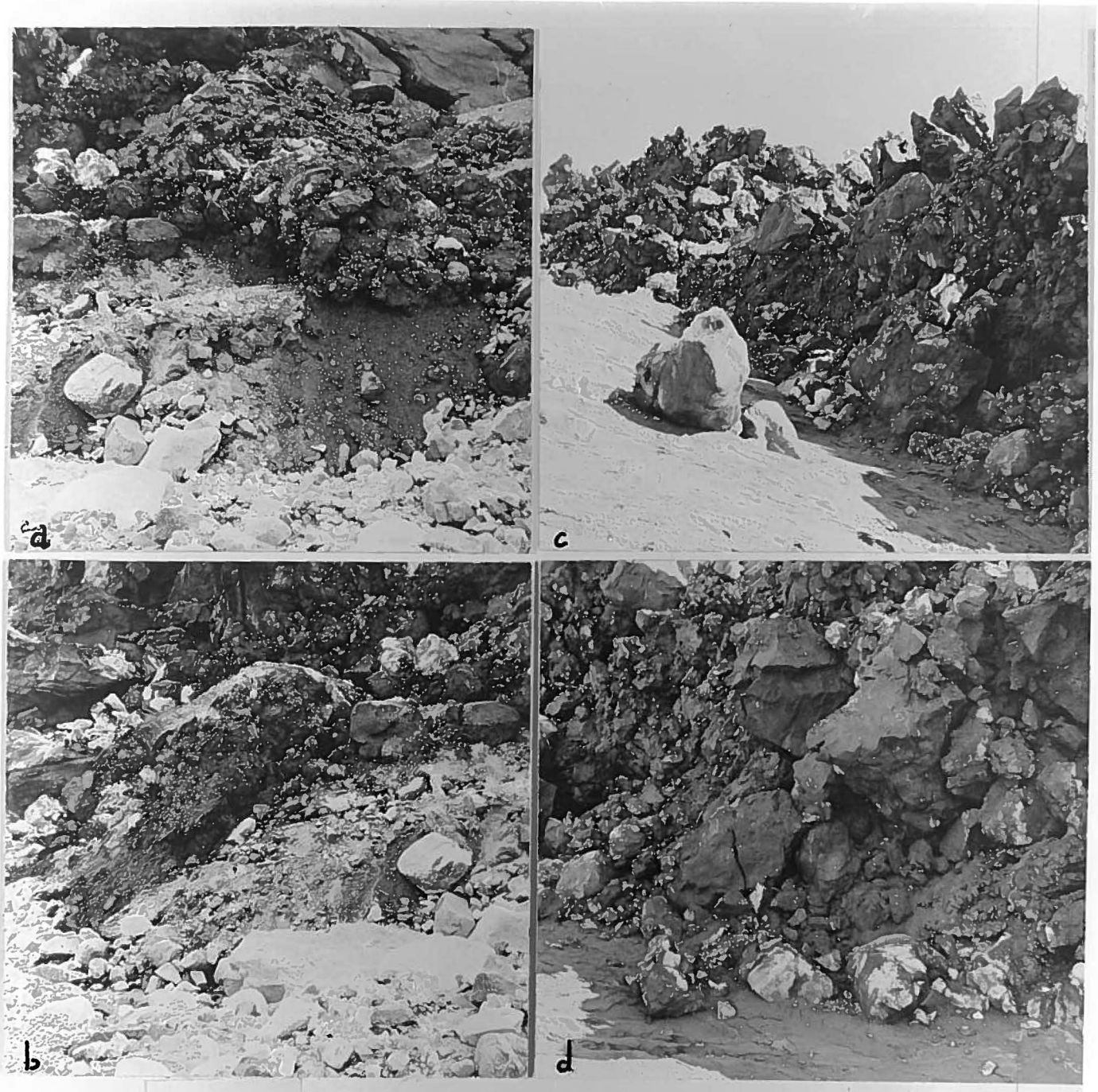


PLATE XVI

Glacier ice intermixed with debris, (a) and (b) at the toe of the glacier, (c) and (d) at the left edge near the toe.

PLATE XVII Panoramic view of the terminus of the glacier.

became intermixed with debris at its front base. Plate XVI shows lower portions of the edge near the front of the glacier composed of blocks of ice intermixed with debris.

An additional process of incorporation of debris into the basal portions of the glacier was not observed directly, but is postulated on the basis of the above observations. Suppose the large push moraine would finally come in contact with a body of dead ice. The push moraine would then be squeezed and drawn out between the active ice and the dead ice. On further advancing the dead ice would be reactivated and the material of the push moraine would become englacial debris. The process envisioned is shown in stages in Figure IV.

Incorporation of dead ice

As the active front of the glacier came into contact with the dead-ice in front of it, the dead-ice became reactivated and formed part of the active flow. The dead-ice was very thin - 60 to 100 feet thick - and was covered with ablation moraine about one foot in thickness. The active part of the glacier was much thicker.

The time spent at the glacier did not allow a detailed examination of the process by which the dead ice was incorporated into the active glacier, nevertheless some observations may elucidate the problem.

Firstly, the ablation moraine covering the surface of the dead-ice also covered the surface of the active glacier. Plate XVII shows the front of the glacier with ablation moraine cover.

The exact mechanism of transformation of dead-ice into active-ice is not known in detail, but the following generalizations can be put foreward. Firstly, the

ablation moraine covering the dead-ice also covering the active glacier. Secondly, the thickness of the dead-ice is much less than that of the active glacier: 60 to 100 feet for dead-ice and about 500 feet for the active glacier. Consequently "squeezing" of the dead-ice is taking place before it becomes part of the active glacier. This means that the dead-ice is not overridden by the active glacier but is retained at the front and after "squeezing" becomes part of the active glacier. Thirdly, near the toe of the glacier some shear zones are present which dip up stream (Plate XVII). Consequently during squeezing some of the ablation moraine from the dead-ice is incorporated englacially into the active glacier.

From this it may be said that dead-ice with its ablation moraine is retained in the frontal portions of the glacier and is not overridden.

Because of the "squeezing" of the dead-ice, all of the debris contained by it, either as englacial or ablation moraine, becomes concentrated near the front of the advancing glacier.

Conclusions

The short time of study was not sufficient to obtain quantitative results of the phenomena studied. On the other hand qualitative results obtained show that the Steele glacier is suited for studies in detail of some glacier processes which are too slow to be observed otherwise.

The main points observed on the Steel glacier may be summarized as follows:

a) At the toe most of the movement of the glacier was along the base.

b) The distribution of flow rates across the glacier was not symmetrical.

c) The rate of flow varied from 20 to 46 feet per day depending on location.

d) Dead-ice from a previous glacial advance was incorporated into the active glacier by squeezing rather than overriding.

e) Ablation moraine derived from the dead-ice covered the surface of the active glacier near the terminus.

f) The large push moraine was advancing mainly on a slip at its base.

g) Small push moraines were rapidly incorporated into the base of the active glacier, thus enriching the front of the glacier with debris.

References Cited:

Washburn, B. and Goldthwait, R. (1937): Movement of South Crillon Glacier, Alaska; Geol. Soc. Am., Bull. vol. 48, pp. 1653-1664.