A STRUCTURAL AND MORPHOGENETIC INVESTIGATION OF THE VAUGHAN LEWIS GLACIER AND ADJACENT SECTORS OF THE JUNEAU ICEFIELD, ALASKA, 1961-1964

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ABSTRACT

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by Theodore F. Freers

This three-year study of the Vaughan Lewis Glacier in the Boundary Range north of Juneau, Alaska, involved investigations of the structure and deformation of a series of unique strain features, including surface wave-bands and associated two-dimensional ogives or arch bands (Forbes' bands). Three morphologic units in the glacier are described: (1) an accumulation névé zone at 5400 to 6000 feet, with an area of 5.5 square miles; (2) an icefall zone, a mile long with a descent of 1600 feet; and (3) a negative wastage zone extending from the mean névé-line (4200 feet) a distance of 6 miles to the terminus. Wave-ogives are first exposed on the icefall's apron and are increasingly revealed downglacier as successive hyperbolic ogive arcs, with crests up to 800 feet apart. In plan, they are convex downglacier. In cross-section, the waves have a maximum apparent amplitude of 80 feet. Measurements have been made on an array of movement stakes placed in the accumulation and ablation zones. Comparative firn structure studies and surface movement records have also been obtained on both the Vaughan Lewis and adjoining Taku Glacier. A regime comparison is also

developed by area-elevation analyses, showing the Taku with a 6 to 1 ratio of névé to wastage area, opposed to a 2 to 1 ratio on the Vaughan Lewis Glacier.

With respect to the Vaughan Lewis bands, alternating zones of clean and debris-entrained ice accentuate the pattern although, in fact, the bands consist of myriads of tectonic folia, apparently slice or flow-crystallization structures. White-ice layers or aerated "veins" occur as inlays in the folia. They appear on the surface as fine-grained, non-foliated stripes of white-ice, 1 to 2 feet wide and several hundred feet long. They are intermittent and usually dip steeply upglacier, or inward towards the center from the sides. In the icefall zone, folds of ice are found separated in places by white-ice layers similar to, but wider than, those of the wave-bands. Planimetric and ice-core studies, as well as cross-sectional plotting of these structures, provide clues to the genesis of the wave-bands and ogives. The white-ice layers between folds in the icefall, and the white-ice layers within the wave-bands, are indicated to have originated as winter snow compressed between the folds. At the base of the icefall, where the surface gradient falls off sharply, the complex of folds is raised above the glacier surface by increased compression. The structures are seemingly abetted by summer ablation on the downglacier side, thus furthering the wave appearance. As the deformed ice moves downvalley, differential ablation at the surface continues to reveal the white-ice structures as embossed features extending across-glacier in the remarkable arcuate patterns described.

The combined character of the waves and ogives, which in this study specifically defines the wave-ogive, is considered to be the result of rhythmic discontinuous englacial movements and stresses, probably reflecting annual climatic perturbations in the névé zone. On this basis the total of 73 wave-bands and ogives measured in the negative wastage zone suggests that ice presently exposed at the terminus is less than a century old. The empirical and structural observations and streaming flow profiles described corroborate that the lower glacier area is in a state of down-wastage and slow regression in spite of the vigorous regime of the upland névé and the dynamic stresses revealed by wave-band development below the icefall. The explanation reverts to the area-elevation statistics, which illustrate the proportionately small nourishment zone involved.

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Theodore F. Freers

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PREVIEW OF THE RESEARCH PLAN

The Vaughan Lewis Glacier[1] is nourished by the crestal névé of the Juneau Icefield in the Alaska-Canada Boundary Range (Fig. 1). This glacier displays one of the most striking series of ogives or Forbes' bands of any glacier in the world. The spectacular nature of these bands (Figs. 2 and 3) has invited the attention of early researchers on the Juneau Icefield both on the ground and during many aerial reconnaissance and survey flights over the region (Miller, 1952a). Such has also stimulated the present investigation carried out intermittently between 1961 and 1964 (Freers, 1965a).

The Vaughan Lewis Glacier with its pronounced pattern of crevasses, surface undulation, and internal structures presents an array of complex problems in structural glaciology and glacier mechanics. From the accumulation zone to the terminus, this glacier involves many areas of stress--the most prominent of which is the icefall. Among other unusual characteristics is the termination of a large part of the glacier in interior drainage basins (ice-dammed lakes) while the rest flows on toward Berners Bay and the ocean (Fig. 3).

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[1]Named for William Vaughan Lewis (1907-1961) eminent British glaciologist from Cambridge University, who was tragically killed in an automobile accident while enroute to Alaska as one of the first visiting professors of the Glaciological Institute and the Juneau Icefield Research Program during the summer of 1961 (Journal of Glaciology, 1963).

The unique glaciological problems on this glacier are too complex to be resolved by the reconnaissance-type investigation herein involved, but it is hoped that this investigation will at least provide some fundamental information essential to future glaciological studies of the Vaughan Lewis Glacier or any other glacier having similar structural characteristics.

The Vaughan Lewis Glacier problems were brought to the author's attention in 1961 by Dr. Maynard M. Miller, Director of the Juneau Icefield Research Program (JIRP) and also of the Glaciological Institute at Michigan State University. He suggested that a brief survey of the glaciomorphology, structure, and surface movement be made during the 1961 field season with additional data gathered during a subsequent summer season. A number of descriptive notes were made on this glacier's characteristics in August and September 1961 in addition to initiating a program of surface movement records. In 1963, the glacier was again studied with the emphasis on obtaining more quantitative data. With the help of other participants in the Juneau Icefield Research Program in 1964, further information has become available for incorporation in this study (Havas, 1965; Kittredge, 1965).

The surface movement measurements have yielded data that can be compared with other wave-band glaciers elsewhere in the world and which, when fully analyzed, will reveal the nature of stresses present at the surface of such glaciers.

A significant factor in the study is the wealth of glaciological data gathered for the past 20 years on the upper Taku Glacier, the north branch of which adjoins the Vaughan Lewis névé (Fig. 4). These data should eventually be invaluable as control for comparative analysis of the mass transfer of the Vaughan Lewis and Taku Glaciers. Also invaluable are the JIRP field station meteorological records from Camps 8 and 10, which are representative of the high and low névé zones of the Juneau Icefield. Previous morphological investigations of glaciers on the Juneau Icefield and elsewhere in the Boundary Range provide further information which can be closely allied to the Vaughan Lewis Glacier study. In addition glaciological studies in other cordilleran regions of the world provide a basis for some comparison outside of the Alaskan region (e.g., Vareschi, 1942; King and Lewis, 1961; and Miller and Prather, 1965).

Studies of the Vaughan Lewis and Taku Glaciers centered around two main camps on the Juneau Icefield. One of these was Camp 10 (Fig. 1), a permanent research station comprising a half-dozen aluminum covered buildings situated on a granitic nunatak about 400 feet (120 m) above the 3500-foot (1075 m) névé of the Taku Glacier. This was the main base of operations, particularly for the lower névé studies. The upper névé headquarters was Camp 8, lying three miles (5 km) from the eastern edge of the Vaughan Lewis névé (Figs. 1 and 4). Camp 8 has several large permanent buildings and served as the main base of operations for the upper névé studies of the Taku and

Vaughan Lewis Glaciers. Temporary field camps were also occupied on the upper Taku névé, 6000 feet (1825 m) for Camps 8A and 8B, and at the top of the Vaughan Lewis icefall, 5600 feet (1700 m) for Camp 18. During fair weather personnel worked from these various field camps making glaciological, geological, botanical and meteorological observations and measurements. Even summer storms are not uncommon in the high Boundary Range, so fortunately during the more severe storms with winds up to 100 miles (160 km) per hour, the field parties were able to take refuge in the permanent station facilities.

In the course of these studies, travel on the glacier was done on skis and by oversnow vehicles. Of course, in areas below the névé-line, all travel was on foot with mountaineering safety precautions constantly invoked. The combination of oversnow vehicles, permanent campsites, and long summer daylight often permitted up to 12 full hours of field work each day.

Initially the investigation plan regarding the Vaughan Lewis Glacier involved surface movement measurements by theodolite in and below the icefall, and the obtaining of structural orientation data on in-ice structures of the apron of the icefall with special attention to the wave-bands and ogives. The essential reconnaissance observations and measurements were accomplished in 1961. During the subsequent field seasons additional data were gathered on the stratigraphy of the upper Vaughan Lewis firn-pack and adjoining upper Taku névé, as well as on the inlaid structures of the lower part of the glacier and in its terminal zones. Some of these data are incorporated as a matter of record as well as for purposes of this present study. The raw data and notes have now been analyzed and a literature survey completed. These analyses comprise the main element of this presentation. The hope is reiterated that the conclusions drawn from the analyses may be of value in the continuing phases of these icefield investigations.

I. INVESTIGATIONS ON THE VAUGHAN LEWIS GLACIER

Physical Setting

The Vaughan Lewis Glacier as part of the Juneau Icefield is located in the Northern Boundary Range of the Alaska-Canada Coast Mountains. Its Latitude is about 58°48' N., Longitude 134°12'W (Fig. 1). Its drainage is westward from the summit névé of this icefield, and its nourishment as well as wastage areas lie entirely in southeastern Alaska. The glacier's cirque névé is on the south flank of Mt. Ogilvie, 7780 feet (2375 m), a boundary peak on the British Columbia-Alaska border (Fig. 4).[1] Regionally the Coast Mountains, in this sector referred to as the Boundary Range (Bostock, 1948), comprise a northwest-trending cordillera with a central core of a granitic intrusive--the Coast Range Batholith. On both flanks of the Boundary Range, the surface geology grades outward from this crystalline core into metamorphic and then sedimentary rocks (Buddington and Chapin, 1929).

The Juneau Icefield is a large area of coalesced valley and mountain glaciers embracing upwards of 1200 square miles (3000 sq km). Two main glacial trunks flow from the crestal

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[1]Note recently published U. S. Geological Survey Juneau (D-1) Quadrangle 1960 showing this glacier also bounded on the north by the Storm Peaks (Gale, Typhoon, and Blizzard) and on the east by the Matthes Glacier (equivalent to what has been referred to by JIRP for many years as the North Branch, Taku Glacier). In this study, for consistency with other published reports, the older terminology is applied.

névé at 6200-6500 feet (1900-1975 m); these are the Taku Glacier, draining south to Taku Fiord in Alaska, and the Llewelyn Glacier which drains northward to terminate at 2500 feet (750 m) near Lake Atlin in northern British Columbia (Fig. 1). On the Taku Glacier, studies have been conducted by the Juneau Icefield Research Program since 1946 in three primary zones. A lower 4000-foot (1225 m) zone, a broad intermediate 5000-foot (1525 m) bench zone, and an upper 6000-foot (1825 m) crestal plateau. Part of this upper névé plateau nourishes the Vaughan Lewis Glacier, as noted in figure 1.

The 1961-64 Investigations of the Vaughan Lewis Glacier

1. Area and Hypsometric Relationships

The Vaughan Lewis Glacier (Fig. 4) is an "alpine" glacier as defined by Ahlmann(1948). Actually, the glacier's shape, when plotted on an area-elevation graph (Fig. 5), is that of a valley glacier of the alpine type. The combined surface ice and firn of the Vaughan Lewis Glacier cover an area of about 9 square miles (25 sq km)(Appendix A). The prime area of positive or net accumulation above the 1961-65 mean seasonal névé-line at 4200 feet (1275 m) has an area of approximately 6.10 square miles (15.20 sq km) (Fig. 6). The prime ablation zone, from an altitude of 4200 feet (1275 m) to the terminal area, covers an area of about 2.94 square miles (7.37 sq km). This zone is well illustrated in figure 4. From the figure 6 plot it is also seen that by far the greatest area, 5.65 square miles (14.18 sq km), lies between the 5400-foot (1650 m) and 6000-foot (1825 m) contours, with the least in the icefall sector or spillway zone where an area of less than 0.08 square miles (0.20 sq km) lies between 3800 feet (1150 m) and 5400 feet (1650 m). Regime-wise this spillway may therefore be considered of negligible import.

2. Glaciomorphic Sectors

The morphology of this glacier encompasses three major divisions: the high-level cirque basin, the intermediate level icefall section, and the main lower level valley glacier segment. The total, in fact, represents the Vaughan Lewis-Gilkey Glacier complex (see again Figs. 2 and 3). Detailed description of each of these general morphologic units is facilitated by further breakdown into six glaciomorphic and regime sectors as shown in figure 7. One of these, Sector A-A', is common to the Vaughan Lewis and the upper Taku Glaciers. The other four (B, C, D, and E) lie only on the Vaughan Lewis Glacier. Area A-A' is a 5800 to 6000-foot (1775-1825 m) névé zone on the Vaughan Lewis-Taku Glacier divide (see map in Fig. 7). In this zone the only pertinent research with respect to this present study involved measurements on firn stratigraphy, density, glaciothermal conditions, and ablation. Movement records were also obtained on an across-glacier transect bearing approximately due west from Camp 8, as discussed later.

In figure 7, Sector A represents the prime accumulation zone lying above the top of the icefall; i.e., above 5500 feet (1675 m). In this zone the first indications of strain from tensile stresses in the icefall are seen as arcuate crevasses, exposed in some years at elevations down to about 5500 feet (1675 m). Sector B represents the highly crevassed and seracced and relatively narrow area of the icefall ranging from 5500 feet (1675 m) down to 4000 feet (1225 m). Sector C is the apron-like zone of wave-bands extending fan-wise out from the foot of the icefall. This apron is longitudinally about 1.5 miles (2.5 km) in length lying between the elevations of 4000 feet (1225 m) and 3600 feet (1100 m). Sector D is the narrow zone of ogives (Forbes' bands) which extends into the terminal sector of the glacier. Arbitrarily this zone ends when the ice has become so ablated and crevassed that the bands are no longer recognizable; i.e., below an elevation of approximately 2100 feet (640 m). Sector E is defined as the area of the terminus lying between the elevations of 2100 - 1600 feet (640 - 490 m).

a. The Crestal Névé or Prime Accumulation Zone

While part of this sector (Fig. 8) actually lies between 5600 - 5900 feet (1700 - 1800 m) on the crestal névé of the Taku Glacier, it may be assumed that the general climatic conditions are comparable to those affecting the Vaughan Lewis névé at 5600 - 5900 feet (1700 - 1800 m).[1] For the present study, investigations in this sector were made on

[1] Some evidence, however, has been reported, based on recent weather observations at Camps 18 and 8 that the upper Taku segment is in fact slightly more continental in geophysical character than the Vaughan Lewis névé in that it is higher and somewhat farther inland.

the firn stratigraphy, on glaciothermal conditions in the uppermost firn-pack, and on ablation and accumulation. These observations are applicable to both of these adjoining glaciers.

(1) Firn Stratigraphy

Investigation of the firn stratigraphy was made using various techniques to obtain stratigraphic profiles. The most accurate but laborious method is to dig a test pit into the firn, but it usually gives only limited results because of the great time and energy involved in reaching significant depths. Crevasse wall studies are the next most reliable method and one which permits depths of 60 to 100 feet (18 to 30 m) to be obtained. The 3-inch (7.6 cm) diameter hand core auger (old S.I.P.R.E. model), hereafter referred to as hand auger, is almost as reliable a method. This hand auger allows penetration of the firn to nearly as great depths, but again at a considerable expenditure of time and energy. In this study a depth of only 58 feet (17.6 m) was reached using this technique. The fourth method is the Rammsonde or sounding probe technique which allows firmness characteristics of the firn to be determined to shallow depths; the maximum being about 15 feet (4.5 m). The fifth and last method is the use of an electrothermal borer. This is the least reliable, but permits information at the greatest depths. As such, it can furnish supplemental information which in conjunction with that from the four other methods is valuable. If possible, a combination of all of these methods is desirable in such glaciological interpretations. The main accomplishments of these measurements were determination of density profiles and the amount of retained net accumulation (Figs. 7-12).

Test pits.--During the 1961 field season a test pit (8B, Fig. 8) was dug at Camp 8B to a depth of 20 feet (6 m). The 1960 ablation surface was found at a depth of 18.5 feet (5.6 m) (Fig. 9). At the time of this measurement (9 September 1961) there was nearly two feet (0.6 m) of snowcover on the 1961 ablation surface. Thus the firn thickness representing net retained accumulation for the 1960-61 budget year was 17.5 feet (5.3 m). Density in this 17.5-foot (5.3 m) increment ranges from 0.52 to 0.59 giving a mean or bulk density of 0.55. Density determinations (Appendix B, Part 2) were made in the pit wall using a 250-500 cc hand corer (Fig. 10).

Figure 9 represents the south and west walls of the test pit (8B-61). It is noted that the date of this field sketch was 9 September 1961. This was a week past the end of the 1961 effective ablation season at this elevation. Many diagenetic structures are shown in the 1960-61 firn increment. Among these were ice strata, columns and lenses and other irregular glands of diagenetic ice (Miller, 1955a).

A similar test pit (8B-63) was dug in 1963 at Camp 8B. Again, density determinations were obtained by using a 250-500 cc hand corer in the pit walls. The density profile for this pit (Fig. 11) reflects a significant depth-hoar stratum at about 14 feet (4 m) (see Appendix C, Part 2).

Crevasse walls.--In 1961 the stratigraphy of a crevasse located at Site 8D (Fig. 8) about one-half mile south of Site 8A was measured as a check against the results obtained by the other methods. The results are compared in the measured stratigraphy for Sites 8D and 8A in figures 12 and 13. This crevasse reached a maximum apparent depth of 95 feet (29 m). The 1960-61 net retained accumulation measured in this crevasse is approximately the same as that given in test pit 8B, in spite of the fact the 8D site was at a 200-foot (60 m) lower elevation. The retained accumulation segments for earlier years were also measured in this and adjoining crevasses with the results extending the record back with confidence to 1951 (Fig. 12, Site 8D at 5700-foot [1750 m] elevation.)

Hand auger.--A hand auger was used within 25 feet (7.5 m) of the 1961 Camp 8B test pit and also as close to the electrothermal bore site. Core samples were taken at selected intervals for density determination. Because of compressive and torsional stresses exerted on the core samples by drilling, the accuracy of the deep bore-hole densities is considered to be less than the smaller hand corer densities obtained in test pits. Density determinations in the test pit and upper crevasse wall segments were made from two or more samples at the same level. Each density determination (Appendix B, Part 1) was made from single core samples representing one foot (0.3 m) or less in vertical length. As these were obtained by vertical drilling instead of the horizontal samples taken in the test pits and crevasse wall measurements, this accounts for some of the variation between the readings obtained by these different methods.

The 1962 summer density measurements were made using the hand auger to obtain cores of firn to a depth of about 30 feet (9 m). The two bore-hole sites were again at 8A and 8B (Fig. 8). Figure 14 shows the density profiles at these two sites and reveals the close correlation possible on a flattish névé surface over a distance of as much as a mile (1.6 km). The 1961 ablation surface is interpreted on the basis of the reduced density (depth-hoar effect) at about 17 feet (5 m) (Egan, 1965; also Appendix D).

Rammsonde.--Rammsonde penetrations were made in Sector A in 1963. The rammsonde is an instrument which measures resistance of snow or firn to penetration when a known weight is dropped a known distance forcing the penetrometer (ram) into the firn. The resulting data were plotted as a ram profile for comparison with the previously noted density curve in figure 11. The rough correspondence of these curves is considered corroborative.

Electrothermal borer.--The electrothermal borer (Fig. 15) was used to penetrate to 151 feet (46 m). This particular borer, a type not previously used on the Juneau Icefield, was modified from a pattern employed on the glaciers of Mt. Rainier (Miller, 1959).

The drill unit was operated from a 2.5 KW, 120 volt, Onan generator. The drill was started in a 22-foot (6.7 m) hand auger hole. It was suspended by a 7/16 inch (1.1 cm) manila rope, marked at 5-foot (1.5 m) intervals. Electricity was conducted to the drill bit by General Electric insulated cord (NP-1300) of 0.58 inch (1.5 cm) O. D., consisting of double copper leads, embedded in composition and sheathed with black rubber. The electrical leads were connected to the drill through a watertight coupling.

Low power (1.5 KW) used in the borer allowed slow penetration. This slow rate of penetration with readings taken every one-half hour allowed an interpretation of subsurface ice structures and density differences.

Thermal boring began at 1815 hours on 29 August 1961 and reached the total depth of 151 feet 2 inches (46.2 m) on 4 September 1961. The elapsed time was 137 hours. A total of 6 hours during this period the borer was shut down for maintenance and other reasons. The shut down times are recorded in Appendix E.

A large knot in the suspension line 20 feet (6 m) above the borer at times would freeze to the drill-hole wall. The times of the knot freezing are indicated in figure 16 by the letters K. F. The freeze-ins occurred at depths of 29 feet (8.8 m), 131 feet (39.9 m) and 120 feet (36.6 m). Freeing of the frozen knot was accomplished at the 29-foot (8.8 m) depth by using short, quick jerks on the suspension ropes. This method did not work for the other deeper freeze-ins. To loosen these, anti-freeze was poured into the bore hole. The problem might have been prevented by tying a less bulky knot; however, the freezing-in was turned to an advantage as it proved that subfreezing conditions existed in the firn-pack at these depths. These observations are substantiated in a later section when the actual measurement of englacial temperatures is discussed.

Figure 16 is a graphical representation of the bore-rates at various depths. Also shown is a curve of total depth times total boring time. In other words curve A represents the bore-rates at specific depths and indicates the variability of boring in the firn-pack as a result of density and temperature differences. Curve B represents the time it took to bore to any given depth. This latter curve also reveals the overall increase of the boring time with depth. Curve B is seen to approach an asymptote to the lower right corner of the graph.

(2) Glaciothermal Measurements

Data regarding the thermal characteristics in the upper 151 feet (46 m) of firn on the 5950-foot (1825 m) névé (Sector A) were also gathered during the 1961 field season. This was done with the suspicion that some knowledge of the englacial temperature characteristics of the crestal névé might prove to be germane to the long-term analysis of all factors possibly controlling mass transfer of ice through the Vaughan Lewis icefall. Because of logistical complications the data could be obtained, however, only on the adjoining Taku névé. Thermistor heat sensing devices were employed in the 151-foot (46 m) electrothermal bore hole and the 60-foot

(18 m) auger hole, both at Camp 8A (Fig. 8). The thermistor equipment was provided by the Foundation for Glacier Research. The Geophysics Laboratory of the U. S. Geological Survey manufactured the equipment from specifications established for the Juneau Icefield Research Program.

The thermistors are "small discs of sintered manganese and nickel oxide, 0.2 inches (0.5 cm) in diameter and 0.04 inches (0.1 cm) thick. An axial copper lead, 0.02 inches (0.05 cm) in diameter, is secured to each with an intermediary spot of ceramic silver paste, all of which is enclosed in vulcanized cables. The resulting alloyed semi-conductor provides a 4.4 per cent negative change in electrical resistance per degree Centigrade in temperatures at room temperature and a 6 per cent change per degree Centigrade in the vicinity of -30°C. Western Electric Company manufactures this thermistor (Type 17A). Measurements can be made to an accuracy of 0.01°C by means of an appropriate Wheatstone Bridge" (Miller, 1955b).

Two thermistor cables (Nos. 332 and 333) were used at the Site 8A. Each cable was identical, being 180 feet (54.9 m) with 18 thermistors placed at 10-foot (3 m) intervals. These cables were recalibrated in the spring of 1961 by the USGS Geophysics Laboratory and are believed accurate within the stated limits.

Cable No. 332 was placed in the 60-foot, 3-inch (18.2 m) auger hole (Bore Hole No. 2, Fig. 8). Cable No. 333 was placed in the electrothermal bore hole (Bore Hole No. 1, Fig. 8). The bore holes were about 40 feet (12 m) apart on an east-west line at Site 8A. After the cables had been lowered into their respective holes, the tops of the bore holes were sealed to prevent significant air circulation. Readings were not made until the holes were thermally stabilized for periods from 24 to 72 hours. Readings were then made at all thermistor levels on a 6 to 24 hourly basis. All readings and times recorded are given in Appendices F and G, as previously listed by Andress (1962).

For reasons made clear below, the interpretation of the above-noted glaciothermal records is given after discussion of the interpretation of the stratigraphic and density measurements.

(3) Interpretation of Stratigraphy and Density

Each of the techniques used to gather information on the Vaughan Lewis-Taku Glacier névé contributed to the overall knowledge of the net retained accumulation. Examination of the data for each of the years (1961-1964) provides a basis of comparison in a later chapter, briefly considering aspects of mass transfer in the Vaughan Lewis and Taku Glaciers. As calculated from the area-elevation comparison in figure 5, over 60 per cent of the Vaughan Lewis Glacier accumulation zone lies at the same elevation as Site 8B. Similarly, 30 per cent lies at the same elevation as the Site 8D crevasse south of 8A. This, added to their geographical proximity,makes it reasonable to assume that the annual net retained accumulation on the névés of each of these glaciers is nearly the same.

In 1961 the net retained accumulation was 17.5 feet (5.3 m) of firn at the Camp 8B test pit, and 19.5 feet (5.9 m) of firn on a crevasse wall south of Camp 8A. Both of these accumulation increments had a bulk density of 0.56, or a water equivalent of 9.8 feet (2.98 m).

Although the 1962 measurements are not as complete, the densities determined from bore-hole cores taken at Sites 8A and 8B reveal a net retained accumulation of about 17 feet (5.2 m) of firn for the 1961-62 budget year.

The 1963 test pit density profiles similarly reveal a total retained accumulation of 14 feet (4.3 m) of firn at Site 8B for the budget year 1962-63. The ram profile (Fig. 11) in Sector A also corroborates the stratigraphic similarity to the firn at Site 8B. This additional evidence supports the conclusion of comparable net accumulation on the upper Taku névé and on the Vaughan Lewis névé.

(4) Interpretation of Electrothermal Bore-Rates and Englacial Temperatures

Data from the englacial temperature measurements reveal the presence of a retained 1960-61 winter's cold wave in Sector A-A'. The plotted depth profile of these temperatures in figure 17 shows a sharp temperature increase below 30 feet (9 m) which is presumed to be the effective depth of penetration by the previous winter's cold, as of 6 September 1961.

Generally the density of firn systematically increases downward in a firn-pack, except for irregularities imposed by zones of depth-hoar, diagenetic ice, or annual ablation surfaces. In a temperate glacier (in-ice temperature 0°C), the boring rate of an electrothermal drill would be expected to decrease gradually, as a function of progressive density increase as it descends deeper into the glacier. Curve B (Fig. 16) represents this asymptotic increase in density at Site 8A, in September 1961. Curve A represents the bore-rates in inches per hour (cm/hr) at any given depth in the firn, and hence reveals that the initial boring rates between about 5 and 39 feet (2 and 12 m) are less than the boring rates between depths of 39 and 58 feet (12 and 18 m).

This seemingly anomalous situation is best explained by reference to the englacial temperature plot in figure 17. Here the slower bore-rates may be attributed to the affects of retained winter chill (especially between about 10 - 30 feet (3 - 9 m). On first examination one is tempted to conclude that lower ice temperatures would more rapidly conduct the heat away from the drill bit, hence slowing the rate. However, because it takes only 0.5 calorie to raise the temperature of ice $1^{o}C$ and because the subfreezing englacial temperatures are so slight (as shown in figure 17), in this case the chill zone may be concluded to affect the drill rate in some other way.[1] Miller (1952b) shows that the impediment of drilling through a relic cold zone is not necessarily attributed to the loss of heat alone. Instead the colder firn surrounding a borer may create a freezing condition along the unheated upper portion of a

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[1]It is mentioned that Andress (1962) and Miller (1963) also discuss this phenomenom. Andress and the writer worked together on this phase of the field work.

bore shaft causing some of the loose, partially-melted firn and snow to stick to the shaft and thereby to increase its frictional drag.

Below 40 feet (12 m) down to about 65 feet (20 m)(Fig. 16) a relatively higher bore-rate suggests that the cold zone was penetrated. Temperatures below 50 feet (15 m) (Fig. 17) vary between -0.10°C and -0.05°C also reflecting the attenuation of the cold zone at greater depth. However, as seen at the base of the figure 17 curve at a depth of 120-140 feet (36-42 m), a slightly lower temperature reading was made. This is interpreted as a relic cold zone from a severe winter long ago. Corroborating these actual measurements of noticeable temperature depressions at 30 feet (9 m) and 120-130 feet (36-39 m) is the previously discussed freezing-in of the suspension rope at these same three places or close within these zones; i.e., at 30 feet (9 m), 120 feet (36 m), and 130 feet (39 m). Again note the relationship depicted in figure 17.

Comparison of the englacial temperatures in Bore Hole No. 1 and No. 2 at Camp 8B reveals a similar trend, although Hole No. 2 (hand-augered hole) showed slightly higher temperatures. The difference is attributed to differences in the sizes of the bore holes. The hand auger had a bit diameter of 3 inches (7.6 cm), but the hole was enlarged to about 5 inches (12.7 cm) by abrasion and peripheral compaction caused by drill rotation and the moving of drill tools in and out of the hole. Bore Hole No. 1 had an almost constant

2-inch (5 cm) diameter from the electrothermal bore. A larger hole allows more air circulation and poorer ice/thermistor contacts than in a smaller hole. For this reason the thermistor readings taken in the 151-foot (46 m) electrothermal hole are deemed more reliable.

All temperature measurements below the top of the bore holes to a depth of 151 feet (46 m) were subfreezing. Therefore, on the basis of the writer's previous discussion of similarity in climatic regimes on these adjoining névés, the upper Taku and Vaughan Lewis névés are both probably subtemperate. The significance of this interpretation and the need for further measurements of this kind directly on the Vaughan Lewis névé will be considered at the end of this presentation.

b. The Icefall Zone

An arbitrary criterion for denoting the top of the icefall is that point where the tension crevasses are seen with their downglacier walls lower than their upglacier walls. In effect this is where vertical shear-strain is first noted. For the period of this study, this point is identified at an elevation of about 5500 feet (1675 m) (Fig. 20). The bottom of the icefall is arbitrarily taken at about 4000 feet (1225 m), which is the lowest point immediately upglacier from the first undisputed wave-band. The line of this depression is easily seen in the photograph of figure 2, and is diagrammatically noted at the 4000-foot contour position in figure 20.

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As the ice moves downglacier from the 5500-foot (1675 m) contour, larger crevasses develop and eventually the slope steepens with the glacier's surface virtually disintegrating into a zone of seracs and ice pinnacles. Although crevasses near the top of the icefall were generally arcuate and long and wide, none were seen to have survived this disintegrating movement within the icefall.

Near the 1963 seasonal névé-line at 4400-4500 feet (1350-1375 m), a distinct change in the type of surface movement was noted. The lack of transverse crevasses in this zone, during the field studies of 1961 and 1963 and also during the aerial photographic examinations, indicates a lack of extending and a dominance of compressive flow. In August, 1961, a significant structure in the ice was observed just below the névé-line. This structure was a distinct isoclinal, recumbent anticline, comprised of bubbly glacier ice and serving as strong evidence of compression (Fig. 18). An examination of similar folds was made and logged during the 1961 field season. A description of this phenomenon follows, starting with the first ice fold; i.e., the highest in the icefall, at an elevation of about 4400 feet (1350 m). Nine ice folds were counted in the icefall and are depicted as F-1 to F-9 in figure 20. Most of these were continuous although F-3, F-6, and F-8 were segmented or discontinuous at the surface. The reader is urged to note again the photographic view of these features so well shown in figure 2.

Ice fold F-1 lies at the bottom of the highly seracced zone of transverse crevasses depicted in figure 20. This fold was actually hardly discernable among the maze of seracs, some of which rest on its surface. It extended across the entire width of the glacier, about one-third mile (one-half km), and had an amplitude of about 10 feet (3 m) and a width of about 20 feet (6 m). On the crest of this fold, near its north end, several shallow crevasses were found, resulting from the lateral expansion of the ice as it emerged from the narrow rock defile through which the icefall flowed. These crevasses lay in a radial pattern and characterized each of the folds in Sector B. Here, also, englacial foliation along the crevasse walls was found to be nearly vertical.

Fold F-2 was similar to F-1 but with an amplitude of about 12 feet (3.6 m). It, too, was continuous across glacier with a few more shallow radial crevasses on both its north and south ends. Here again along the crevasse walls, foliation was found to be nearly vertical.

Fold F-3 consisted of three segments in line across glacier, each of which is depicted in the schematic representation. The amplitude of each segment was about 10 feet (3 m). These folds had the appearance of symmetrical double plunging anticlines, a characteristic which is difficult to see until virtually standing on top of them.

Fold F-4 was considerably larger than those previously noted. This one had an amplitude of 20 to 25 feet (6 to 8 m) and was about 100 feet (30 m) wide, and extended continuously across glacier. On its crest were a few remnant seracs carried down from the seracced and crevassed zone above. On the north end of F-4, part of the ice had fallen away at the time of the 1963 observations exposing a clean cross-sectional view of the fold. The fold was close to the position of the overfold photographed in 1961 (Fig. 18). As in the earlier observation this ice had folded, without visible fracturing, into a recumbent anticlinal structure.

Fold F-5 was measured to be about 50 feet (15 m) wide and was found to be continuous across glacier. Radial crevasses were more numerous indicating a relatively greater lateral expansion of the ice. Foliation along the crevasse walls dipped downglacier near the surface and at depth was nearly vertical.

Between Fold F-5 and F-6 an inlay of white, fine-grained, non-foliated ice was found--hereafter referred to as a "white-ice layer." The white-ice layer between these folds was about 12 feet (3.6 m) wide and was composed of fine-grained glacier ice, from a distance looking more like granular firn. On both sides this inlay had sharp contacts with the coarsely-grained, foliated bubbly glacier ice of the main ice body, thus giving a characteristic dike-like appearance.

Fold F-6 appeared to consist of two intermediate size segments each extending over one-half the glacier's width. These may possibly have represented two distinct folds. The two segments were widest, 80 to 100 feet (25 to 30 m), at the margin of the glacier and narrowest where they pinched out at the center. From the margin to the center these structures resembled plunging anticlines with overlapping ends. Foliation, as observed along the radial crevasse walls, was seen to be much contorted and to dip both up and downglacier. A white-ice layer, similar to that described above and about 10 feet (3 m) wide, extended across about one-half the width of the glacier between Folds F-6 and F-7. Again it is mentioned that this white-ice layer had no apparent foliation.

Fold F-7 was another continuous structure with an amplitude of 10 to 15 feet (3 to 5 m). Radial crevassing was even more prominent in this case; and the foliation was expressed on each crevasse wall as a pattern radiating hub-like from a point below the surface, but each folium always dipped upglacier.

Fold F-8, similar to F-3, consisted of three segments separated by white-ice layers. The white-ice inlays were notably wide between the plunging ends of each segment. This pattern is considered to be significant and will be discussed later.

Fold F-9 was the largest fold of all, being 125 to 150 feet (38 to 45 m) wide and with an amplitude of about 30 feet (9 m). It was also continuous across glacier. What is designated here as fold segment F-9a was seen as a relatively small structure about 160 feet (50 m) long and 15 feet (5 m) wide. Winter snow retained in an elongated surface depression below F-9 and south of F-9a prohibited the examination of the area between Fold F-9 and Wave-Band 1 (WB-1) in figure 20.

c. The Wave-Band Zone

The most striking morphologic feature of the Vaughan Lewis Glacier is the series of wave-bands which characterize Sector C (Fig. 21). In general, wave-bands or wave-ogives, as they properly might be termed (see glossary at end of paper), in plan view are seen as a series of hyperbolic-shaped structures having a wave-like cross-sectional surface, usually best developed on the apron at the base of icefalls. Downglacier these surface waves attenuate and the two-dimensional ogive patterns accentuate.

In the case of the Vaughan Lewis Glacier the wave-bands have exceptional amplitude. The magnitude of this amplitude is not fully appreciated until one descends to the glacier apron and sees the wave-bands from the side (Fig. 2). The apparent amplitude (Fig. 22) varies from 80 feet (25 m) at the base of the icefall and decreases downglacier to 0 at a point about 1.5 miles (2.5 km) below the icefall. The maximum true amplitude may be as much as half the values indicated in figure 22. The wave length of the bands varies from 300 to 500 feet (90 to 150 m). Five of the bands were measured and their average wave length computed at about 400 feet (120 m).

In figure 22 the surface profile of wave-bands 1 - 5 is shown. This figure was constructed from measurements obtained with a hand level and a 100-foot (30 m) tape during the 1963 field season. A brief description of these five wave-bands is given below. It is pointed out that snow that has drifted into the swale between the bulges of the wave-bands obscured their true amplitude and precluded observation of the ice lying below the snow cover.

Wave-Band WB-1 in figure 22 designates the first large band at the foot of the icefall. The height of the band from the swale on the upglacier side was about 45 feet (14 m), and on the downglacier side about 80 feet (25 m) (Fig. 22). Within WB-1, and outcropping on its surface, were many white-ice layers (Fig. 19). These were much narrower than those between the folds in the icefall, and were 1 to 3 feet (0.3 to 1 m) wide and up to several hundred feet (meters) long. Sometimes they extended across the entire glacier's width. They stood above the glacier's surface about 1.5 feet (0.5 m) as a result of differential ablation produced essentially by the difference in albedo between the white-ice and the coarse bubbly glacier ice of the band. It was observed on many of the wave-bands that two separate white-ice layers, as seen on the surface, would join and continue as a single white-ice layer. Along a crevasse wall, which cut through the junction of these joining white-ice layers, it was also noted that the separate layers dipped in opposite directions. The pertinent geometric relationships are depicted in figures 23 and 24, with respect to Wave-Bands WB-2 and WB-4. The appearance in many instances was of an eroded anticline. Thus, these features are hereafter called "white-ice anticlines." In several places the white-ice layers of white-ice anticlines were seen to join in more than one place giving, in plan view, a canoe-shaped pattern.

During the 1961 field season, ice cores were taken with a hand auger from both a white-ice layer and from the coarse-grained bubbly glacier ice. Cores at depths of 3.3 feet (1 m) in the white-ice layers were found to be smooth and relatively unbroken. Conversely, the bubbly ice cores were short, rough and broken into short monocular segments of one-half to two-inch (1.3 to 5 cm) thickness (Fig. 25). The short monocular segments broke along the foliation planes in the bubbly ice. Seven white-ice layers were counted on WB-1 and they penetrated into the ice as far as could be seen into a 50-to 60-foot (15 to 18 m) deep crevasse. The strike of the foliation followed the curved trend of the wave-band, and in most places the folia dipped upglacier.

Wave-Band WB-2 as noted in figures 21 and 22 was another large band with an upglacier height of about 25 feet (8 m) and a downglacier height of about 50 feet (15 m). Its maximum width at the glacier center was 480 feet (145 m). White-ice layers on this band were long and continuous. Measurements were made on the dip of the master folia and the white-ice layers along a crevasse wall (cross-sectional view shown in Fig. 23). These structures generally dipped upglacier except in the area of the white-ice.

Wave-Band WB-3 had an upglacier and downglacier height of about 20 feet (6 m) and a width of about 400 feet (120 m) (again see Figs. 21 and 22). Two white-ice layers on the upglacier side of the band extended more than one-half the glacier's width.

Wave-Band WB-4 had an anomalous cross-sectional form, in that the amplitude on its upglacier side was higher than on its downglacier side. The relationship is shown in figure 22. In addition, the swale upglacier from WB-4 is lower than the swale on its downglacier side. Attention is drawn to this, as usually each successive swale downglacier is lower than the preceding one. Because of this there was ponding of a large volume of meltwater behind WB-4 and deviation of a medial drainage channel toward the margin of the glacier (Fig. 2). The anomalous pattern of amplitudes described above could reflect a significant change in bottom topography below the icefall, although also it could connote stress variations in time.[1]

The sketch of the white-ice layers and foliation given in cross-section in figure 24 shows a case of dominantly vertical or steep upglacier dips. As in the inset sketch of figure 23, this figure also shows a diagrammatic view of the white-ice layers in plan. Here the two vertical white-ice layers strike along the surface parallel to the curve of the wave-band and join each other, suggesting a symmetrical anticline.

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[1]A recent preliminary seismic profile below the icefall has indicated that there is indeed a low yet definite bedrock threshold below the area of Wave-Bands Nos. 4 & 5 (Kittredge, 1965; and Miller, 1966).

Wave-Band WB-5 (Figs. 21 and 22) was more like the other wave-bands with a higher downglacier side of 15 feet (4.5 m) than the upglacier side of 10 feet (3 m). It had a width at the center of 350 feet (105 m). There were four white-ice layers on the upglacier flank. Foliation paralleled this band and generally dipped upglacier.

WB-5 was the last of the wave-bands on which hand-level measurements were obtained. From this point to the terminus only descriptive field notes were made. Downglacier from WB-5 the wave-bands rapidly lost amplitude. Wave-Bands 6 to 15 in Sector C all exhibited white-ice layers. Almost all of the white-ice layers were on the upglacier flank of the swell. At Wave-Band 15 the crest or leading edge of the wave-band became the dark part of an ogive. The trailing side and trough became the light part of an ogive.

d. The Ogive Zone

This sector includes that part of the glacier from Ogive 16 through Ogive 67. As noted in the glossary, ogives (Forbes' bands) are similar to wave-bands in plan view, but do not have significant surface amplitude. They are alternating light and dark areas of ice, generally ogive-shaped but changing shape with the change in stress and type of glacier flow prevailing at the surface. In this zone the Vaughan Lewis Glacier has a consistently sloping surface of about $3^{\circ}45'$ downglacier over a distance of about six miles (9.5 km).

Observation of the light and dark parts of the ogives revealed that the dark part never had any white-ice layers. The white-ice layers were always in the light part of the ogive and were observed all the way to Ogive 67 near the terminus. For the present interpretations this is a very significant observation, as will be shown. In a few instances the white-ice layers were foliated but they were generally non-foliated.

Differential ablation on the dark part of the ogive resulted in a humpy surface, with the humps being quite irregular in form and a foot (0.3 m) or less in height. A greater amount of dirt was observed on the ice on the upglacier side of these humps. The dirt material was not of large particle size on the ogives, except for one large boulder about 10 feet (3 m) high by 6 feet (2 m) long which is considered to be an erratic. Most of the debris was sand size or smaller. The texture of the bubbly glacier ice itself was relatively coarse, with individual ice crystals attaining centimeter size. No distinction could be made between the light and dark part of ogives, except for the above-noted white-ice layers being restricted to the light part of the ogives.

A study was made of a set of U. S. Navy vertical aerial photographs taken of the glacier 11 July 1948 one of which is shown in figure 3. On these photographs Ogive 16 had nearly equal areas of light and dark, while farther down-glacier the white part of the ogives had over twice the surface area of the dark parts. Also surface movements are reflected by changes in plan shape of the ogives as they move downglacier. For example, when the wave-bands first emerge from the base of the icefall, they are ring-shaped and have a radius of curvature of about 900 feet (275 m). When they have moved about 7 miles (11 km) from the base of the icefall, they become as pointed arches (ogives) and have a radius of curvature of at least 6500 feet (1975 m). This is, of course, empirical evidence of a streaming type of flow or mode of mass movement.

e. Terminal Sector

Ogive 67 was the last recognizable ogive because of the large number of crevasses resulting from the flow of the glacier into side valleys (Fig. 3). Parts of ogives beyond 67 can be seen, however, so the total number of wave-bands and their downglacier counterparts, the ogives, is set at approximately 73. If these structures have time significance such a statistic can be important.

In view of the drainage into the ice-dammed lakes shown in figures 3 and 4, and because the Vaughan Lewis-Gilkey Glacier complex is the main valley glacier system in this sector of the icefield, one might ask the question are the side valleys near the dual terminus lower than the Vaughan Lewis Glacier. The answer appears to lie in the self-dumping character of these lakes (Miller, 1952a), an annual event which could not take place if the side valley floors were lower than the valley floor of the Vaughan Lewis-Gilkey Glacier complex. Thus it is only the Vaughan Lewis Glacier's ice surface which is higher. In other words these are hanging side valleys with their outlets at present blocked by ice. Therefore, the lower part of the Vaughan Lewis Glacier may be presumed to continue to flow along the main valley while only a portion of its upper part sloughs off into the referenced side valleys (Freers, 1965b). With respect to the periodic drainage of the ice-dammed lakes at the Vaughan Lewis termini the release of water is catastrophic, and takes place usually before mid-summer, via englacial and/or subglacial outlets. Detailed studies have not yet been made of this interesting phenomenon.

3. Névé-Line Characteristics and Positions

Long-term changes in mean névé-line position are one of the useful indicators of a glacier's regime; but these changes should be interpreted together with stratigraphic information from the névé (Egan, 1965). The annual late summer position of the névé-line[1] is affected by many factors--the most important of which are the amount of net retained accumulation, the length of the effective ablation season, and the orographical relationship, including the

[1]Referred to in J.I.R.P. reports as the seasonal névé-line (Miller, 1963). The mean névé-line represents the average position over the latest decade.

glacier's size and gradient within the area of the névé-line's short-term variations. As far as the glacier's total mass budget is concerned, the morphology, orientation, and area elevation factors must also be considered.

On the Vaughan Lewis Glacier these considerations are of unique concern because the icefall and its basal apron may be considered to lie within a zone of maximum névé-line variation; i.e., from 3500 to 5400 feet (1075 to 1650 m). The U. S. Navy aerial photographs, taken on 11 July 1948, reveal the midsummer transient névé-line on the Vaughan Lewis Glacier to be well up within the icefall, at 4400 to 4500 feet (1350 to 1380 m); while on the adjacent Gilkey Glacier to the north, and the unnamed tributary merging with the Vaughan Lewis Glacier from the south, the névé-line rested somewhat lower respectively at about 4200 feet (1275 m) and 4100 feet (1250 m). A similar difference in névé-line elevations has been observed on these glaciers in subsequent years. It is of interest, therefore, that the Vaughan Lewis Glacier rises abruptly from Sector C, through the rock-bordered icefall (Sector B) for about 1500 feet (450 m). Therefore, the effects of bedrock radiation as well as sunlight are less on the upper Gilkey Glacier where a gentler gradient and different orientation pertain (Fig. 4). Thus, confinement, morphology, gradient, and orientation seem to be the critical geographical factors in the névé-line positions of these adjacent glaciers.

The 1961 to 1964 seasonal névé-line positions on the Vaughan Lewis Glacier were observed in late September of each year. Observations in 1964 placed the final seasonal névé-line position at about 395 feet (1204 m) due in part to a short ablation season (Miller, personal communication). This is the lowest on record also for the Taku Glacier as shown by the following table of comparisons. From J.I.R.P. records (Egan, 1965b; and Miller, 1963 and 1966) the positions since 1956 are also noted. This decade of record provides a basis for a mean névé-line determination.

Approximate Seasonal Névé-Line Positions on Vaughan Lewis and Taku Glaciers Over the Past Ten Years

	Vaughan Lewis Glacier		Taku Glacier	
	Feet	Meters	Feet	Meters
1965	4100	1250	2800	853
1964	3950±	1204	2450	747
1963	4450	1356	3000	914
1962	4200	1280	2950	900
1961	4400	1341	2900	885
1960	4500	1372	3100	945
1959	4400 (est.)[1]	1341	3000	914
1958	4300	1311	3000	914
1957	4600 (est.)[1]	1402	3200	975
1956	4600 (est.)[1]	1402	3200	975

The five-year mean for the Vaughan Lewis névé-line position for the years 1961 to 1965 is about 4200 feet (1280 m), as opposed to about 2800 feet (853 m) on the Taku Glacier. The mean névé-line for the Vaughan Lewis Glacier over the past decade is approximately 4350 feet (1325 m); for the Taku Glacier, 2960 feet (903 m). Even though the

[1]Estimated from tabulated difference in known years, as well as from Taku and Lemon Glacier névé-line trends (J.I.R.P.).

last several years have proved to be exceptionally positive in the regime sense (Egan, 1965b), and even though the current trend is toward a lowered névé-line, this still places the seasonal névé-line several hundred feet above the base of the Vaughan Lewis Icefall. Thus, within the range of present climatic pulsations even in abnormal years the wave-bands have been well exposed at the end of summer. Using 4200 feet (1280 m) on the cumulative area-elevation graph (Fig. 5) as the average névé-line position for the present decade (i.e., since 1960), the area of the ablation zone is seen as 2.94 square miles (7.37 sq km) and the accumulation zone as 6.08 square miles (15.2 sq km). Thus, about a 2 to 1 accumulation-ablation area ratio pertains on the Vaughan Lewis Glacier.

The Vaughan Lewis Glacier's total area is 9.02 square miles (25.07 sq km). The comparison with respect to the cumulative area-elevation characteristics, as previously noted, is given in figure 5. The mean névé-line positions of each glacier are also compared on this figure. That for the Taku Glacier, however, has been figured from the past 20 years of observation rather than only since 1956, as given in the foregoing table. This longer-term value is therefore cited, giving a mean position of 3000 feet (914 m). This means a 1200-to 1500-foot (365-396 m) lower névé-line on the Taku Glacier than on the Vaughan Lewis Glacier. Again, the difference is ascribed to the orographical and geographical factors discussed.

On the Taku Glacier, the mean névé-line position on the graph indicates a lower glacier ablation zone of about 30 square miles (75 sq km) and a névé accumulation area of about 185 square miles (464 sq km). The result is an accumulation-ablation area ratio of 6 to 1 for the Taku Glacier compared with the 2 to 1 ratio on the Vaughan Lewis Glacier. Therefore, the fluctuation regimes of these two glaciers cannot be compared without detailed consideration of their area-elevation statistics--an analysis clearly beyond the scope of the present study. It is readily seen from this, however, that a considerably greater ablation relative to accumulation is to be expected on the Vaughan Lewis Glacier than on the Taku Glacier. Hence the lower glacier englacial structures on the Vaughan Lewis Glacier should be expected to be exceptionally well exposed as, of course, has been amply illustrated in figures 2 and 3.

4. Surface Movement Records

a. Surveyed Observations

Measurements were made of the surface movement on the Vaughan Lewis Glacier during the summers of 1961, 1963, 1964, and 1965. The 1964 survey records, however, were obtained by Havas (1965); with supplementary mapping and geophysical data obtained in 1964 and 1965 by Kittredge (1965 and 1966).[1] A pattern of movement stakes was

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[1]The latest report by Kittredge is not discussed in this presentation as it came to the writer's attention during the final typing of this manuscript.

initially established on the wave-bands in August 1961. These are shown in figure 26 with surface velocities and directions indicated. A series of readings were made on prominent seracs and ice pinnacles in the icefall for purposes of comparison with the stake information as it was, of course, impossible to place stakes in the icefall. A 138-foot (42 m) base line was established on a ridge adjacent to the foot of the icefall (Fig. 26). In 1961, the readings were taken from each end of the base line on each stake (designated as F in the figure); and on the seracs, or ice pinnacles (designated as P in the figures). Upon analysis of the data, some exceptionally high velocities were computed, as indicated on stakes F-1 through F-6. This suggests either errors in measurement or unexpected conditions in the glacier below the icefall (see footnote regarding data for these movement stakes in Appendix H, Part 1). The results are included in Appendix H, Part 1, for future comparison. Some of the data, however, appear reasonable as do the relative movement values. For example, the relative movement between stakes F-1, F-2, and F-3 gives 20.8 feet (6.3 m) per day, 45.8 feet (14.0 m) per day, and 35.8 feet (10.9 m) per day. As absolute values, these statistics may be open to doubt, but as ratios they are not unreasonable. It is considered that the absolute readings are probably in error as the theodolite sights were made at distances of a mile or more, and almost directly along the line of stake movement.

The readings on stakes F-7 through F-11, and on seracs P-1 through P-3 and P-6 through P-8, give more favorable results (Appendix H, Part 2). These summer velocities fall within the limits of glacier movement expected when compared with data on comparable icefalls elsewhere, as discussed below. From the measurements it is noted that no velocities were greater than 7.4 feet (2.3 m) per day for the movement stakes in the wave-band zone (Sector C), or 13.3 feet (4.1 m) per day for the ice pinnacles in the icefall (Sector B). By projecting these summer velocities to a minimum annual figure, the pinnacles P-2 and P-3 would give respectively 2200 feet (670 m) per year and 4300 feet (1310 m) per year. These values are comparable to those cited by King and Lewis (1961) on the orographically similar icefall of the Odinsbreen and Austerdalsbreen in Norway; i.e., where velocities of over 3000 feet (914 m) per year have been reported. The direction and magnitude of the movement vectors P-2 and P-3 corroborate the previous interpretations of extension flow in the upper part of the icefall. A striking contrast in movement of the upper icefall segment compared with the lower segment is shown by the plotted vectors for the bottom half of the icefall (Fig. 26).

Ice pinnacles P-1, P-6, P-7, and P-8 show movement in a direction almost perpendicular to the expected longitudinal flow direction of the glacier. This is explained by two considerations: (1) the change of movement from extension to compression flow, as expressed by the closure of crevasses and the development of ice folds; and (2) the emergence of ice from the narrow defile valley of the icefall spillway allowing the lateral expansion of the glacier in its lower apron zone (Sectors B and C).

Examination of movement stakes F-7 through F-11 (Fig. 26) reveals a similar situation. These vectors indicate that lateral expansion persists as the ice moves down valley. For purposes of discussion, hereafter all movement at right angles to the direction of the base line (Fig. 26) will be termed x-movement. All movement parallel to the base line--essentially down valley in the spillway itself--will be referred to as y-movement. Any movement which is vectorally upward or downward (that is in a direction perpendicular to the plane defined by x and y) will be termed z-movement. These vectoral values are noted in Appendix H, with respect to the pertinent data on the 1961 stakes and seracs.

No surveys were made on this glacier during the summer of 1962. In 1963, however, the survey stations were occupied and five of the 1961 movement stakes resurveyed. These measurements provide two-year averages for the velocities at these stakes as noted in Part 1 of Appendix H. In this period the average y-movement for the four stakes in the wave-band zone (Sector C, stakes F-8, F-9, F-10, and F-11) was 14 feet (4.3 m) per day, with the x-movement averaging 1.6 feet (0.5 m) per day. These values are plotted in figure 27, showing the initial 1961 positions, the final 1963 positions, and the average two-year velocity vector in feet per day. The dominance of y-movement indicated by the relative magnitudes in the x and y direction, and also shown by comparing the vector directions plotted in figures 26 and 27, demonstrates how quickly lateral expansion dissipated the deformation effects as ice passed through the main apron sector during this two-year interval.

During the 1964 field season, movement measurements were made on the Vaughan Lewis Glacier by Havas (1965) (Appendix I). The magnitude of movement near the foot of the icefall first decreases from about 1.38 feet (0.42 m) per day to 1.15 feet (0.35 m) per day and then increases to 1.38 feet (0.42 m) per day (Fig. 28).

b. Strain-Rate Analysis

In 1964 strain-rate measurements were made on the seventh wave-band, using a strain diamond on the crest (Fig. 28). Strain-rates were also determined in this year between movement stakes 7 and 8 (Havas, 1965). Havas' analysis of the movement data, in terms of strain-rates in the strain diamond and movement ratio on stakes 7 and 8, shows reasonable agreement. In addition Havas shows that there are compressive stresses at and below the base of the icefall and tensile stresses farther downglacier in the vicinity of movement stakes 7 and 8. This agrees with the structural interpretation given in the following section. Also these data have significant bearing on the interpretation of the development of wave-bands to be considered in the summary chapter.

c. Structural Analysis

Crevasse patterns on a glacier are a reflection of the tensional, compressive and shear stresses in the upper part of a glacier. Analysis of crevasse patterns and other structural shapes can also tell us much about the type of flow occurring at a glacier's surface--particularly whether it is Block-Schollen or streaming flow (Miller, 1958), and extending or compressive flow. Nye (1952) has shown that transverse crevasses form during extending flow but not during compressive flow. He also shows that the shear stresses found at the margin of a glacier will, during compressive flow, form crevasses of less than 45 degrees with the valley wall. During extending flow, the shear stresses will form crevasses at an angle of 45 degrees with the valley wall, and pointing upglacier. A longitudinal compressive stress could be caused by ablation, a concave bed, narrowing of the glacier valley, or movement around a topographic bend in a glacier. Similarly, a longitudinal tension can be caused by accumulation, a convex bed, widening of the valley, or by movement around the outside of a bend in the glacier.

The Vaughan Lewis-Gilkey Glacier complex (Fig. 4) involves all of the above mentioned types of flow. In a more descriptive sense these are alluded to as streaming (parabolic in plan view), Block-shollen (rectilinear in plan view), and composite (combining both of these geometric forms). As pointed out in earlier J.I.R.P. reports (e.g., Miller, 1963), streaming flow connotes maximum relative movement within the ice and Block-Schollen flow connotes maximum basal and marginal slippage. Thus, the structural configurations of the ogives in the lower glacier area may be diagnostic.

The icefall of the Vaughan Lewis Glacier has many transverse crevasses due to a narrowing of the valley and the steepness of the slope. In the lower one-third of the icefall, the transverse crevasses are replaced by many radiating crevasses due to the widening of the valley and the compressive build-up of ice in the apron area. It is reiterated that these structural patterns reflect the type of stress at the surface--dominantly tensile in the upper two-thirds of the icefall and compressive in the lower one-third, a fact corroborated by Havas' strain-tensor analyses.

The plan view of wave-bands as they are formed at the base of the icefall is symmetrically hyperbolic (streaming). This shape rapidly changes as the ice moves downglacier and as ablation effects dominate, resulting eventually in the display of pointed or ogive shapes. Crevasses along the valley wall in the lower glacier section indicate the movement of the glacier to be mostly extension flow--a fact again corroborated by Havas' strain-tensor analyses.

In the terminal sector, the glacier takes a sharp turn into the two low side valleys previously described, and well shown in figures 3 and 4. The result here is an extreme extension flow corroborated by the presence of a multitude of transverse tension crevasses.

In summary, the general movement of the Vaughan Lewis Glacier is by extending flow in the upper part of the icefall and by compressive flow in the lower part of the icefall and in the first mile (1.5 km) below the icefall. Ogive shapes indicate a streaming flow in the lower valley section from the first to last ogives. Thus the main mode of mass transfer in this glacier is concluded to be essentially a streaming type of flow (Freers, 1965b). A comparison with the Taku and other glaciers in the region bears out the regime significance of this interpretation.

II. COMPARISON WITH OBSERVATIONS ON THE TAKU AND OTHER JUNEAU ICEFIELD GLACIERS

During 1961 and 1963 movement measurements and related stratigraphic studies and observations were made on adjoining glaciers of the Juneau Icefield. These are abetted by previous and subsequent J.I.R.P. data. A brief comparison is made with respect to the Vaughan Lewis Glacier measurements which have been described. The statistics discussed below emphasize the particular measurements in which the writer was involved during the 1961 field season.

Higher Taku Névé

Stratigraphy for the Camp 8, 6000-foot (1825 m) névé of the Taku Glacier has already been discussed (Figs. 12 and 13) in conjunction with the Vaughan Lewis Glacier stratigraphy. Movement measurements on Profile VIII (Fig. 1), extending from Camp 8 to the névé divide between the Taku and Vaughan Lewis Glaciers, were made in 1961 as a supplement to the summer of 1960 surveys by McLane (1960, and personal communication) (Part I, Appendix J). The velocity profiles for 1960 and 1961 are plotted in figure 29. These velocities, as will be seen, are considerably less than the velocities found on the lower level cross-glacier transects in the Camp 9 and Camp 10 sectors. The maximum velocity measured in 1960 on the Camp 8 profile was 0.9 feet (0.3 m) per day and in 1961 it was 0.55 feet

(0.2 m) per day. Also the shapes of these curves are much flatter than shown in the two graphs (Figs. 30 and 31) for the lower névés of the Taku Glacier. It should be noted that the Camp 8 profile is distinctly of streaming or shallow hyperbolic form, indicating dominance of englacial flow rather than maximum basal slippage effect. This is comparable to the lower Vaughan Lewis Glacier case.

Intermediate Taku Névé

In 1961 no stratigraphic studies were carried out by the writer at the Camp 9 névé, which lies at approximately 5000 feet (1525 m). Surface movement measurements in Profile VII (Fig. 1 and Appendix K), however, were made and are plotted graphically in figure 30. Here the direction of the transect is westerly with the shape of the flow curve being intermediate between that cited for the upper névé and that for the Camp 10 (lower névé) sector described below. These velocities are greater, than on the crestal névé, with a maximum of 1.2 feet (0.4 m) per day expressed at the center of the glacier. It is interesting that the shape of this curve is comparable to the shape of the first wave-band on the Vaughan Lewis Glacier (Fig. 21). This wave-band may be presumed to reflect more dominantly surface movement than it does movement at depth.

Lower Taku Névé

In 1961 surface movement measurements were conducted by the writer, in company with D. Bingham, on the 3500-foot

(1075 m) névé along a line (Profile IV, Fig. 1) extending westerly across the glacier from Camp 10 (Fig. 31). These measurements reveal an average daily movement in the center of 2.1 feet (0.6 m) per day in 1961 compared with 2.5 feet (0.8 m) per day based on the 1960 survey (Appendix L).

Supplemental to these records, net accumulation measurements were also made along a crevasse wall at the position noted in figure 31. The results of these measurements are given in Andress (1962) and are plotted in figure 13 for comparison with Site 8A. These show a net of 5.7 feet (1.7 m) of 1960-61 retained accumulation. The bulk density was 0.60 which approximates the late-summer firn density. From this may be compiled a positive accumulation of 3.4 feet (1.0 m) (water equivalent) which is deemed representative for the lower névé at this elevation.

With respect to the Vaughan Lewis Glacier study, these lower Taku névé regime and movement data reveal two points of interest. First, the annual retained accumulation in 1961 is seen to be substantially positive at 3500 feet (1075 m) elevation on the Taku Glacier, but is negative at a comparable elevation on the Vaughan Lewis Glacier, as the 3500-foot level was 700 feet (210 m) below the seasonal névé line in that year. Secondly, the surface movement on the Taku Glacier on Profile IV (Camp 10 Sector) is not streaming, but a true Block-Schollen profile, indicating dominance of basal sliding. On the Vaughan Lewis Glacier in contrast, the maximum mass transfer is considered to be englacial.

Other Banded Glaciers on the Juneau Icefield

Many icefall glaciers flow from the periphery of the Juneau Icefield and at least 20 of these glaciers exhibit banding such as ogives or wave-bands (Miller, 1952a). To mention a few, for example the Battle Glacier (Fig. 4) has wave-bands with a minimum of amplitude. However, the ogives are excellent examples, being distinct and persisting to the junction with the Gilkey Glacier. The Herbert and Mendenhall Glaciers also exhibit prominent wave-bands and ogives, similar to those on the Vaughan Lewis Glacier. The East and West Twin Glaciers, near Taku Fiord, also have excellent exposures of wave-bands and ogives, with the best examples on the East Twin Glacier (Leighton, 1951, and Miller, 1952a). However, the shape in plan view of these ogives is distinctly different from the ogives and wave-bands of the Vaughan Lewis Glacier. The main distinction is that the Vaughan Lewis Glacier wave-bands emerge from the icefall as smooth hyperbolic curves and then rapidly deform to pointed arches or ogives. The East Twin Glacier ogives, in contrast, retain a more rounded, ring-like pattern all the way to its terminus. The significance of these differences may be important as revealing trends in overall regime of these separate glaciers, as will be explained later.

III. WORKING HYPOTHESIS ON WAVE-BANDS OF THE VAUGHAN LEWIS GLACIER

Other Theories

Louis Agassiz was the first to use the term ogive for the structures of the type here discussed (Agassiz, 1847). Since that time a number of other terms have been applied--including such as dirt bands (Forbes, 1842), Forbes' dirt bands (Quincke, 1905; Fisher, 1942), and periodic annual banding (Washburn, 1935). Also other features have been called ogives which have a different structural history (Russell, 1897). In the course of such earlier investigations a number of theories and hypotheses have been proposed to explain wave-bands (wave-ogives) and ogives. Several of these theories and hypotheses are now considered as a basis for understanding the hypothesis to be proposed in the present study of the Vaughan Lewis Glacier.

1. Porosity Difference Theory

J. D. Forbes (1842) proposed that alternating light and dark areas of glaciers having what he called dirt bands are the result of in-ice porosity differences. His conclusion was that the light part of dirt bands (in the present study, ogives) represents a more porous zone.

2. Primary Stratification Hypothesis

Louis Agassiz (1847) proposed that ogives are the alternating summer ablation surface and winter snow surface exposed by ablation. This hypothesis was supported later by Hess (1904) and by Vareschi (1942, also in Godwin, 1949). Vareschi's support of this concept was based on the difference and abundance of pollen grains which he found in the light and dark part of the ogives. Deformed and sometimes arcuate primary stratification structures have also been described by Miller (1952a) with respect to certain banded phenomena on the Juneau Icefield, but these have been carefully distinguished from the ogive-type of structure we are considering here.

3. Serac-Crevasse Hypothesis

Observations by Washburn (1935) led him to believe that the dark part of an ogive is the result of dirt infilling crevasses between seracs in the icefall. The wave of a wave-band he concluded to be a former serac ablated into a smooth round wave.

Another serac-crevasse hypothesis was proposed by Fisher (1947). The mechanism here discussed is similar to that of Washburn but instead of dirt accumulating in the crevasses, clean-ice debris gathers in them. The result below the icefall is the clean-ice debris representing lighter parts of the ogive and dirty ice of the serac representing darker parts of the ogive. Fisher also describes "Alaska bands" and attributes them to primary (sedimentary) stratification.

4. Shearing Hypothesis

F. B. Leightón (1951) stated that ogives on the East Twin Glacier on the Juneau Icefield, Alaska, are formed by the periodic occurrence of obstructed extrusion flow at the base of an icefall. In essence, he considers that the change in slope of the bedrock causes obstruction of the glacier flow resulting in low-angled shearing. This shearing movement forms transverse pressure ridges which are the wave-bands. The shearing also concentrates englacial and subglacial debris at the surface to form the dark part of an ogive. This idea of thrust shearing with respect to the East Twin Glacier was originally reported on (in the 1949 J.I.R.P. field season report) by Miller (1952a, see Fig. 37 in this report), who also presented some evidence for the annual periodicity of the wave phenomena.

5. Winter-Summer Theory

King and Lewis (1961) postulate that thin highly-crevassed ice in the icefall is subjected in summer to crystal changes, infusion of dirt and some freezing of meltwater in crevasses. In the winter, the icefall is "protected" by winter snow. When the summer ice reaches the base of the icefall, it forms the dark part of the ogive and the winter ice forms the light part of the ogive. Fisher (1962) proposed a similar hypothesis which differs only in that the winter ice in the icefall is subjected to extreme cold temperature resulting in white bubbly ice. He suggested that the waves are the result of differential ablation due to differences in thermal conductivity and greater albedo of the white bubbly ice.

6. Regelation Hypothesis

Atherton (1963) suggests that the dark part of the ogive is the result of absorption of dust in coarse crystalline ice which formed by regelation on the closure of extension crevasses in the cirque area of icefall glaciers. He further suggests that the coarse crystalline ice is bunched by velocity fluctuations in the glacier at the top of the icefall. These velocity fluctuations are attenuated by rock steps below the glacier in the icefall zone and this results in the waves of the wave-bands.

7. Compression Hypothesis

Kamb (1964) and Shreve and Kamb (1963) state that waves are generated at the foot of icefalls where the change in slope causes the ice above the base of the icefall to slow down to the speed of the ice on the gentler slope below the icefall. The ice is greatly thinned in the summer and is not thinned as much in the winter as it passes through the icefall. The resulting difference in thickness between summer and winter ice is amplified by the great compression at the base of the icefall producing an annually repeating wave form. A modification of these ideas is also considered by Kittredge (1966).

Discussion With Respect to the Vaughan Lewis Problem

Although many of these hypotheses, or a combination of them, help to explain the genesis of wave-bands and ogives on other glaciers, none of them adequately explains the origin of the wave-bands and ogives on the Vaughan Lewis Glacier. These hypotheses will now be examined in the light of the field observations which have been described on the Vaughan Lewis Glacier.

The explanation of the light and dark parts of the ogives via porosity differences is partly true on the Vaughan Lewis Glacier. The light part of the ogives, however, is not composed entirely of fine-grained, white-ice layers, although these are thought to give this part of the ogive its lighter appearance. Also, Forbes (1842) said the light part is more porous and the dark part less porous. As detailed porosity observations were not made on the Vaughan Lewis Glacier at the time of this field work, it is difficult at present to state categorically which part of the ogive is more "porous."

The primary stratification hypothesis seems logical until it is remembered that ogives form only below an icefall. Also, the width of the dark part of the ogives must be considered. Almost all dirty layers in the stratification of firn are less than one foot (0.3 m) thick and normally cannot account for the considerable width which has been found in this case in the dark part of ogives. Primary stratification when exposed at glacier surfaces is generally seen as a system of narrow lines, usually deformed by flow in valley glaciers and accentuated by differential ablation. These are not the smooth hyperbolic curves or pointed ogives with which we are here concerned. Miller (1952a and 1955a) has adequately differentiated such morphogenetically different features on the Juneau Icefield.

The serac-crevasse hypothesis of Washburn (1935) and Fisher (1947) is an unreasonable explanation for the wave-bands and ogives of the Vaughan Lewis Glacier for the following reasons. Observations made from above, below, and on the icefall itself, have shown that no crevasse can travel intact from the névé (Sector A) through the spillway (Sector B) of the icefall (Sector C). The great churning action, fracturing, and ablation which take place during the descent completely destroy the crevasses and seracs.

Leighton's (1951) and Miller's (1952a) original thrust-shearing hypothesis also appears to be inapplicable, at least to the Vaughan Lewis Glacier case, because in spite of a thorough search of the apron and lower glacier surfaces, no evidence of discrete low-angled shearing or of upthrusting of debris could be found.

The King and Lewis (1961) winter-summer theory has some merit, although it does not explain the wave-bands themselves. It is possible that the dark part of the ogive may be, in part, the result of dust being blown onto the ice surface during the transit through the icefall in the summer months.

Atherton's "regelation hypothesis" (1963) completely fails to explain the continuous white-ice layers in the

Vaughan Lewis Glacier wave-bands. Also, his suggestion that wave-bands originate within the icefall, by attenuation of velocity fluctuations through the effect of bedrock steps beneath the glacier in the icefall zone, does not explain why the Vaughan Lewis Glacier wave-bands are formed only below the icefall.

The compression hypothesis of Kamb (1964) comes closest to fitting the evidence of the present study. In his case, the Austerdals Glacier in Norway, he depicts the wave-bands as originating in the icefall proper and shows how brecciated avalanche debris may become incorporated between the wave-bands. This again, however, does not explain the icefolds or white-ice layers described in the Vaughan Lewis Glacier. A modification of the compression concept, however, appears to have merit in the present case.

Summary of Results and Conclusion

Although the following hypothesis may be far from complete, it provides what to the writer is a reasonable explanation of the sequence of events which could result in the genesis of the structural features which have been described on the Vaughan Lewis Glacier.

It has already been shown that a great deal of compression is present in the glacier in the lower part of its icefall and in the apron area immediately below the icefall. Supporting evidences for this lie in the movement data, the lack of transverse crevasses, the folding of the ice, the lateral expansion of ice, and the overall curvilinear shape of the icefolds and wave-bands. Such compressive flow is reflected in the icefall itself as far as the first fold, which has been described at the lower end of the main transverse or tension crevasses in the icefall. It is believed that the maximum compression, however, occurs farther down slope, probably at the true base of the icefall at about 4000 feet (1225 m) elevation. It is at this point that the glacier's surface has been deformed upward to relieve the stress of this powerful compression. This rise of the glacier's surface is the bulge of the first wave-band. It is also considered that the maximum stress effect is expressed in late winter or early spring, details of which are yet to be discussed.

To recapitulate, certain of the structural features which have been examined suggest an orderly and logical sequence of events. These features are (1) the white-ice layers and white-ice anticlines on the wave-bands; (2) the folds of ice in the icefall itself; (3) the white-ice layers in the icefall (all of the above in the icefall and wave-band zones Sectors B and C); and (4) the ogives of the lower glacier area, exposed partially in Sector C but mainly in Sector D. The white-ice layers in the wave-bands consist of fine-grained, non-foliated, white-ice and are continuous, sometimes extending across the total width of the glacier. This ice is extremely white, with no contamination, and with crystal sizes quite uniform throughout. The white-ice layers between folds in the icefall are similar to the white-ice in the wave-bands, although much wider. The white-ice layers occur between folds F-5 and F-9, while no white-ice layers occur between folds F-1 and F-5 (refer again to Fig. 20).

The relationship of these white-ice layers is important evidence with respect to the genesis of wave-bands. It is postulated that winter snow is trapped between the ice folds in the icefall during the accumulation season (see cross-sectional views in Fig. 32, Step 1). As these folds move with the glacier toward the base of the icefall, the compression increases thus forcing the icefolds closer together and initiating metamorphosis of the winter snow into fine-grained white-ice (Fig. 32, Step 2). As the folds reach the point of maximum compression at the base of the icefall (see Fig. 32, Step 3, depicting a hypothetical Step 2 segment moved onto a lower gradient section of the ice apron), two or more folds are raised into the initial bulge of a wave-band. Contemporaneous with this development, lateral expansion takes place as the glacier emerges from the icefall depths resulting in elongation of and thinning of the white-ice into layers (Fig. 32, Step 4). This does not, however, yet explain the white-ice anticlines. The process is the same as described above, but involves a discontinuity in the winter snow cover by protrusion of a small fold segment (see plan views in Fig. 33, Step 1). This fold segment (Step 2) becomes enveloped by the two larger folds resulting in development of a layer on either side of the small fold (Fig. 33, Step 3). These converge at the ends of the small fold into a single white-ice layer.

Then, when later elevated into the bulge of a wave-band, this structure resembles an eroded anticline (Fig. 33, Step 4).

The above explanation shows how the wave-band is comprised of two or more ice folds, and explains the presence of the white-ice layers as inlays within the glacier. As such, they persist for some distance down valley, eventually being ablated away--so that there should be no evidence of them even as relic structures in the terminal zone (Sector E). Examination of the ogives in glaciomorphic Sector D, however, did reveal that some white-ice layers occur in the light part, but few or none in the dark part of the ogives. No difference was noted between the ice crystals or foliation of the light and dark parts of these ogives except where white-ice layers have persited. It is believed that to a considerable extent the light part of the ogive in Sector D is due to presence of the white-ice layers and the dark part to the absence of white-ice layers.

At the point of wave-band attenuation, it was noted that the white-ice layers were on the upglacier side of the wave-bands. The transition from wave-band to ogive was subtle between Wave-Band 15 and Wave-Band (Ogive) 16 (Fig. 21). The leading edge of Wave-Band 15 had become the dark part of an ogive and the trough and upglacier side of Wave-Band 16 had become the light part of the ogive.

Using all of the above criteria, a hypothesis for the development of these banded structures in the Vaughan Lewis Glacier is presented as a concluding statement in this study (also see Freers, 1965a). It is generally accepted that the lower end of a glacier below the névé-line will move faster in summer than in winter (Sharp, 1951). It is also to be expected that the glacier in its icefall segment thins more by ablation during the summer than during the rest of the year. Therefore, if we make the assumptions that the glacier at the base of its icefall moves slightly faster in summer than in winter, and that accentuated summer ablation results in less ice flowing into the apron area at the base of the icefall, then the least compression at the base of the icefall must occur in summer. During the winter the opposite would pertain; i.e., the greatest compression. Such is reasonable also in that the greatest load (snowfall) would be at the end of winter. Thus the maximum bulge of the primary wave-band would be formed during and at the end of winter.

It is of corroborative interest that between the ice folds F-1 through F-5 in figure 20, no white-ice layers were found. This indicates that these folds did indeed form during the ablation season when new snow was not available to incorporate between the developing folds. Folds F-5 through F-9 were observed to have white-ice layers between them and hence are believed to have formed during the previous winter season when much snow was available for incorporation in the depressions between the folds. If any part of the glacier between Folds F-5 and F-9, with white-ice layers between them (Fig. 32), becomes elevated into a wave-band, these white-ice layers will come to represent the light part of a future ogive. Therefore, on this basis one wave-band with its swell and swale, will be formed each year; and the white-ice in this wave-band will represent the winter snow from the previous year. It follows that the 73 identifiable wave-bands in the glacier's total length may represent 73 years. If true, this suggests that the terminal ice is probably about a century old, and hence that all of the ice and associated structures which have been described are of a correspondingly lesser age.

As discussed earlier, streaming flow is dominant on the lower Vaughan Lewis Glacier. This type of flow suggests a tendency towards a negative regime or negative total mass budget in the glacier system. This would at first appear in error in view of the healthy névé zone conditions described. However, this can be explained by the previously cited area-elevation comparisons and the 2 to 1 nourishment to wastage ratio on the Vaughan Lewis Glacier versus the 6 to 1 ratio on the Taku Glacier, the latter of which is in a very healthy advancing state at its terminus. If the concept of one set of wave-bands produced annually is correct, with the corollary that the total age for the Vaughan Lewis Glacier is 73 years to a century old, then the glacier's regime, at least over the past 73 years, has been regressive or negative in total effect. The glacial geological, geomorphic, and geobotanical evidence cited by Beschel and Egan (1965), Miller (1956 and 1963), and Miller and Prather (1965) corroborates this conclusion; and in fact substantiates that this glacier and its neighboring glacier systems have been in a downwasting state for most of the past four centuries. Such a conclusion is in marked contrast to that described elsewhere regarding the past regime of the adjoining Taku Glacier. For such reasons, a complete understanding of the wave-bands and ogive patterns, so beautifully displayed in the Vaughan Lewis Glacier, is of greater significance than might be attached to a purely structural interpretation.

IV. SUGGESTED ADDITIONAL INVESTIGATIONS

As pointed out in the last paragraph of the previous chapter, a structural interpretation does not reveal all of the glaciological implications of wave-bands and their associated ogive structures. Further investigations will not only add to the knowledge of glaciotectonics in the structures described, but may also increase the understanding of the glacier's "open system" as related to climatic cycles.

To accomplish these aims a sound program of investigation should include many techniques, some of which have already been invoked in a continuing study of this phenomenon by the Juneau Icefield Research Program. The technique of terrestial photogrammetry for precise mapping of wave-bands and surface structures is essential, as there is no more accurate way to record changes of structure, orientation and form of individual wave-bands as they move downglacier. In this regard, motion parallax study of movement in the icefall itself might be rewarding. A more comprehensive and thorough stress-tensor study at the base of the icefall and on the wave-bands also would clarify the type and magnitude of stress at the surface of the glacier. In conjunction with these, knowledge of the bedrock topography, determined by very detailed geophysical depth soundings on key transects, would contribute to the overall information of the characteristics of the physical environment acting on the glacier.

Systematic analysis of entrained particulates, both organic and inorganic, and both in the névé and in the light and dark parts of the wave-bands and ogives, might result in additional evidence with respect to the concept of annual pulsation. A petrofabric analysis of ice cores in the white-ice and bubbly glacier ice would especially lead to significant results, as related to mechanics of deformation in the icefall and associated wave-band zones. And lastly, more detailed and continuous firn stratigraphy, glaciothermal, and movement studies should be conducted in the region of the Vaughan Lewis névé, to elucidate the control of weather parameters, especially englacial temperature effects, on the volume of ice passing into the lower valley.

Such further studies so aimed should result in a fuller understanding of the combined effects of continuous versus discontinuous movements in icefall glaciers. They will also point the way toward a better understanding of the basic role of climatic pulsations and their effects on glaciers.

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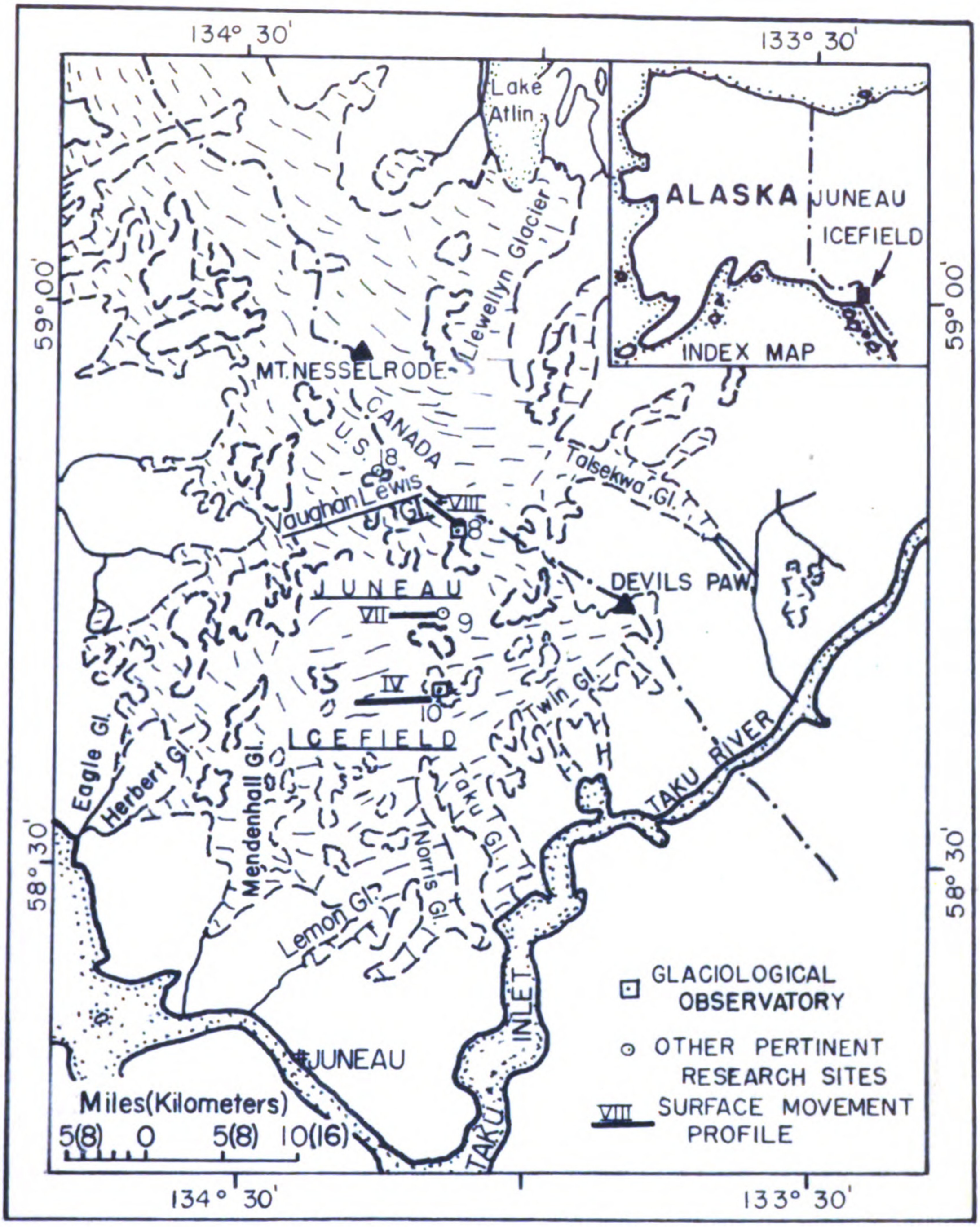


Fig. 1.--Juneau Icefield, Alaska, with index map

Fig. 2.--Oblique aerial photo of the Vaughan Lewis Glacier icefall and wave-bands (Photo by C. P. Egan, 27 September 1963).

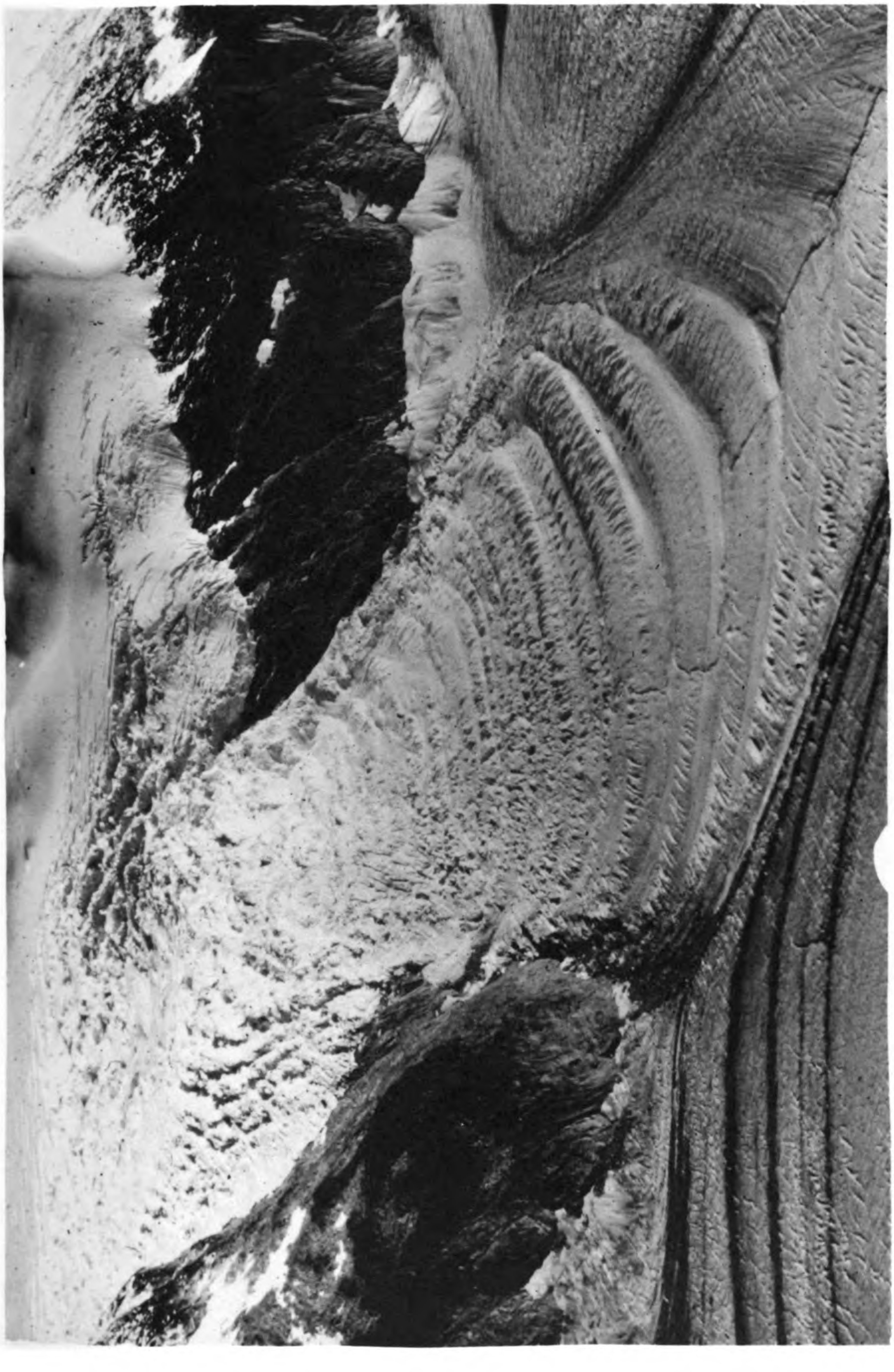


Figure 2

Fig. 3.--Vertical aerial photo of lower Vaughan Lewis Glacier showing ogives in Sector D and the terminal area Sector E. Note ice-dammed lake at each of termini (U. S. Navy Photograph, 11 July 1948).

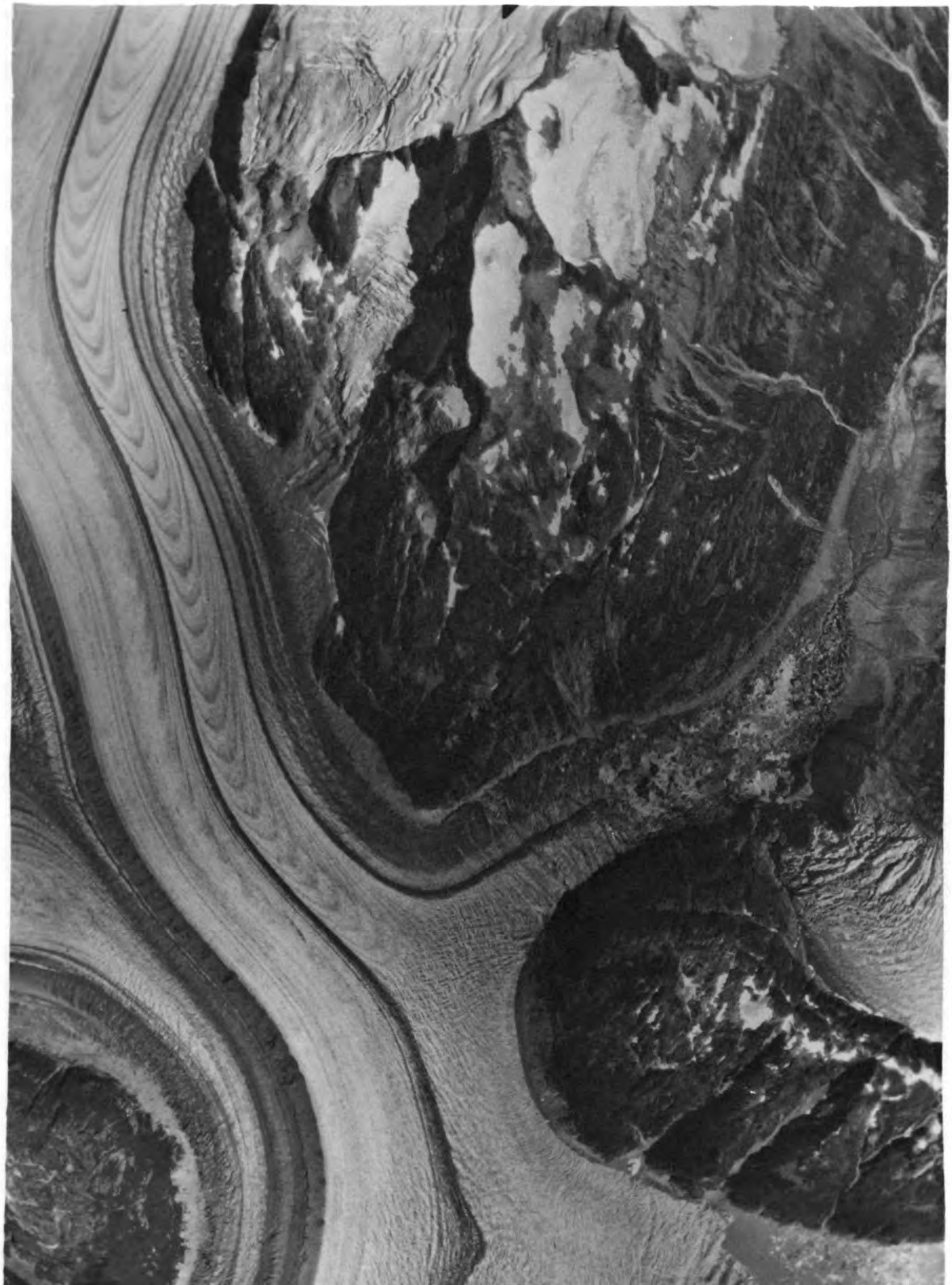
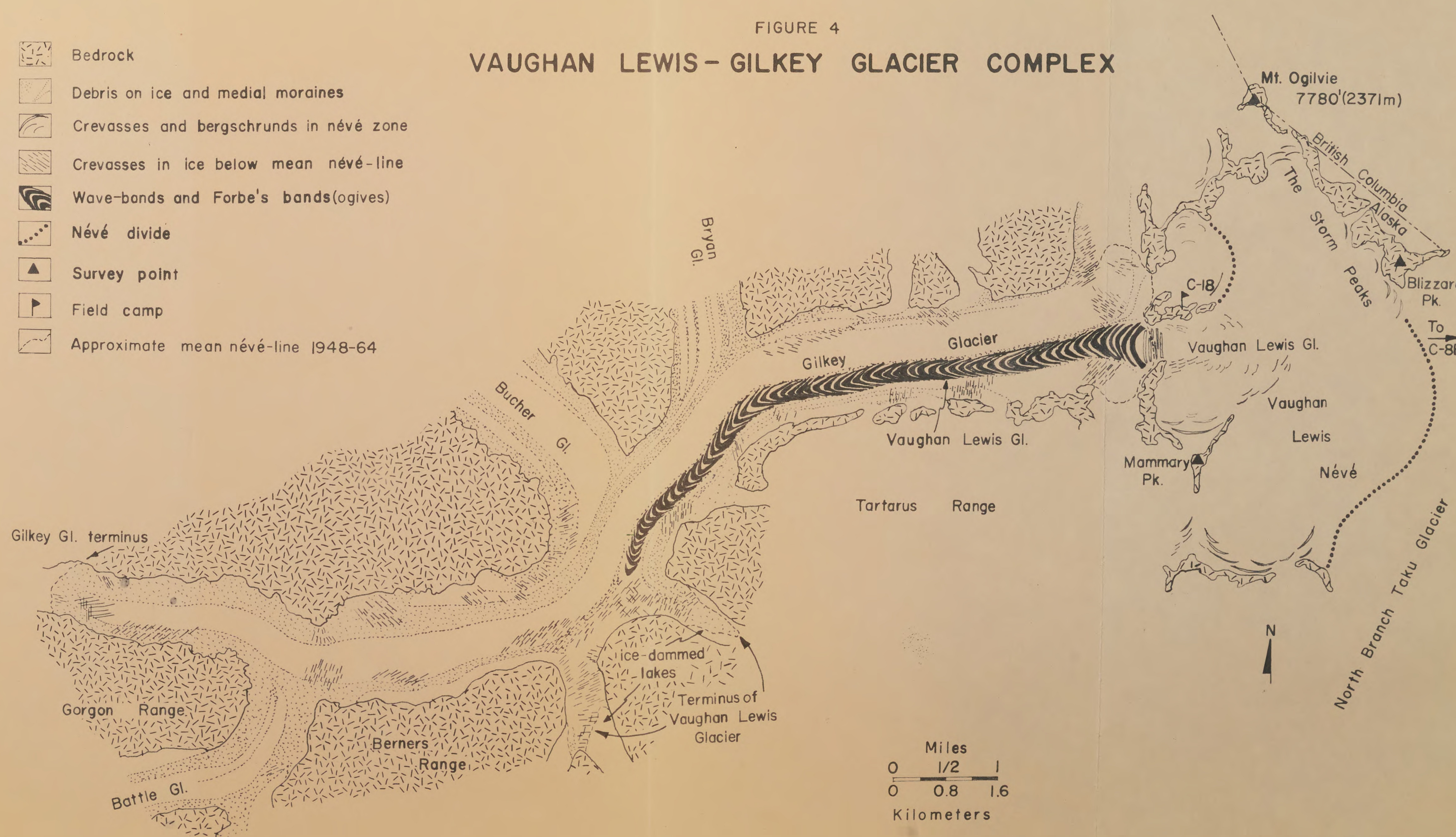


Figure 3

FIGURE 4

VAUGHAN LEWIS - GILKEY GLACIER COMPLEX



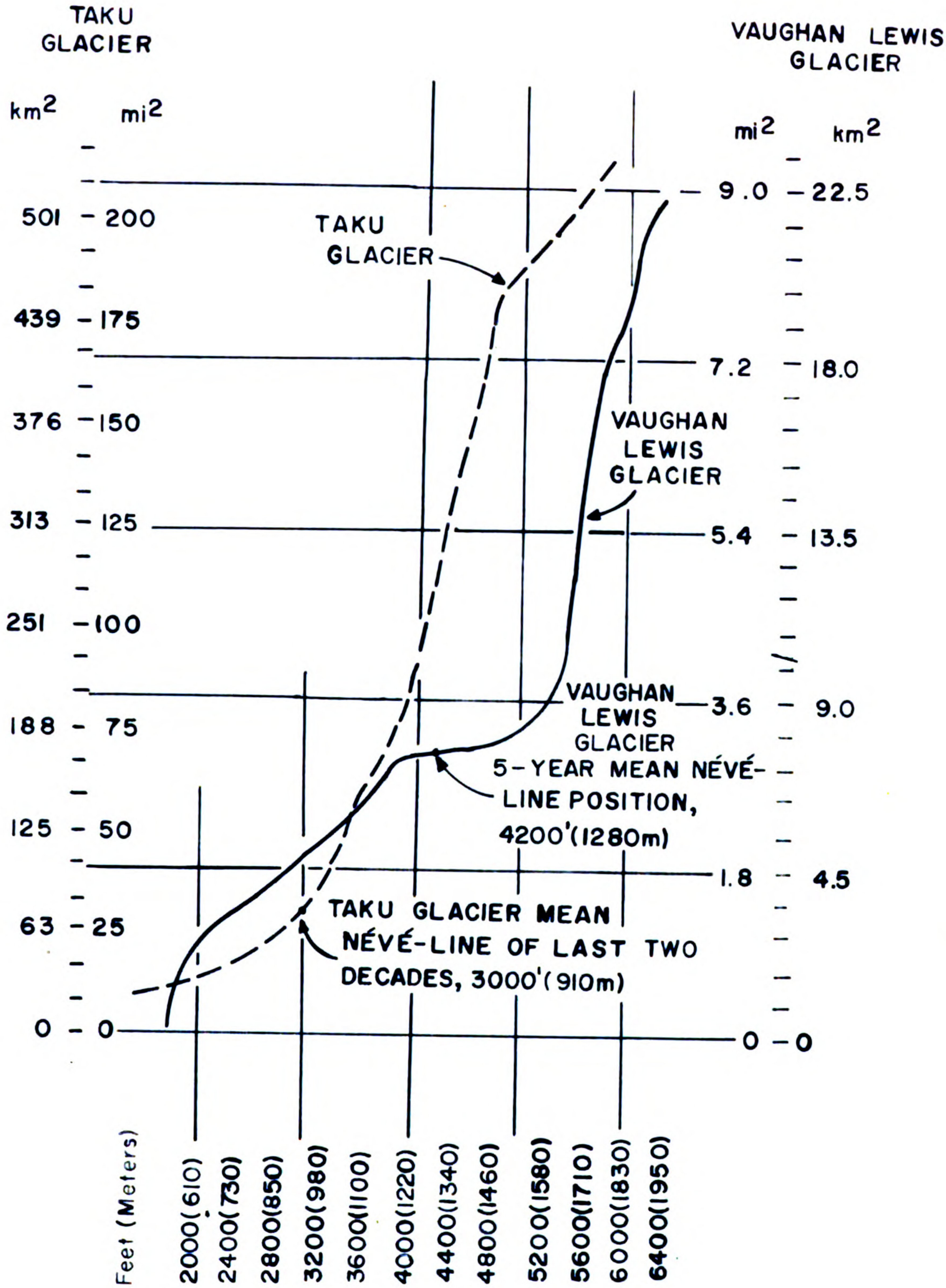


Fig. 5.--Cumulative area curves of the Vaughan Lewis and Taku Glaciers representing total areas below successive 200-foot (60 m) contours.

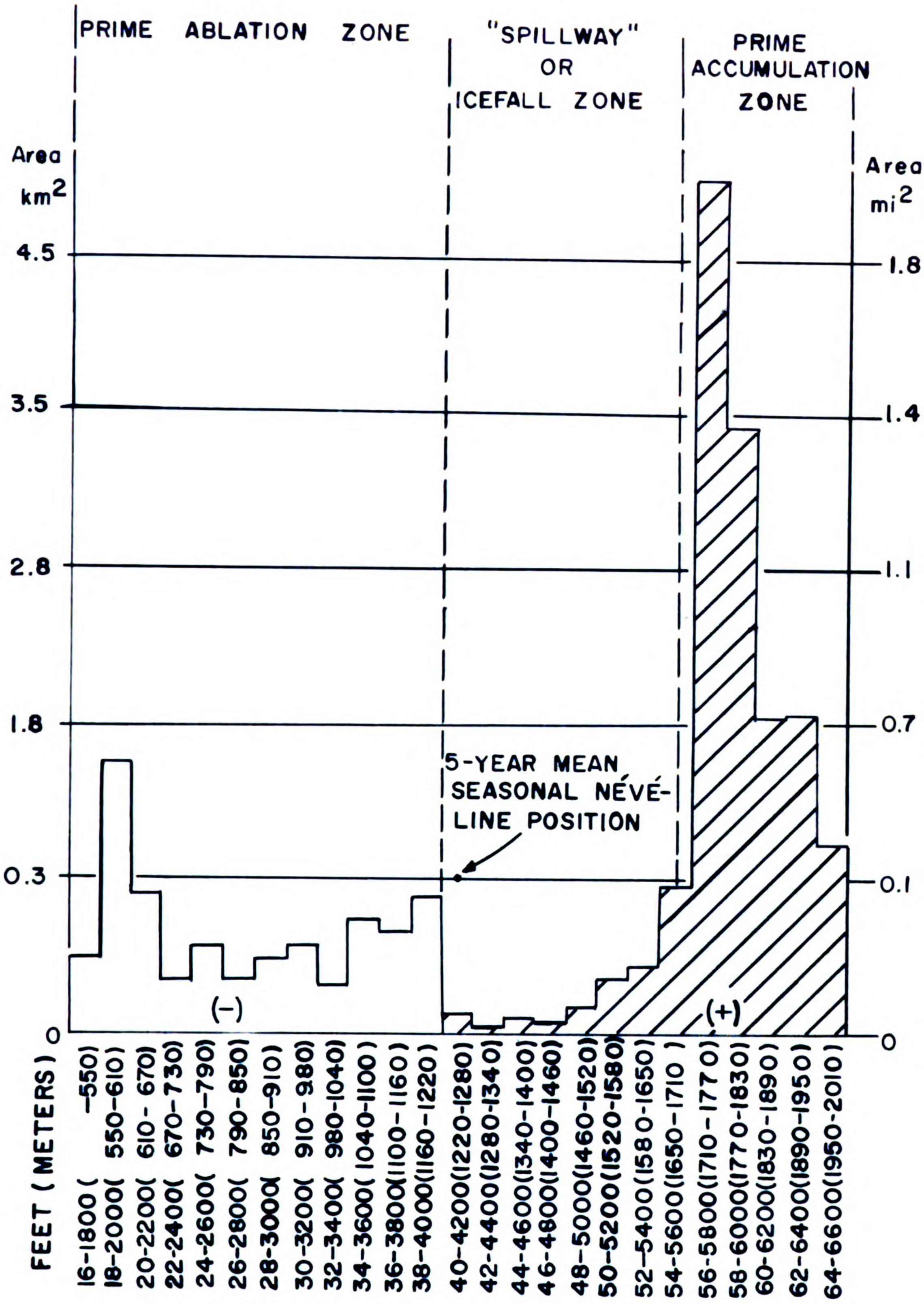


Fig. 6.--Vaughan Lewis Glacier area-elevation histograms showing area between successive 200-foot (60 m) contours.

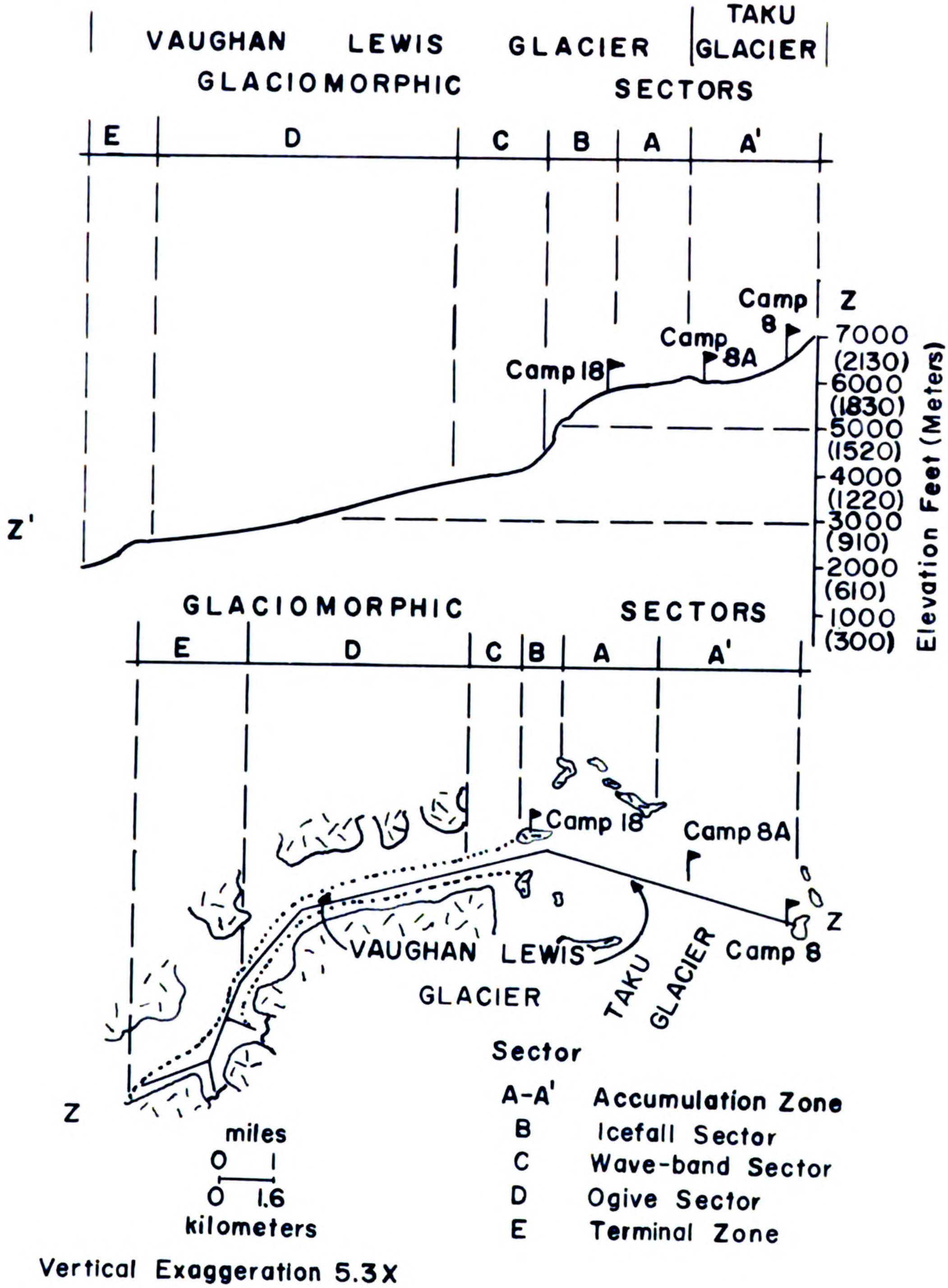


Fig. 7.--Glaciomorphic sectors or regime zones of the Vaughan Lewis Glacier.

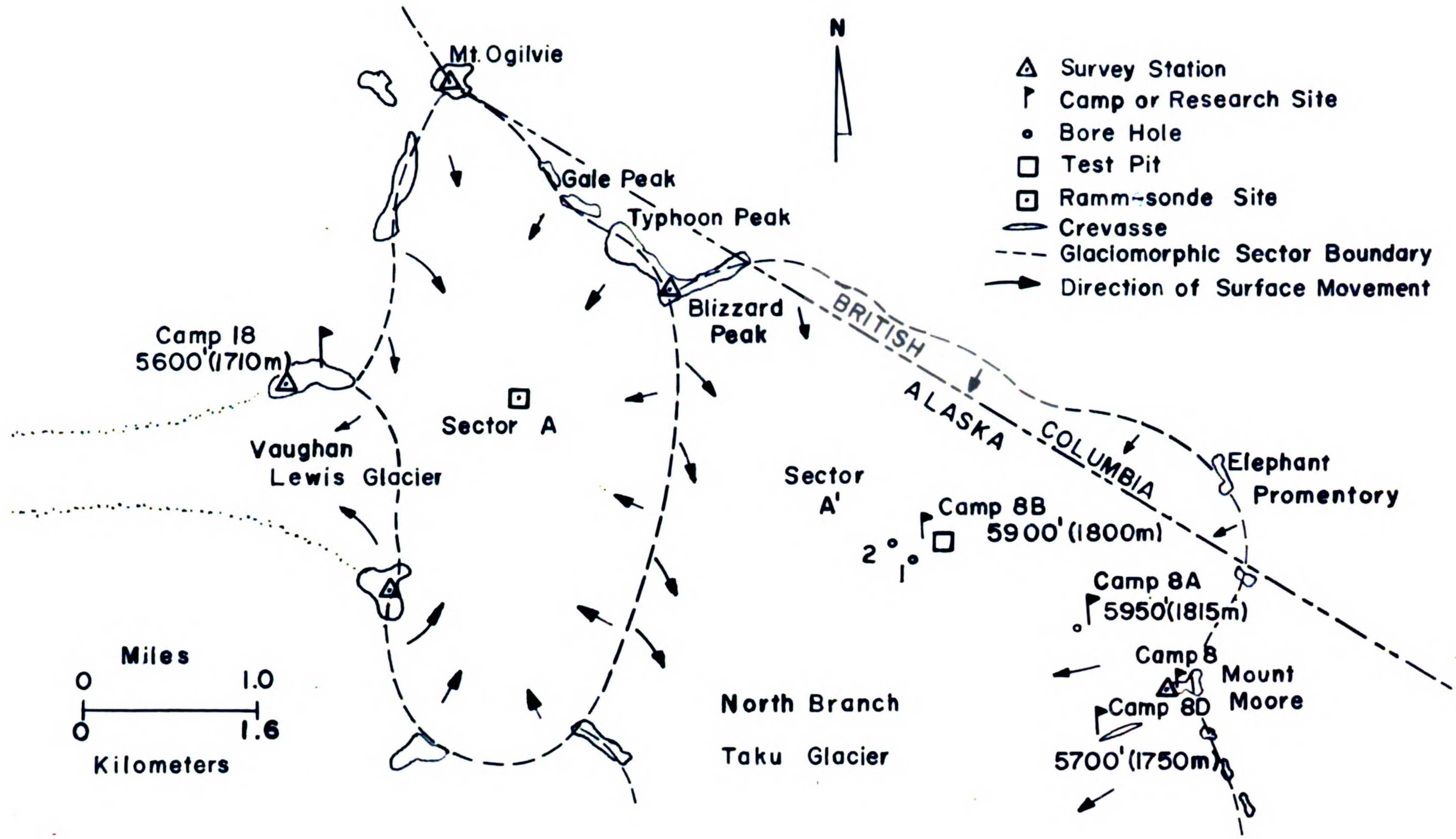


Fig. 8.--Schematic map of zone A-A' Taku-Vaughan Lewis Glaciers, showing névé limits and location of main research sites.

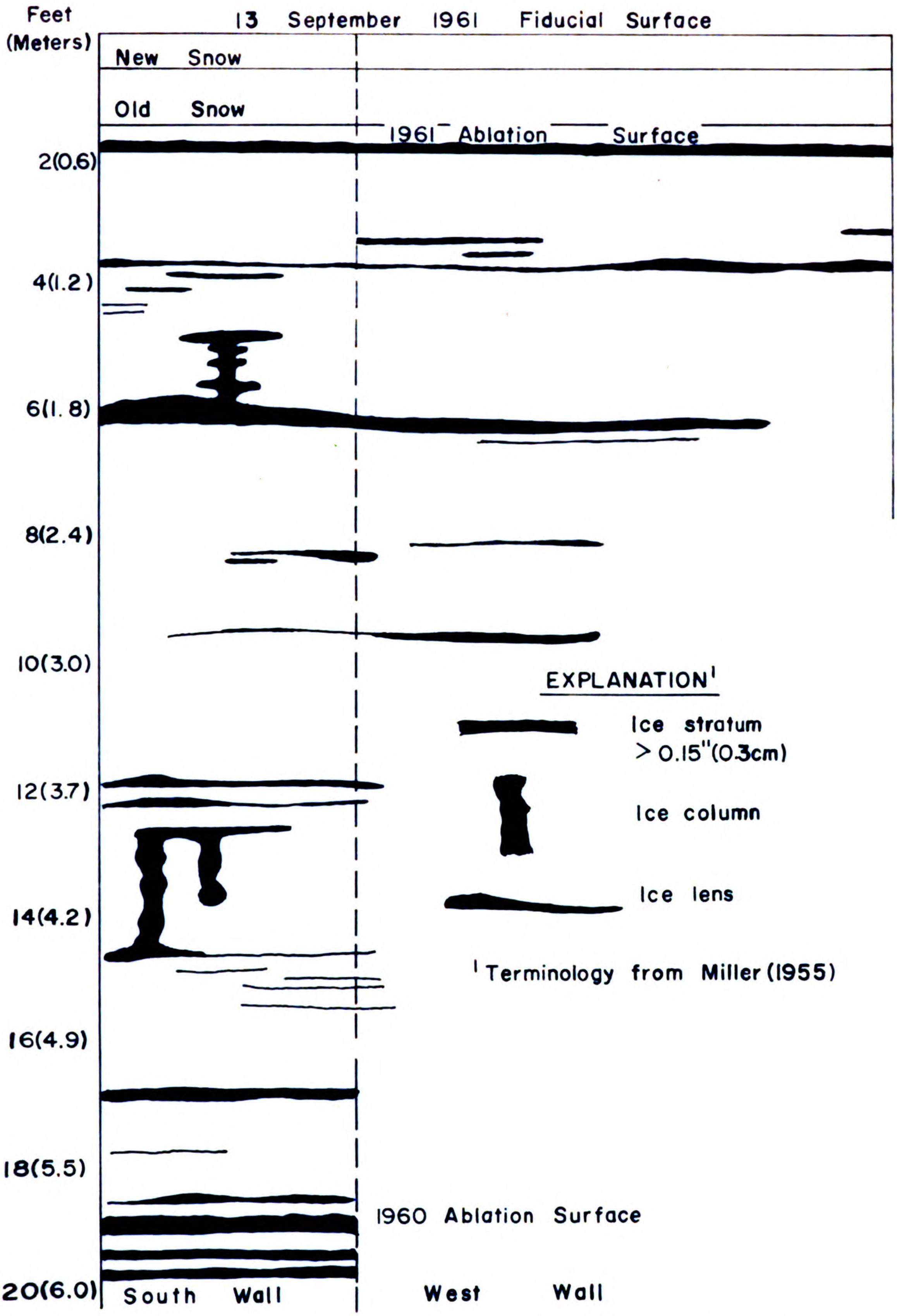


Fig. 9.--Stratigraphy of main test pit at Camp 8B in late August, 1961. (In cooperation with Andress, 1962)

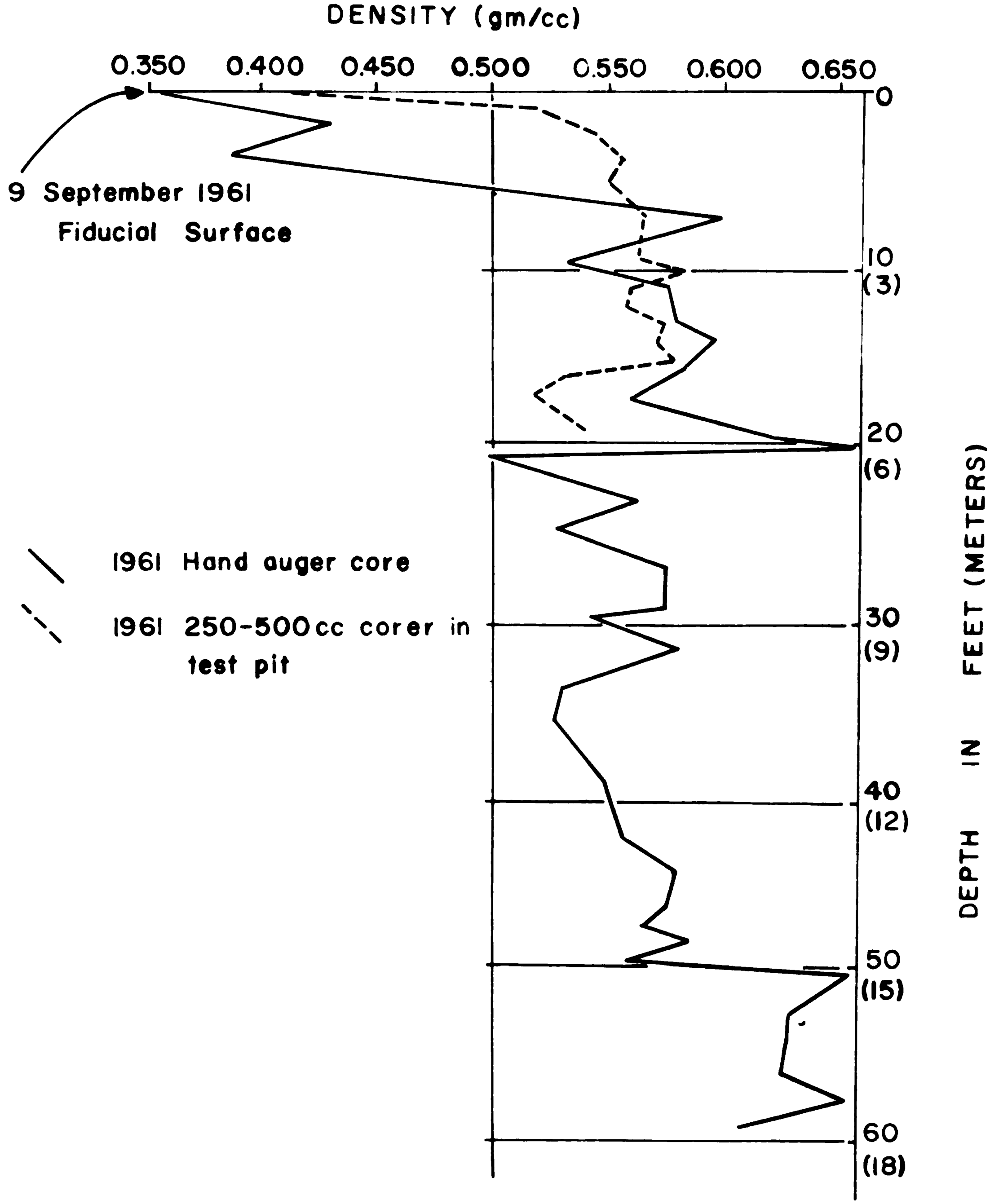


Fig. 10.--1961 density profiles of upper firn in Vaughan Lewis-Taku glaciomorphic Sector A' (Camp 8B).

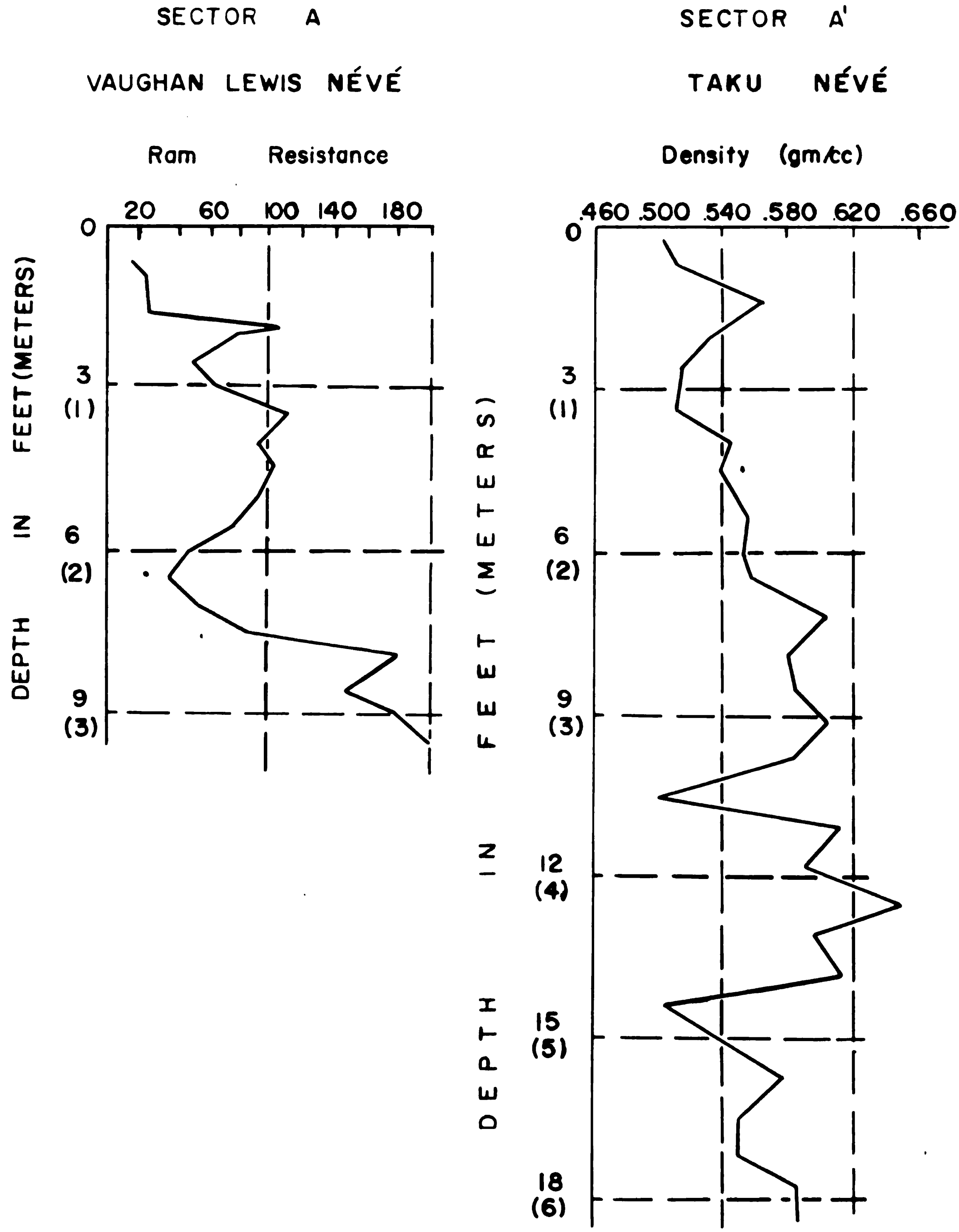


Fig. 11.--Density profile in 1963 firn, Site 8B (Taku Glacier) and ramm-sonde profile, Sector A (Vaughan Lewis Glacier).

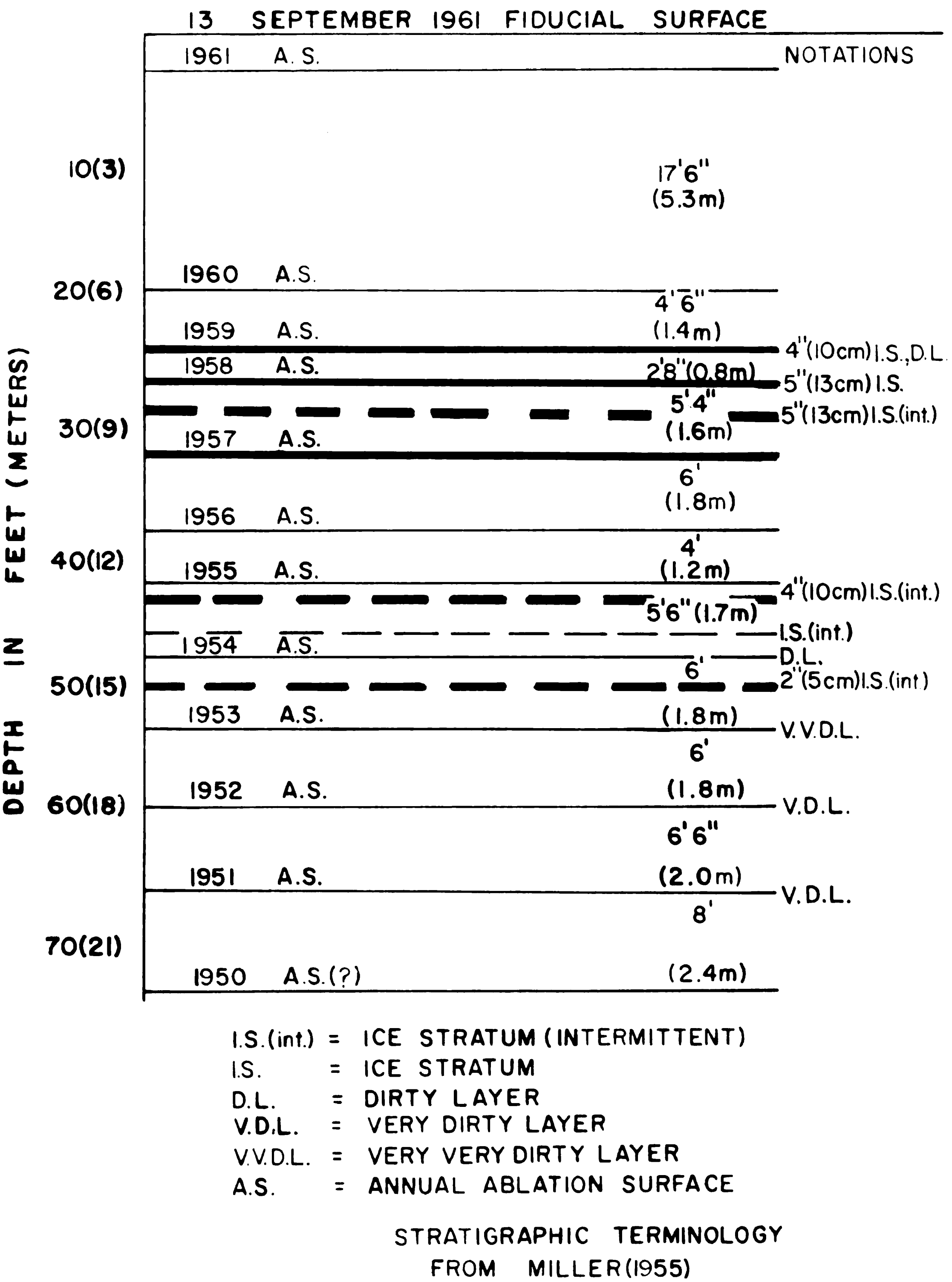


Fig. 12.--Stratigraphy of crevasse wall, upper Taku Glacier, Site 8D, elev. 5700 feet (1750 m), September, 1961. (After Andress, 1962)

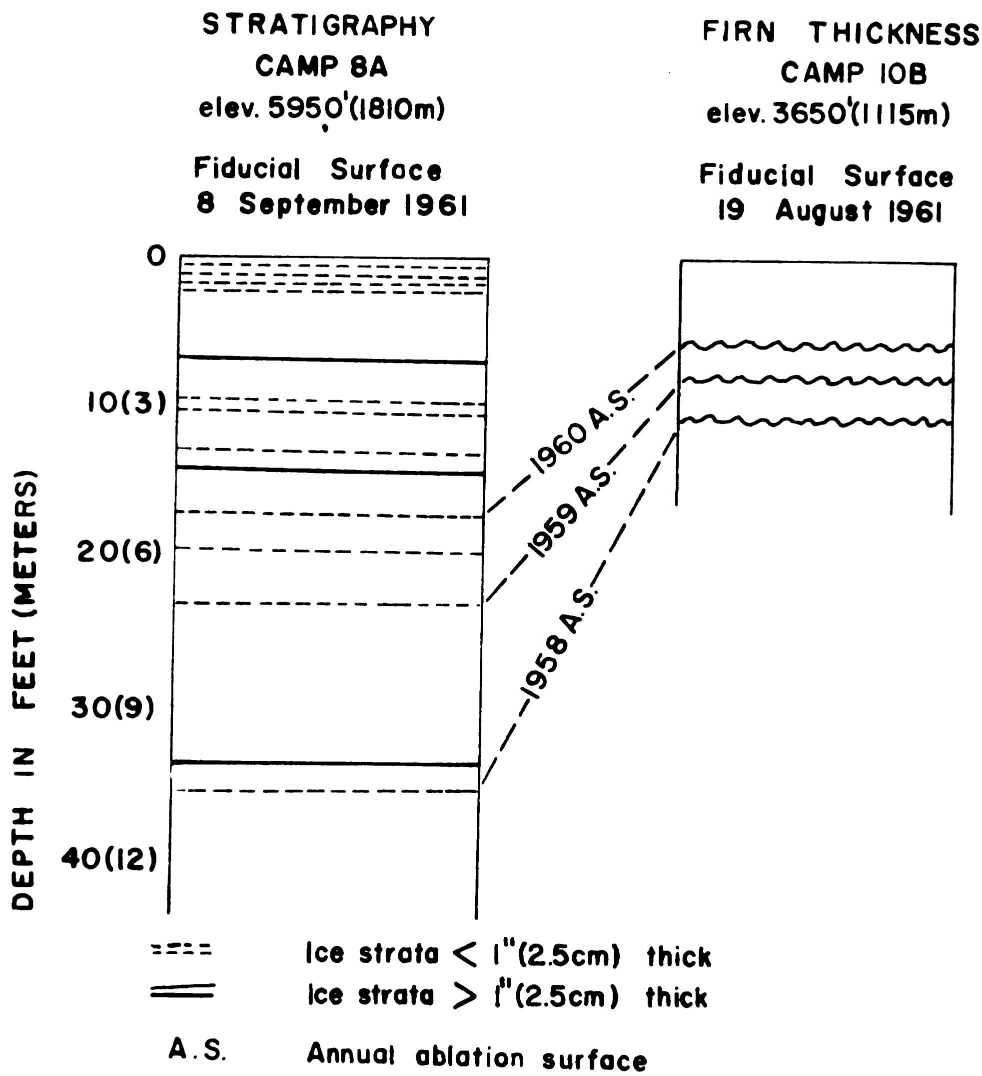


Fig. 13.--Stratigraphy at Site 8A and firn thickness at Site 10B measured from hand auger cores. (After Andress, 1962)

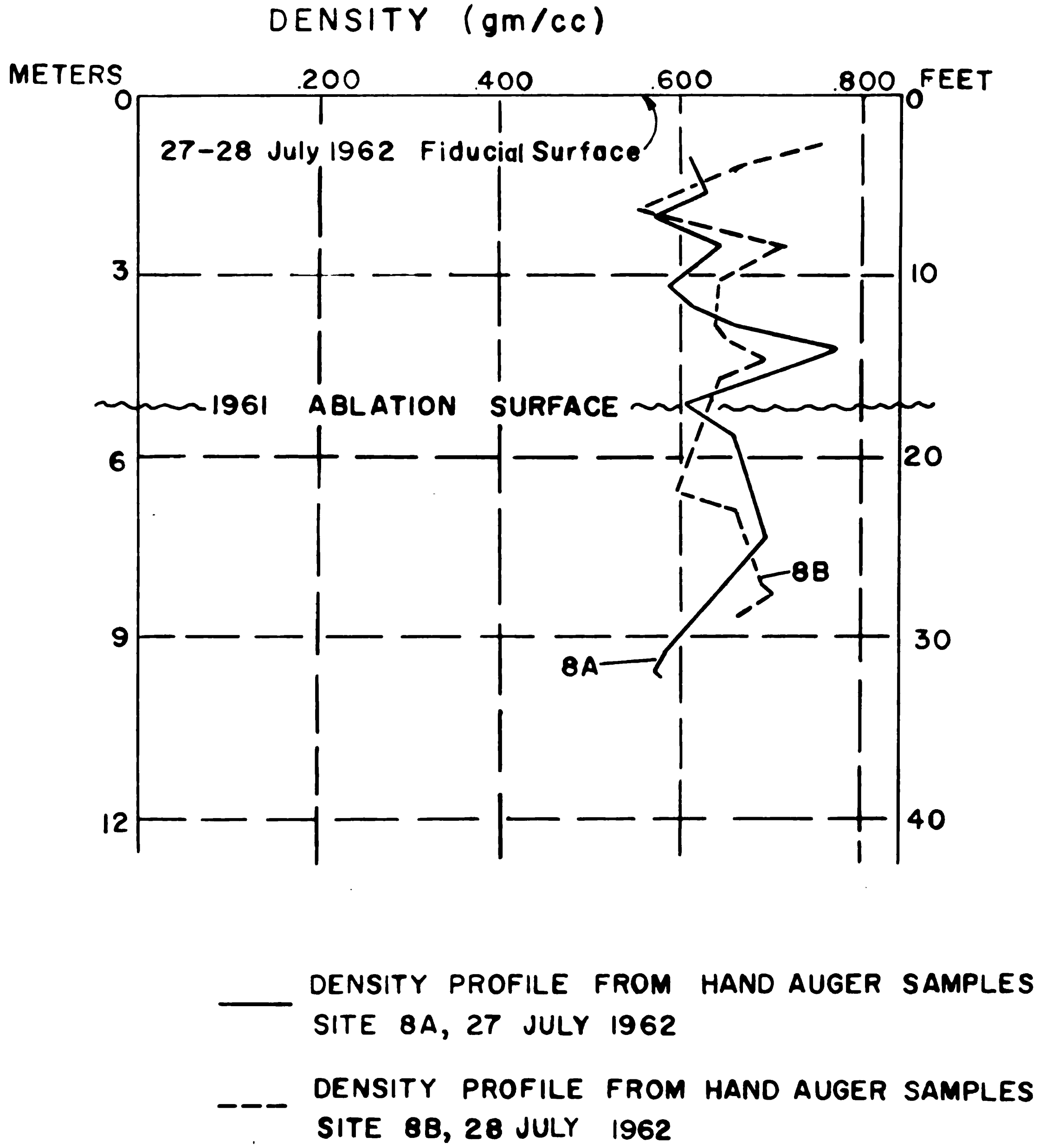


Fig. 14.--Density profile, Sector A', Sites 8A and 8B, upper Taku Glacier névé.

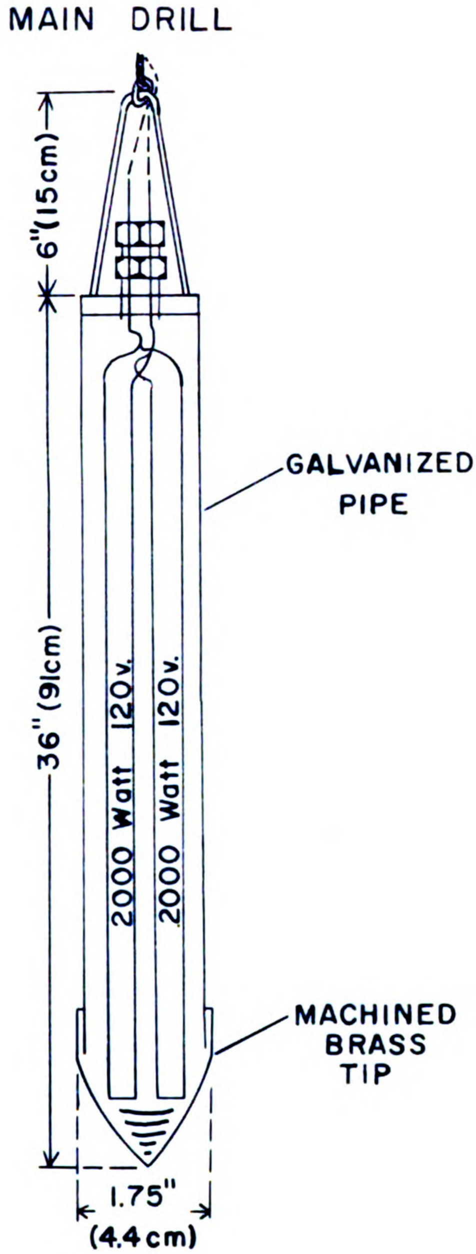


Fig. 15.--Electrothermal glacier drill, 2000-watt element; 120-volt wiring detail as used at Site 8A, upper Taku Glacier, elev. 5900 feet (1800 m), August-September, 1961. (After Andress, 1962)

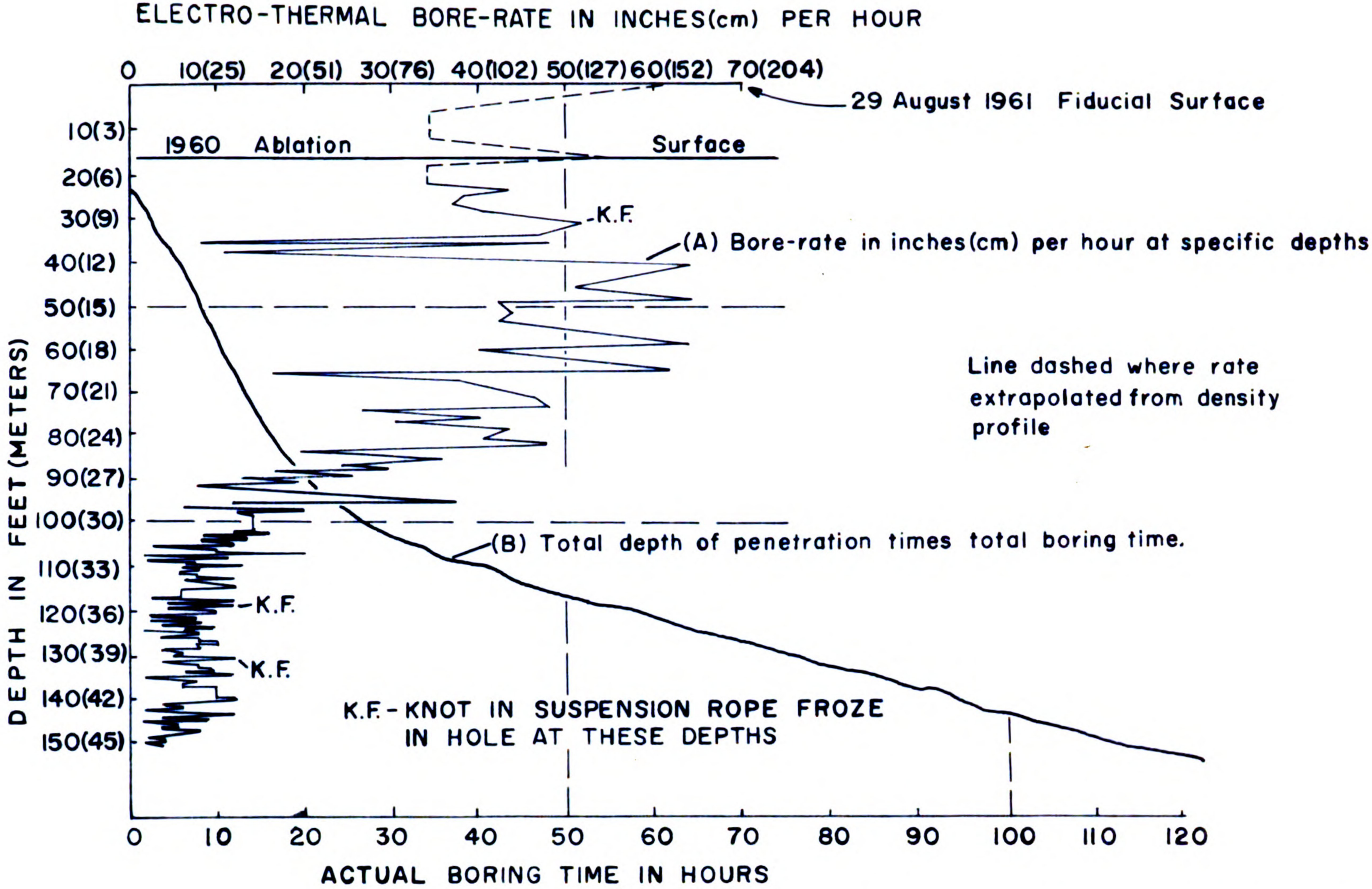


Fig. 16.--Electrothermal borer bore-rate and depth-of-penetration time at Site 8A, 29 August to 4 September 1961.

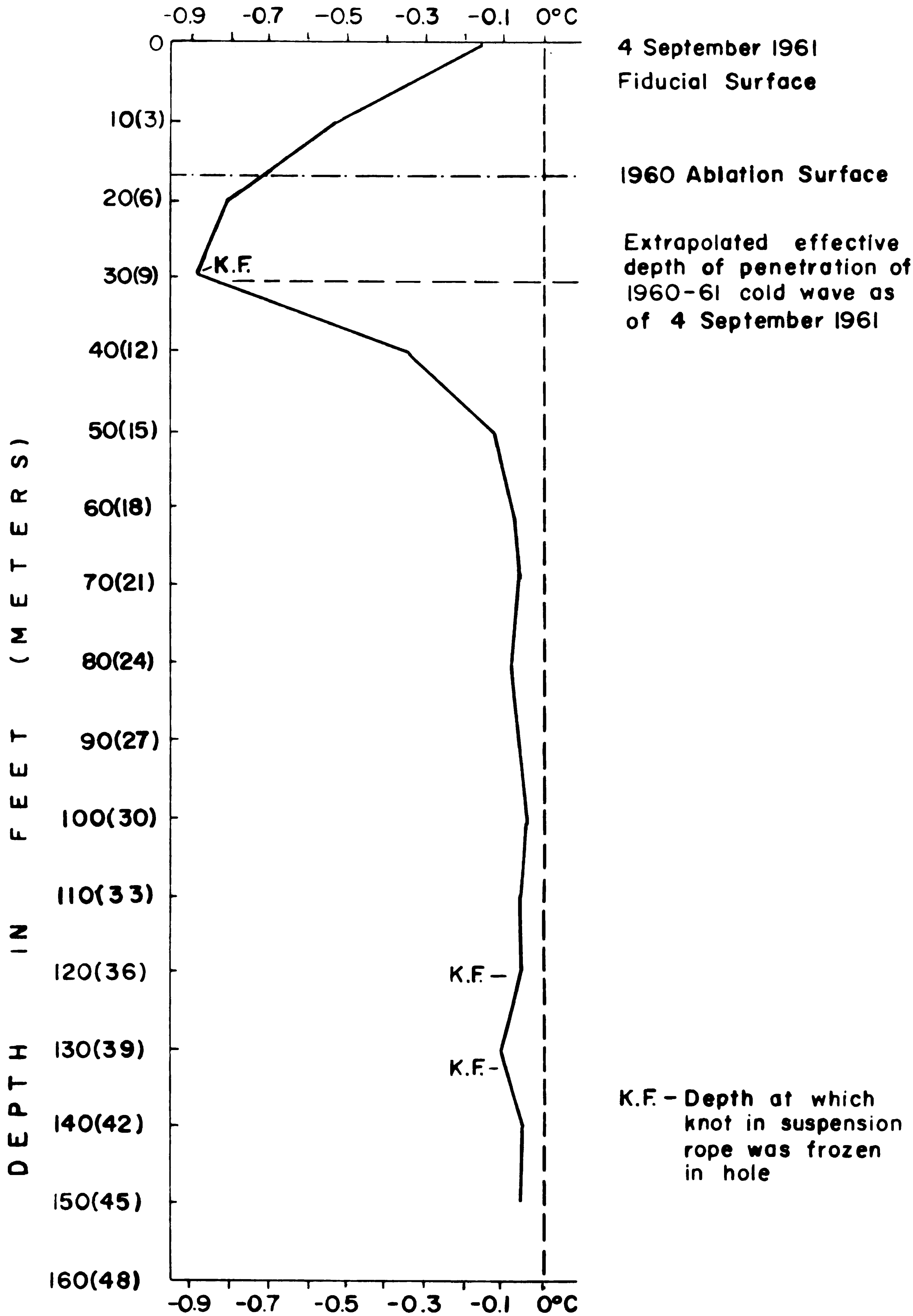


Fig. 17.--Englacial temperature profile in electro-thermal bore hole at Site 8A, Sector A', as of 4 September 1961.

Fig. 18.--Recumbent isoclinal fold in bubbly glacier ice, north side of glacier, near base of Vaughan Lewis icefall (Photo by T. F. Freers, 9 September 1961).

Figure 18

Fig. 19.--Surface expression of white-ice layers on crest of wave-band in Sector C. View looking across glacier toward south (Photo by T. F. Freers, 10 September 1961).

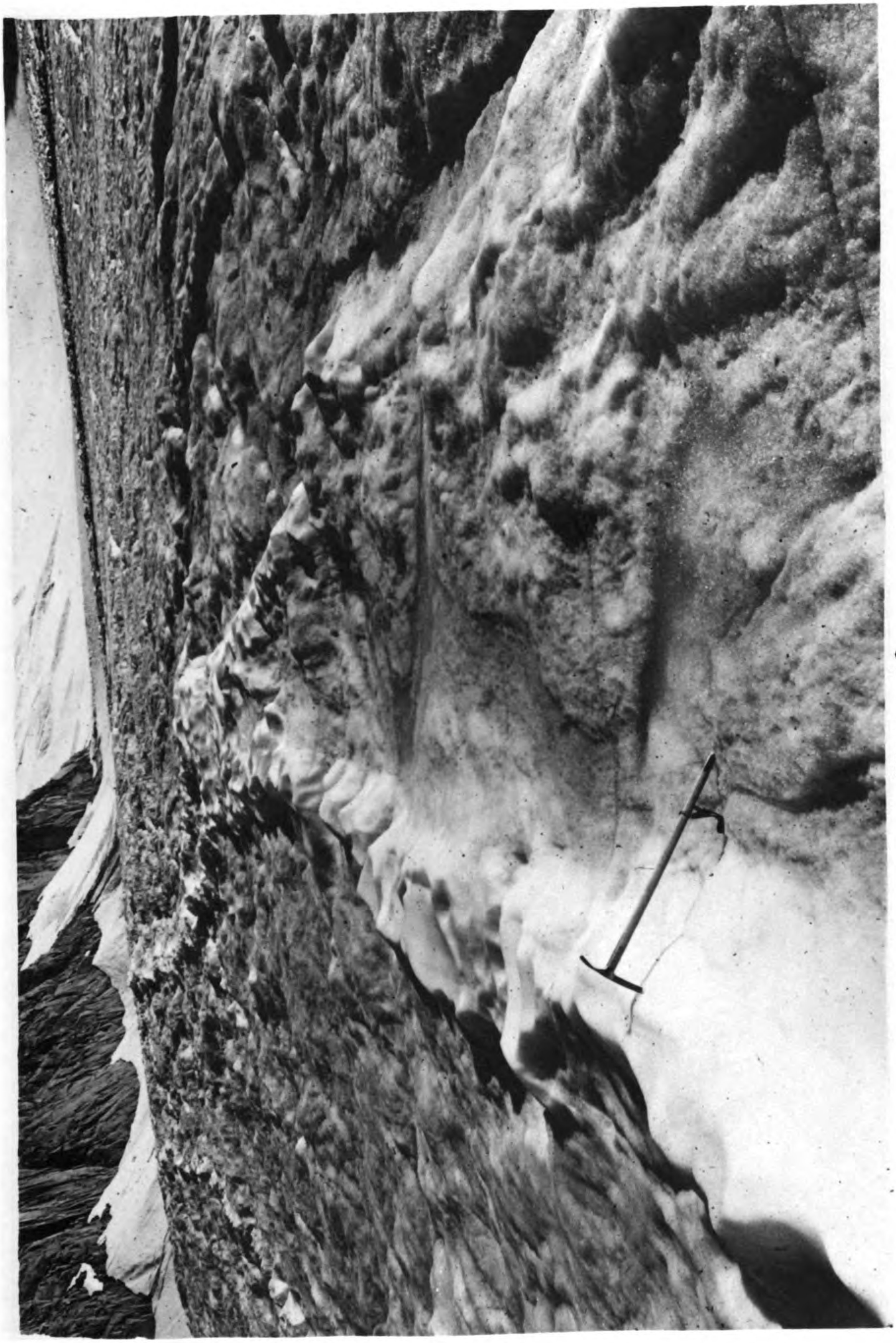


Figure 19

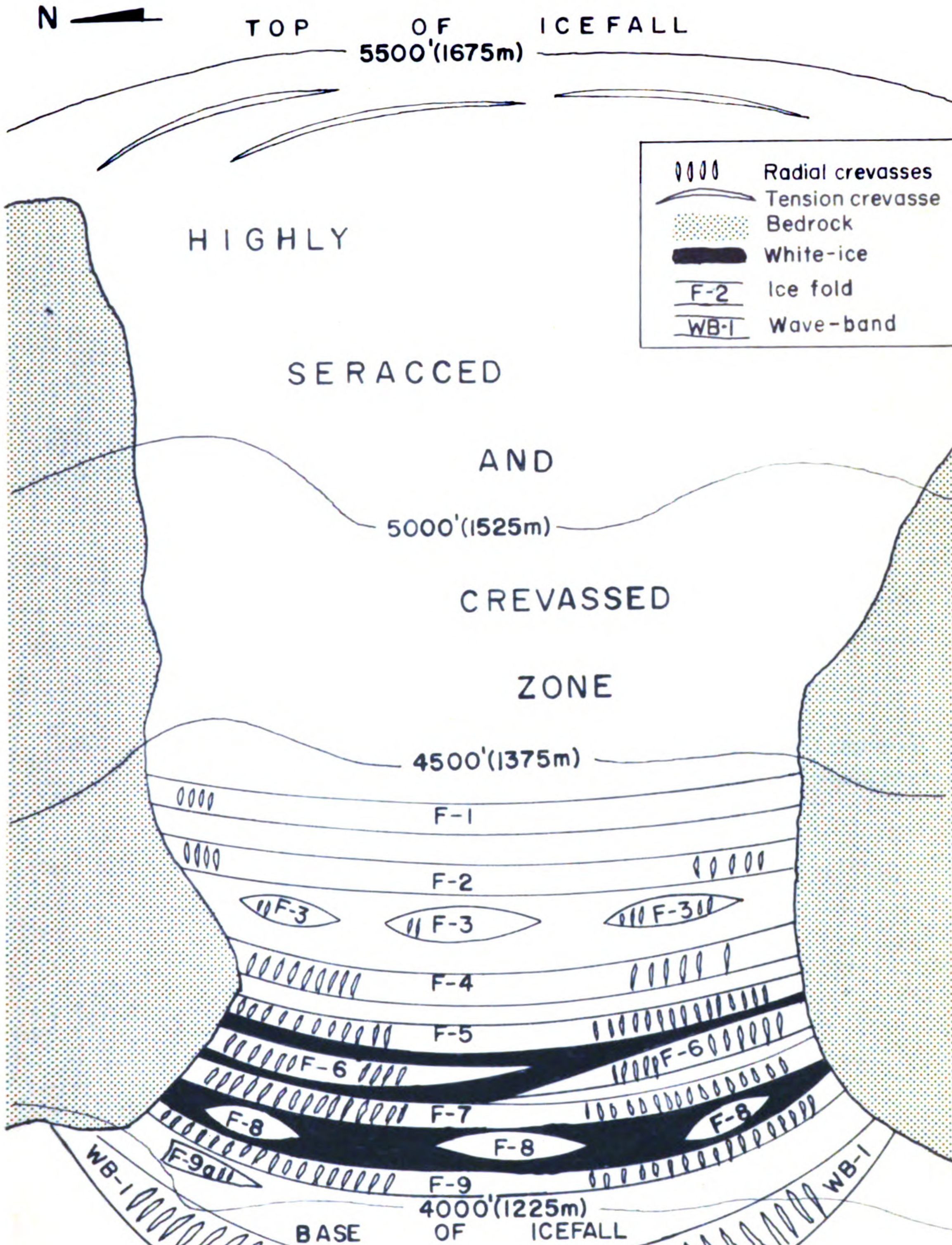


Fig. 20.--Schematic representation of the Vaughan Lewis icefall, Sector B, showing relationship of main structural features between 4000 and 5000 feet (1225 and 1675 m) elevation.

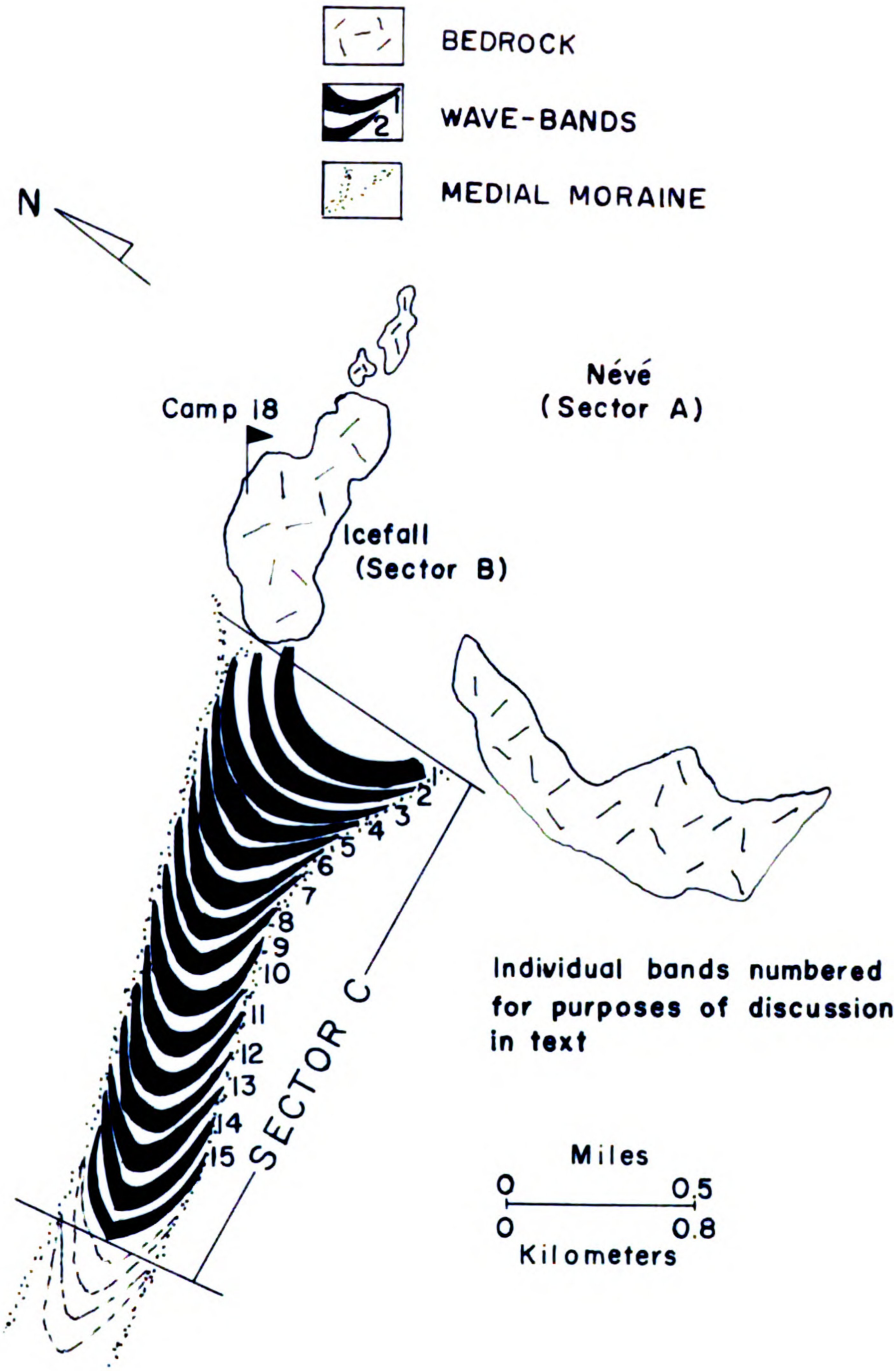


Fig. 21.--Area of wave-bands, Sector C, on the Vaughan Lewis Glacier.

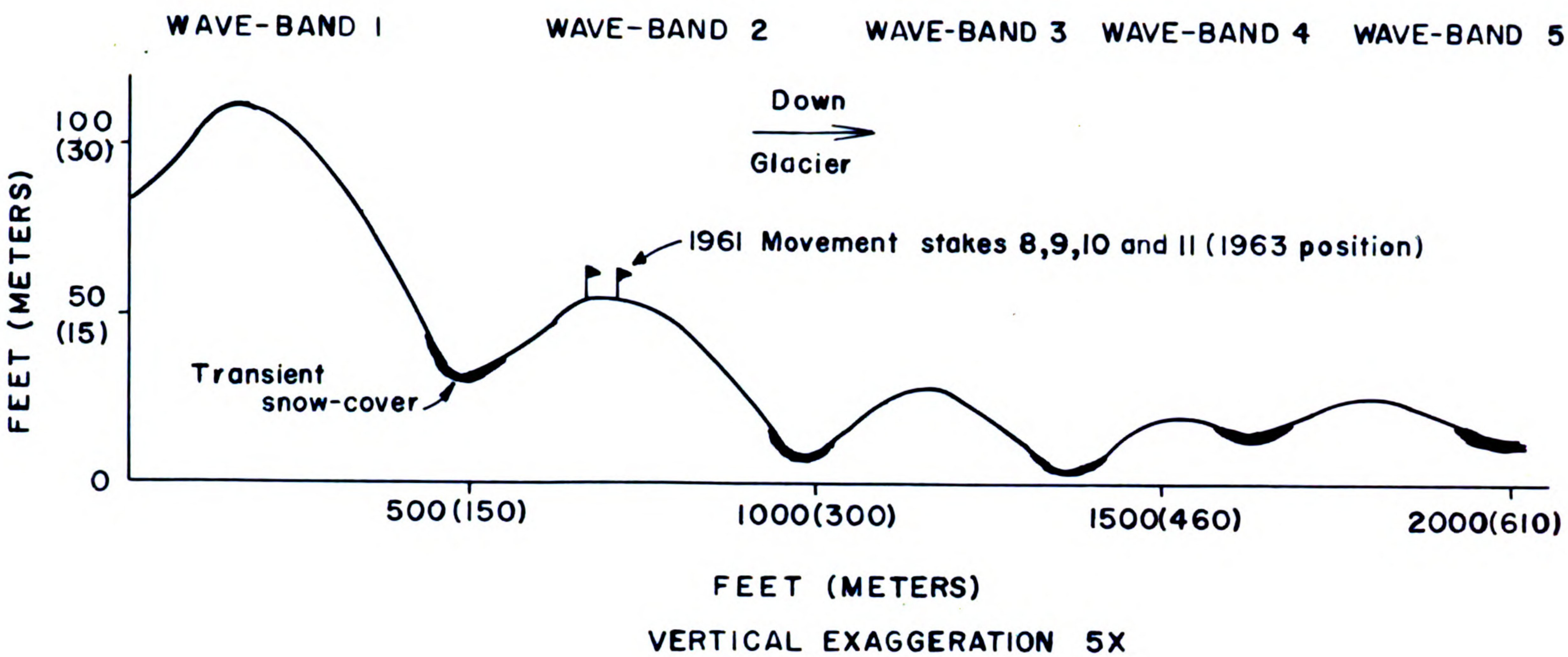


Fig. 22.--Cross-sectional surface profile of Wave-Bands 1 to 5 along the centerline of the Vaughan Lewis Glacier (September, 1963).

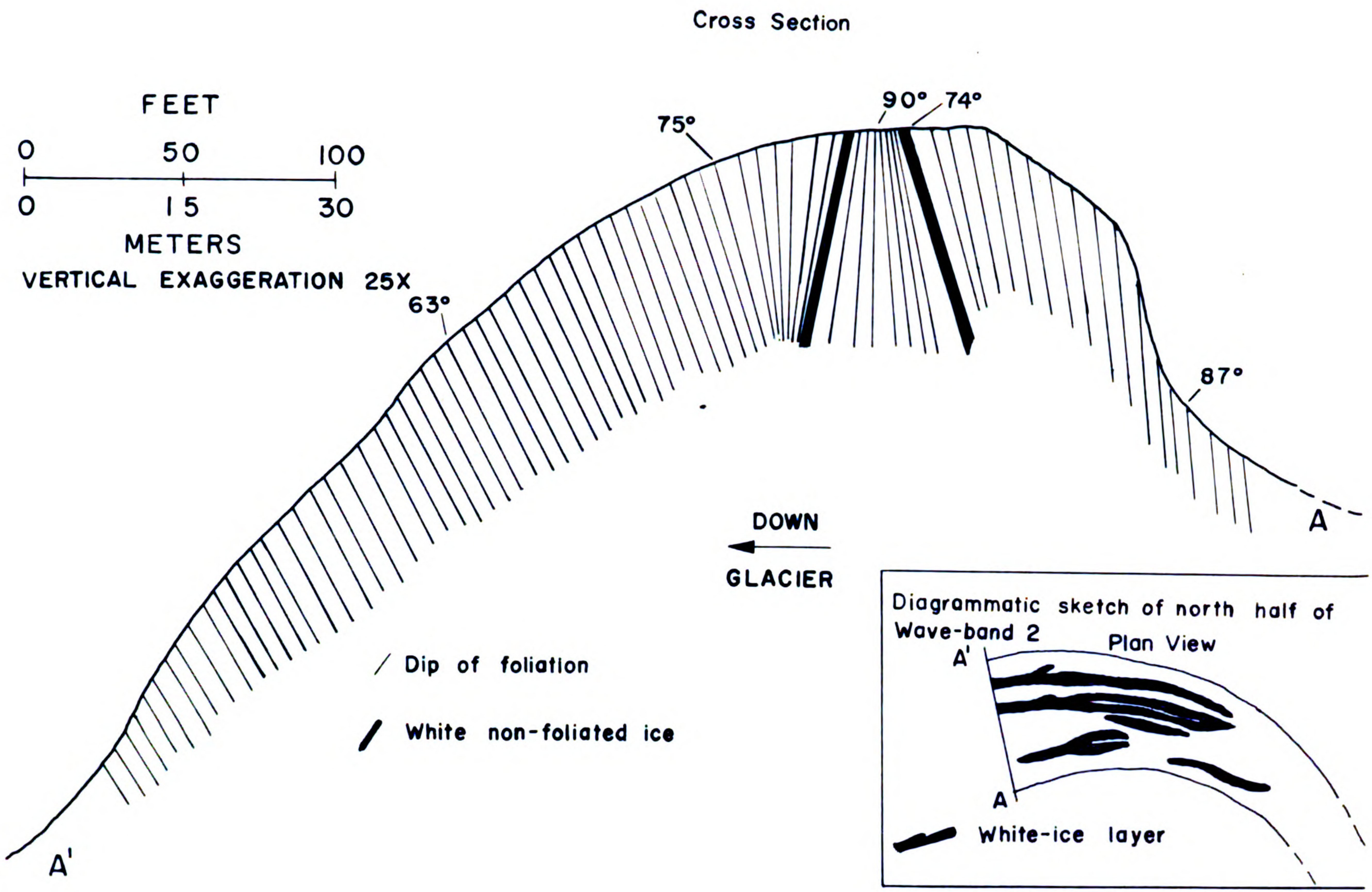


Fig. 23.--Wave-Band 2 showing foliation and non-foliated white-ice along a crevasse wall (September, 1963).

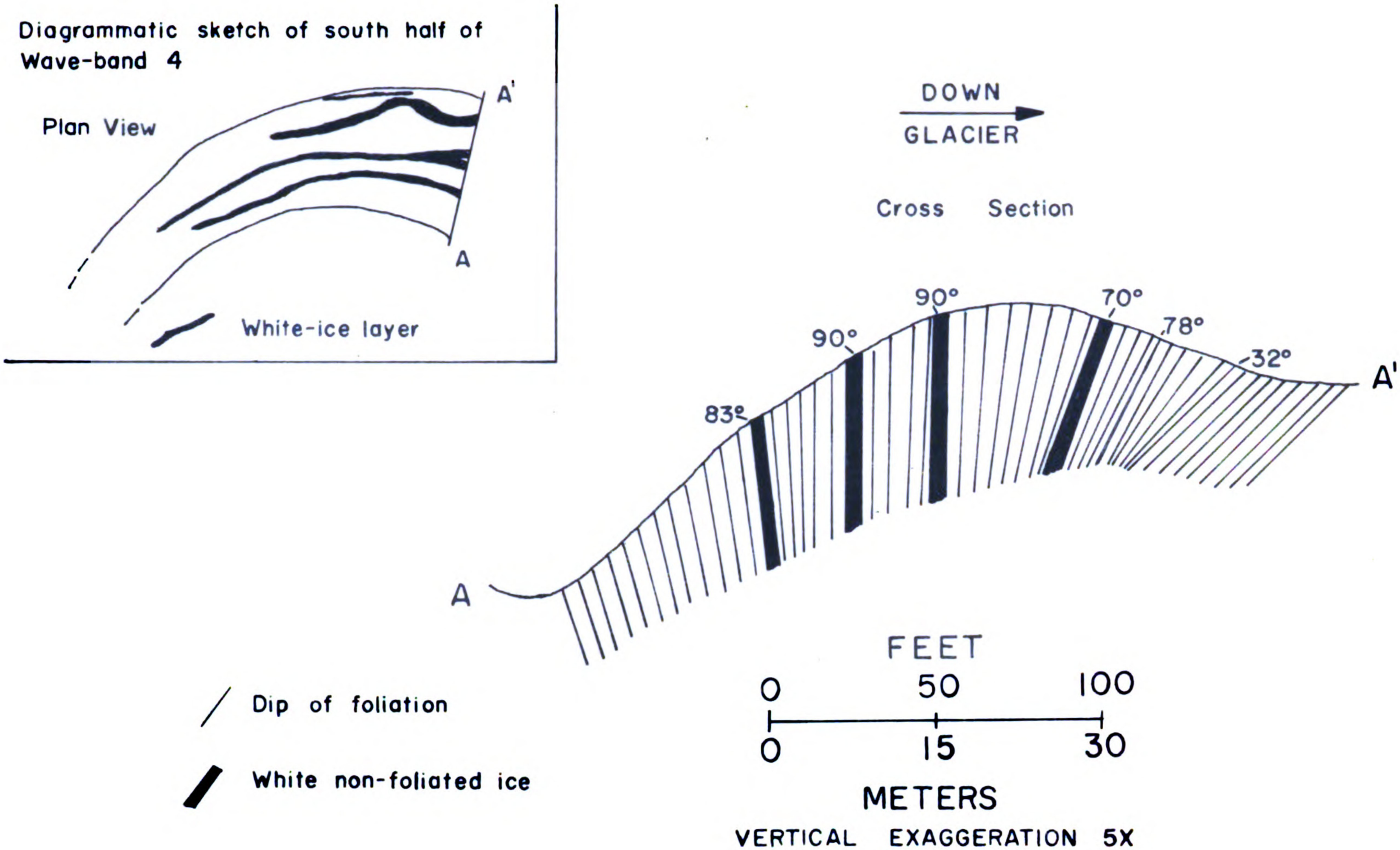


Fig. 24.--Wave-Band 4 showing foliation and non-foliated white-ice along a crevasse wall (September, 1963).

Fig. 25.--Photo of smooth relatively unbroken white-ice cores and rough broken bubbly glacier ice cores. Cores taken within a yard (meter) of each other in Sector C. (Photo by T. F. Freers, 10 September 1961).

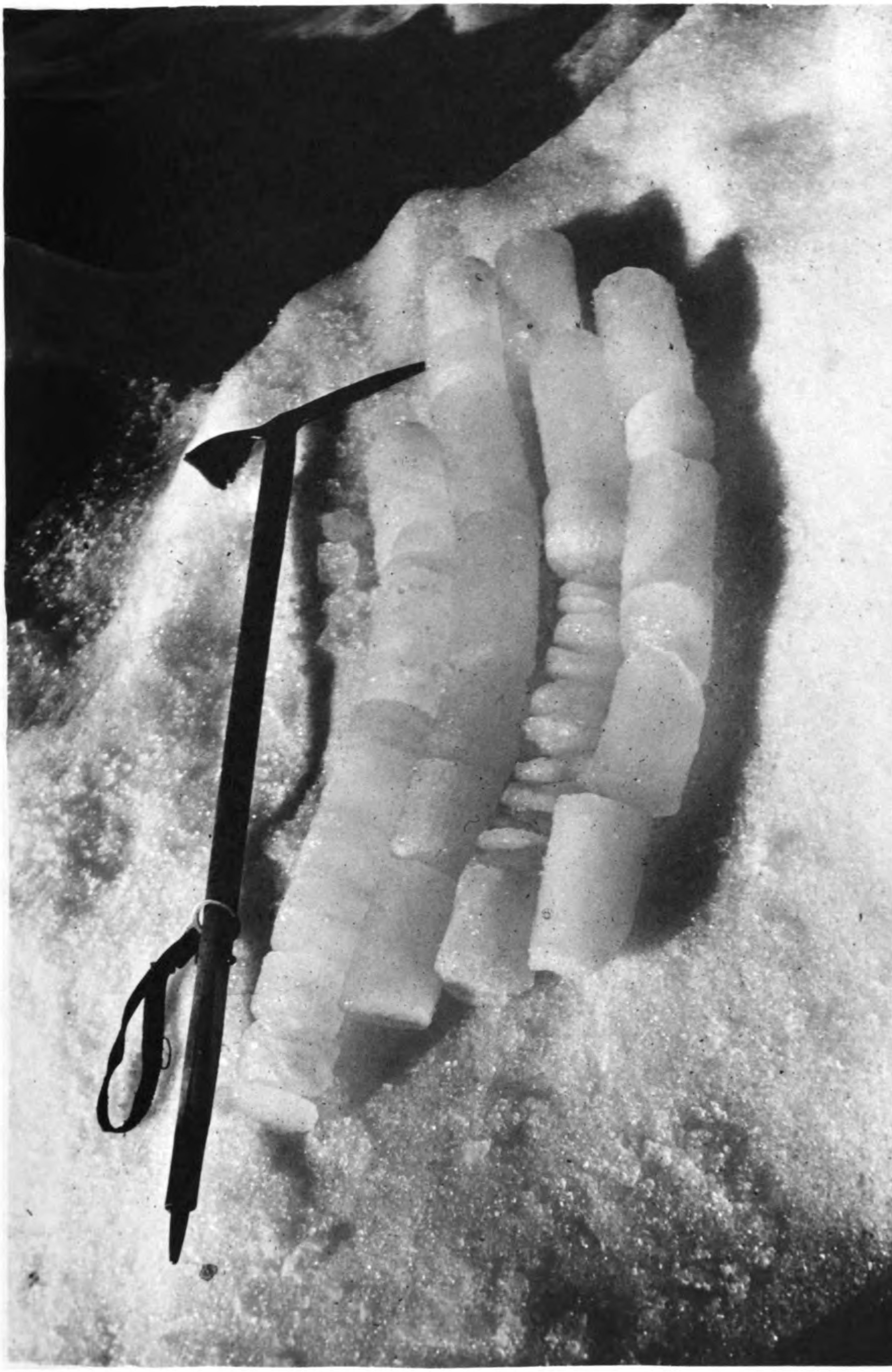


Figure 25

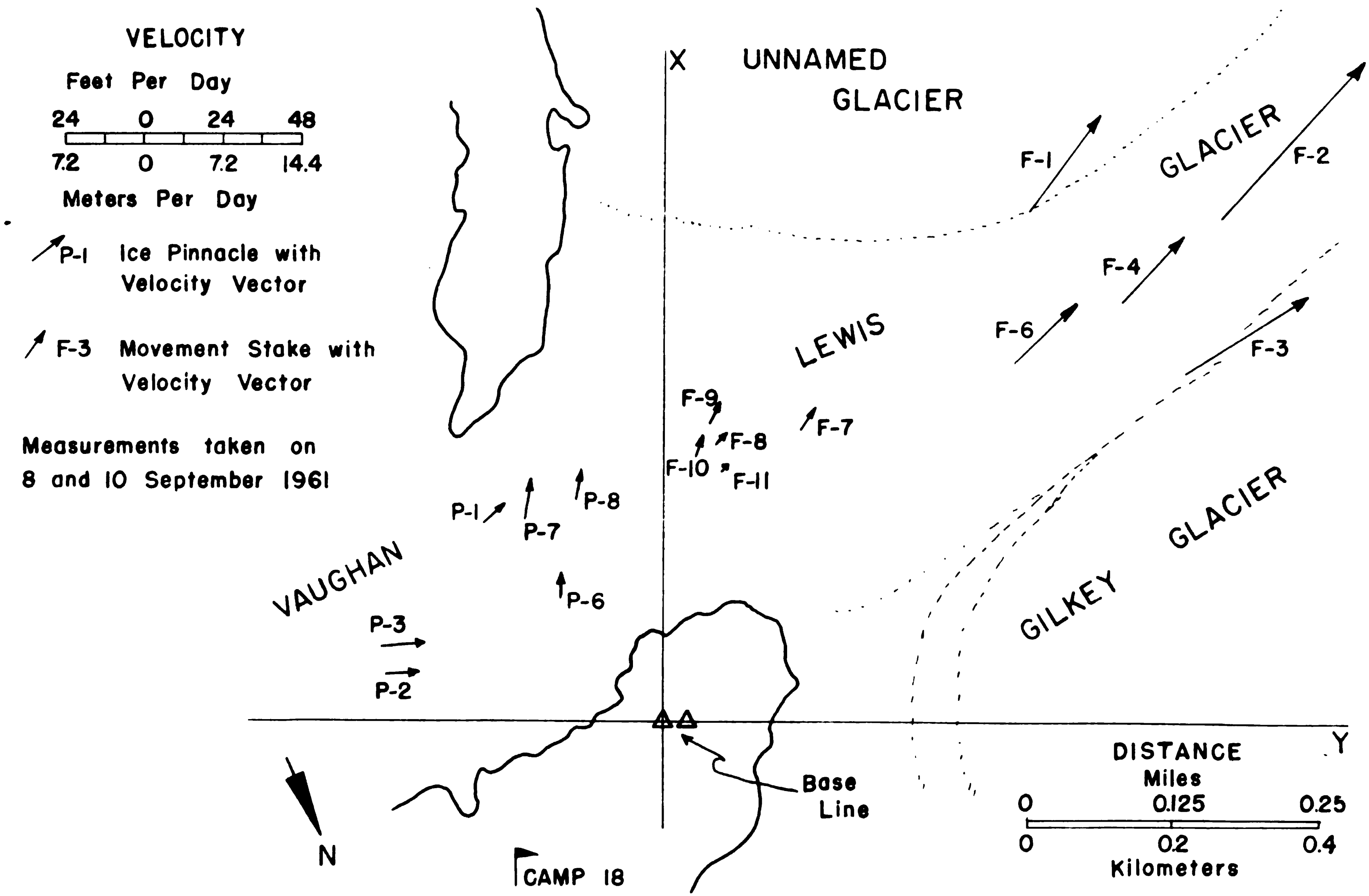


Fig. 26.--1961 surface velocities and movement in the icefall and wave-band zones of the Vaughan Lewis Glacier.

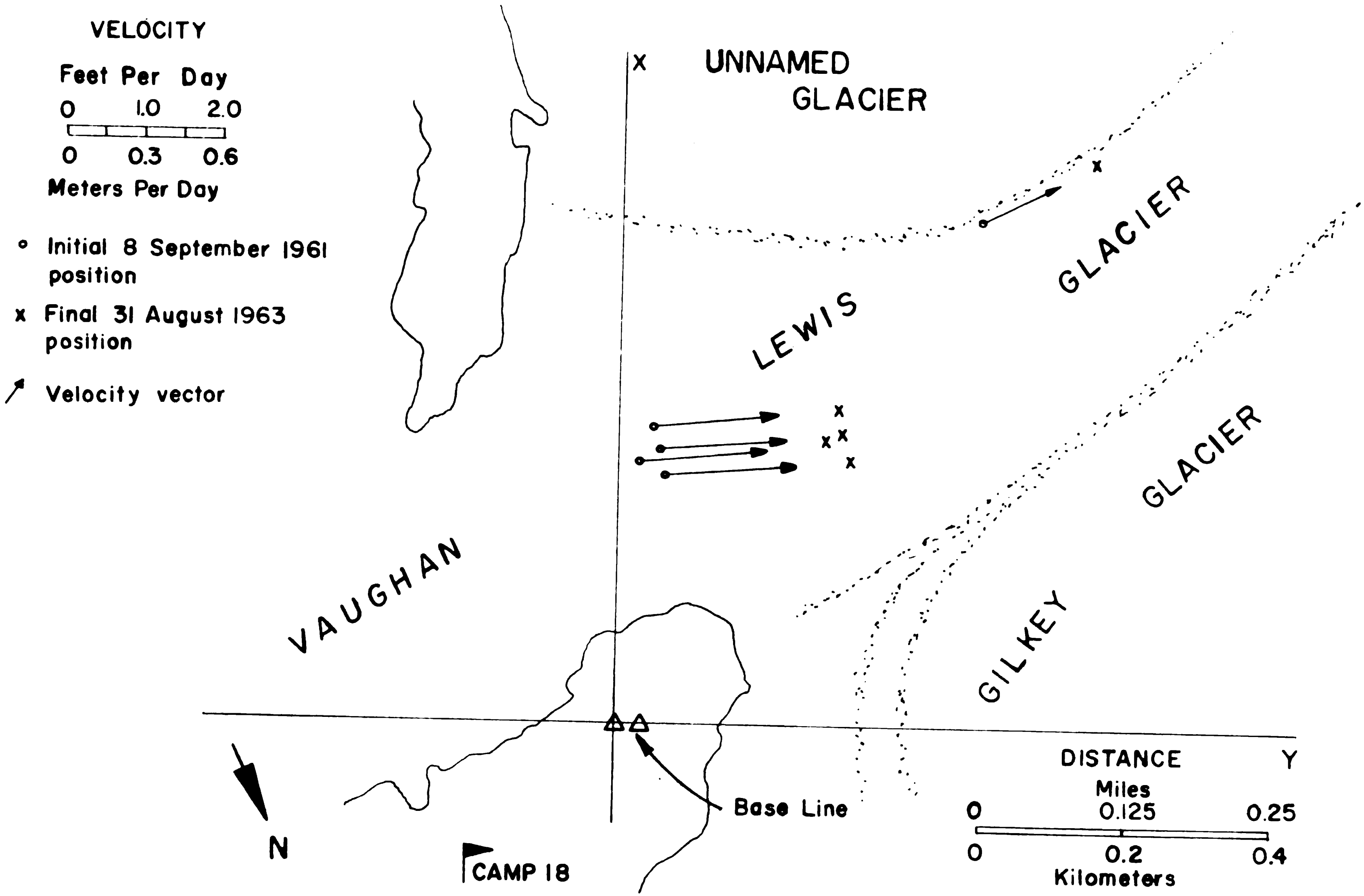


Fig. 27.--Two-year, 1961 to 1963, velocities and movements in the wave-band zone of the Vaughan Lewis Glacier.

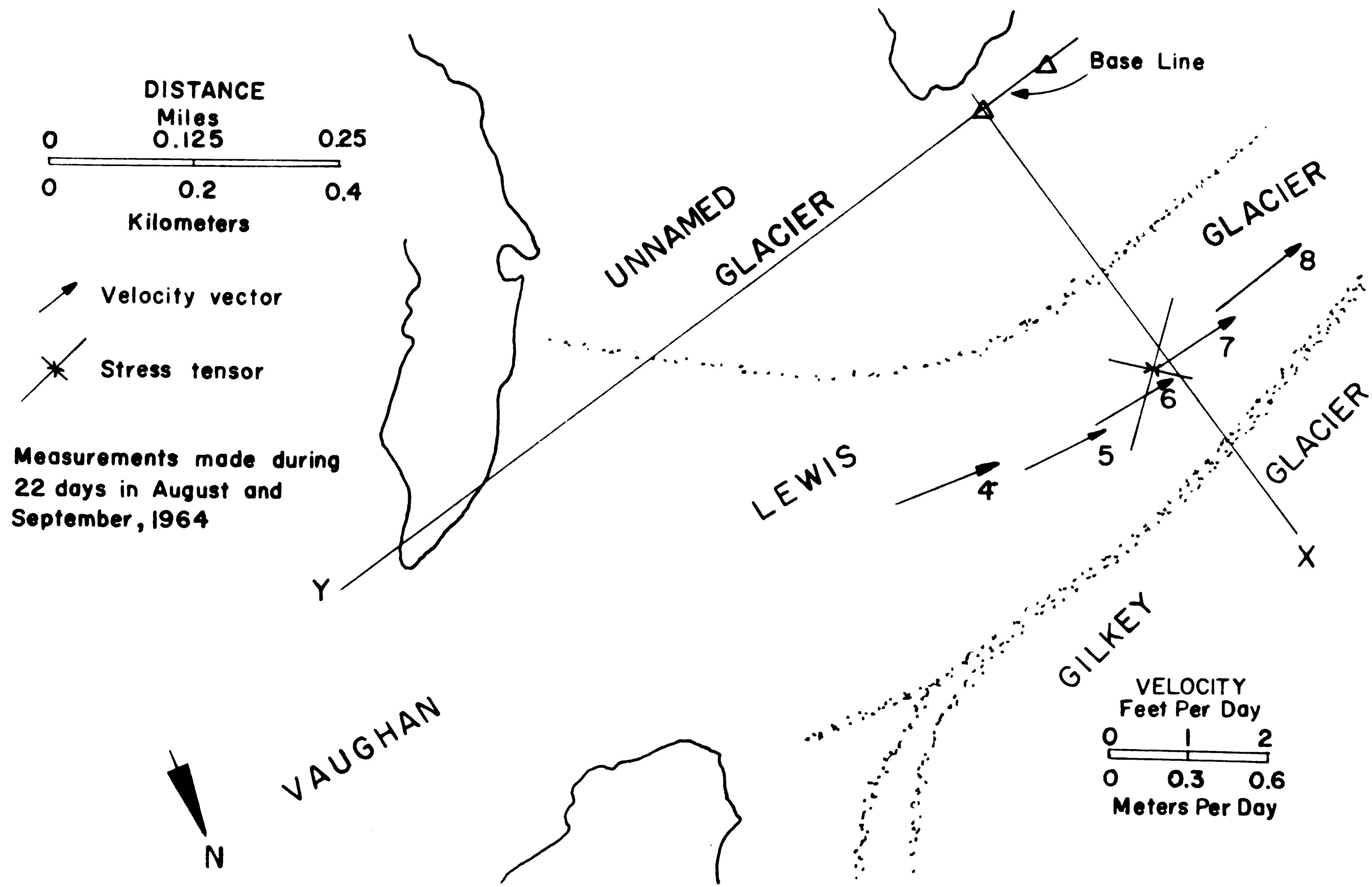


Fig. 28.--1964 velocities, movements and stress tensor in the wave-band zone of the Vaughan Lewis Glacier.

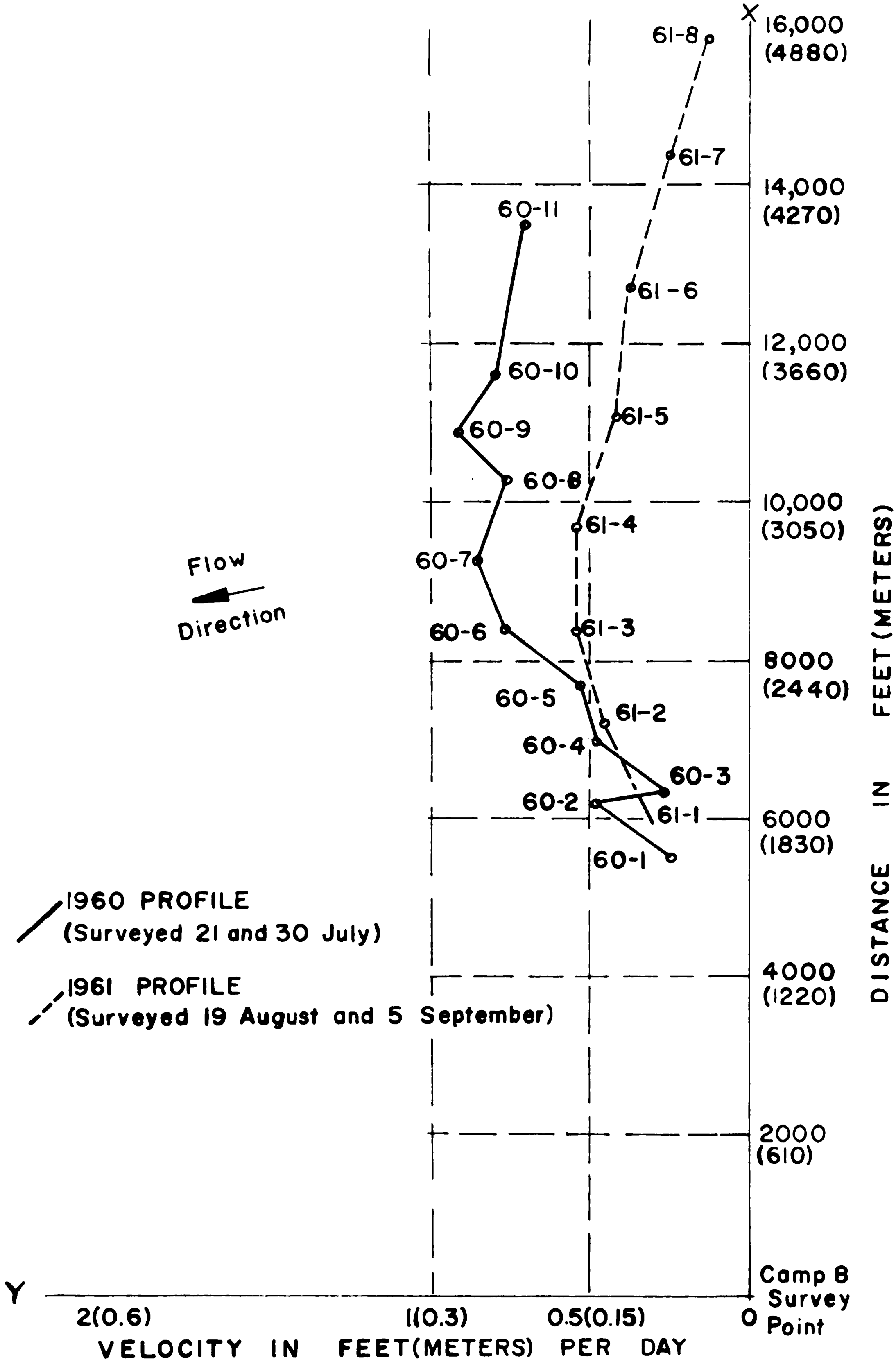


Fig. 29.--1960 and 1961 surface movement along Profile VIII on the North Branch, Taku Glacier in the Camp 8 Sector.

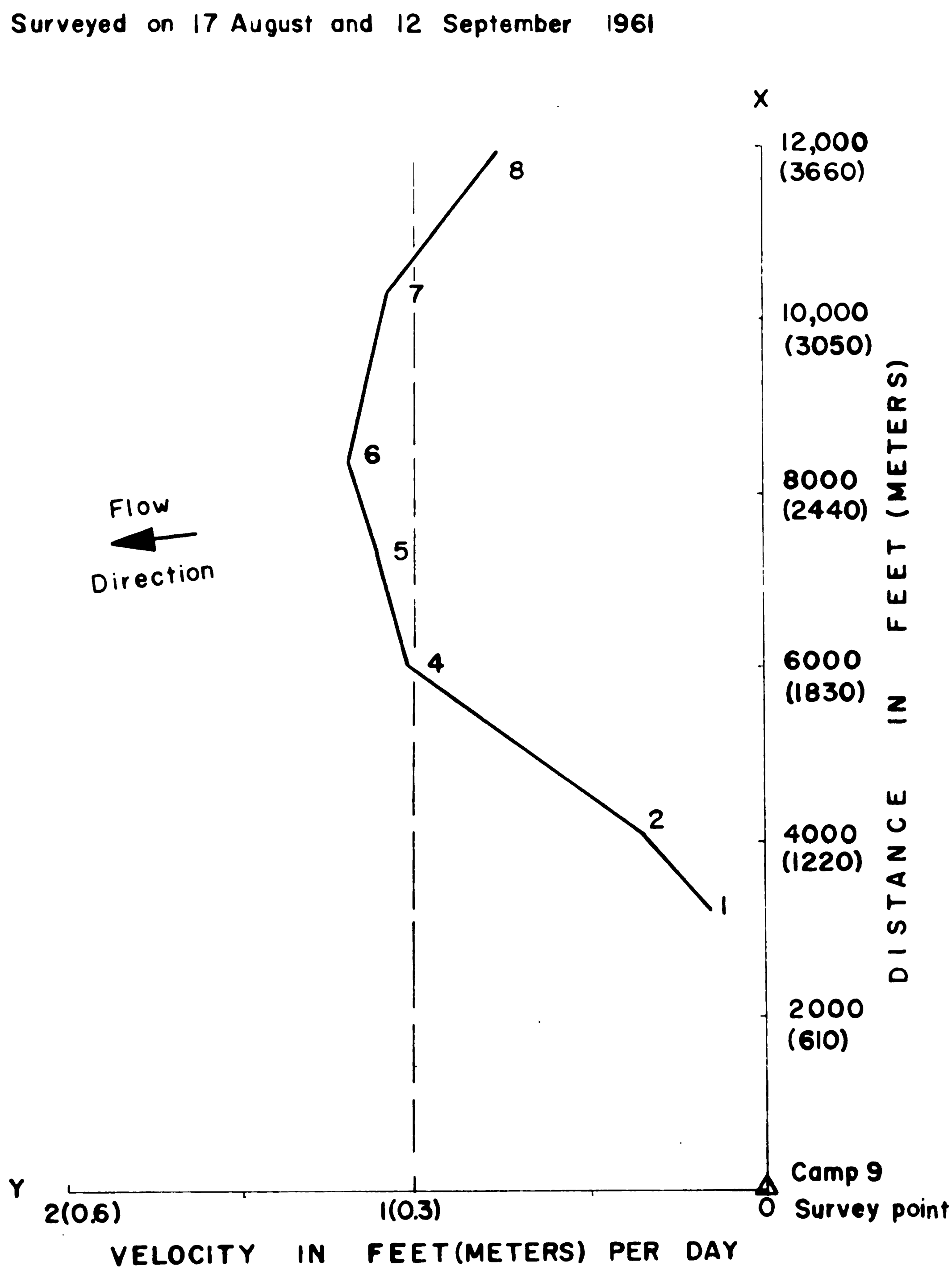


Fig. 30.--1961 surface movement along Profile VII on the North Branch, Taku Glacier in the Camp 9 Sector.

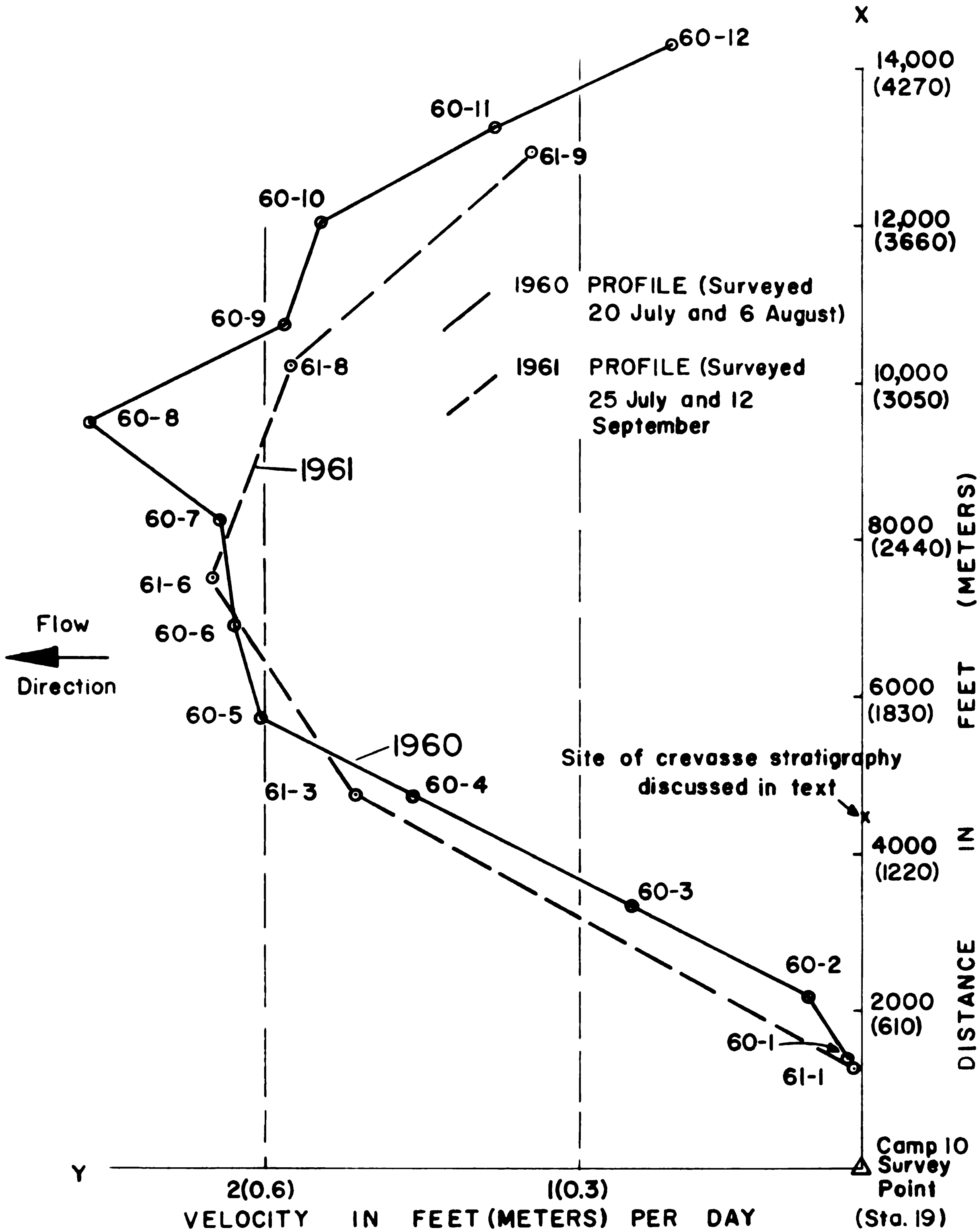


Fig. 31--1960 and 1961 surface movement along Profile IV on the Main Branch, Taku Glacier in the Camp 10 Sector.

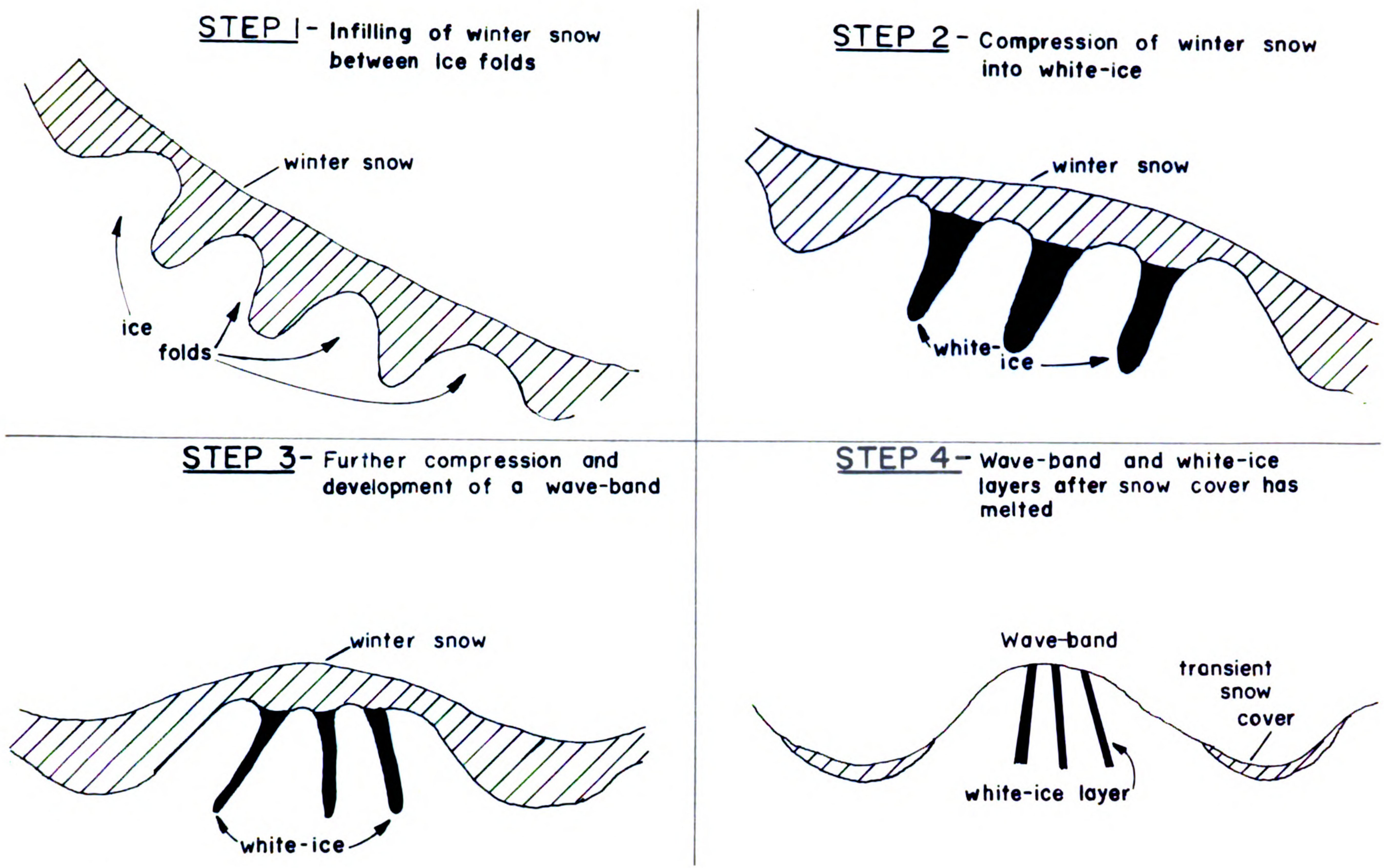


Fig. 32.--Hypothetical sequence of events in the development of a white-ice layer in the Vaughan Lewis Glacier (cross-sectional views).

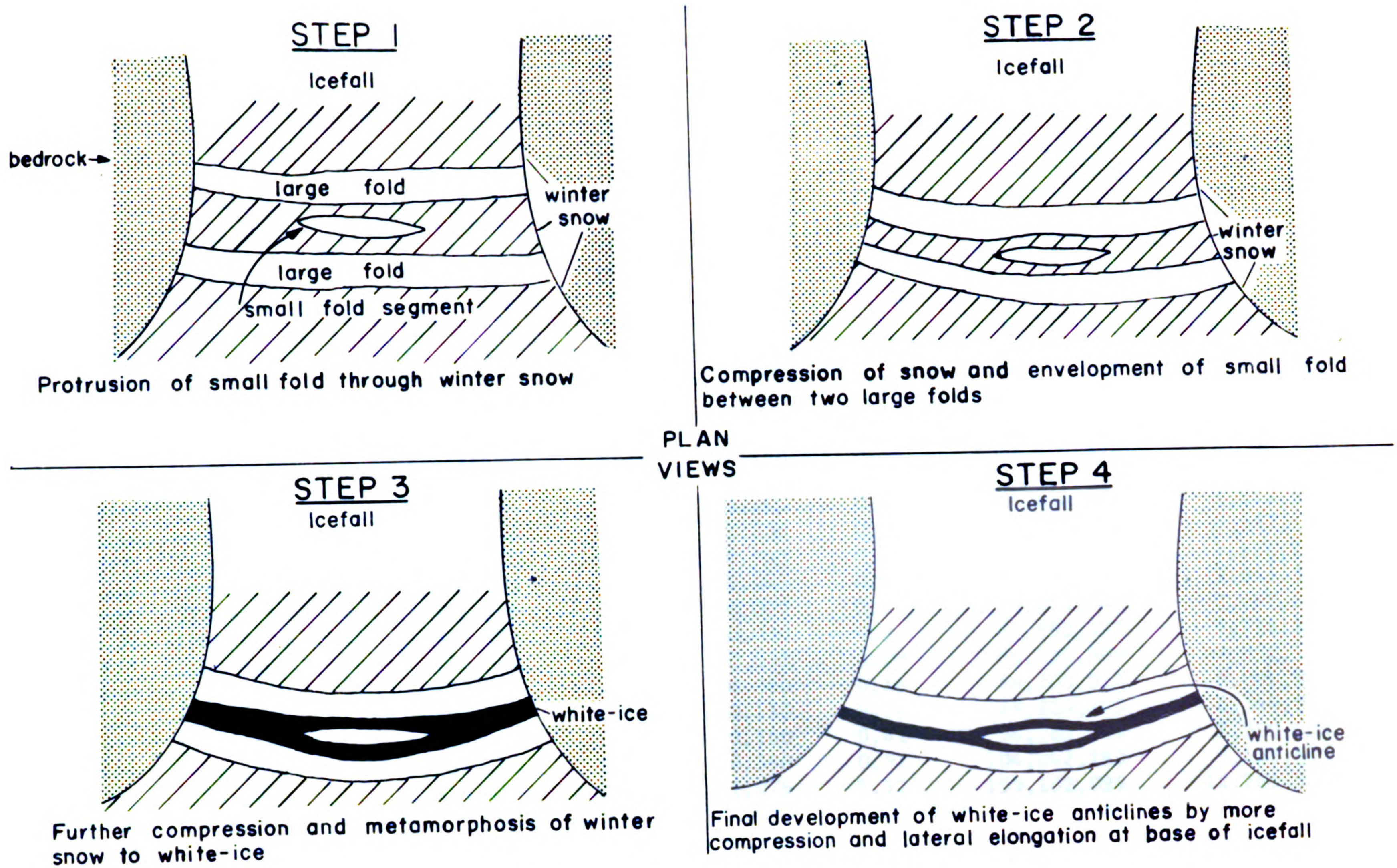


Fig. 33.--Hypothetical sequence of events in the development of a white-ice anticline in the Vaughan Lewis Glacier (plan views).

APPENDIX A

AREA BETWEEN SUCCESSIVE 200-FOOT (60 m) CONTOURS FROM THE TERMINUS TO THE UPPER NÉVÉ ZONE ON THE VAUGHAN LEWIS GLACIER

Contour Interval		Area				Cumulative Area Beneath Each Contour Interval	
Feet	Meters	Square Feet	Square Meters	Square Miles	Square Kilometers	Square Feet	Square meters
16-1800	490-550	4,739,328	440,284	0.170	0.44	---	---
18-2000	550-610	17,563,392	1,631,639	0.630	1.63	22,302,720	2,071,923
20-2200	610-670	9,004,723	836,539	0.323	0.84	31,307,443	2,908,461
22-2400	670-730	3,540,557	328,918	0.127	0.33	34,848,000	3,237,379
24-2600	730-790	5,770,829	536,110	0.207	0.54	40,618,829	3,773,489
26-2800	790-850	3,484,800	323,738	0.125	0.32	44,103,629	4,097,227
28-3000	850-910	4,878,720	453,233	0.175	0.45	48,982,349	4,550,460
30-3200	910-980	5,854,464	543,880	0.210	0.54	54,836,813	5,094,340
32-3400	980-1040	3,206,016	297,839	0.115	0.30	58,042,829	5,392,179
34-3600	1040-1100	7,387,776	686,324	0.265	0.69	65,430,605	6,078,503
36-3800	1100-1160	6,551,424	608,627	0.235	0.61	71,982,029	6,687,130
38-4000	1160-1220	9,060,480	841,718	0.325	0.84	81,042,509	7,528,849
40-4200	1220-1280	1,254,528	116,546	0.045	0.12	82,297,037	7,645,395
42-4400	1280-1340	557,568	51,798	0.020	0.05	82,854,605	7,697,193
44-4600	1340-1400	836,352	77,697	0.030	0.08	83,690,957	7,774,890
46-4800	1400-1460	836,352	77,697	0.030	0.08	84,527,309	7,852,587
48-5000	1460-1520	1,672,704	155,394	0.060	0.16	86,200,013	8,007,981
50-5200	1520-1580	3,624,192	336,687	0.130	0.34	89,824,205	8,344,669
52-5400	1580-1650	4,460,544	414,385	0.160	0.41	94,284,749	8,759,053
54-5600	1650-1710	9,757,440	906,466	0.350	0.91	104,042,189	9,665,519
56-5800	1710-1770	55,059,840	5,115,059	1.975	5.12	159,102,029	14,780,578
58-6000	1770-1830	39,169,152	3,638,814	1.405	3.64	198,271,181	18,419,392
60-6200	1830-1890	20,630,016	1,916,528	0.740	1.92	218,901,197	20,335,921
62-6400	1890-1950	20,769,408	1,929,478	0.745	1.93	239,670,605	22,265,399
64-	1950-	12,266,496	1,139,557	0.440	1.14	251,937,101	23,404,957

APPENDIX B

FIRN DENSITY MEASUREMENTS AND UPPER FIRN STRATIGRAPHY OF THE VAUGHAN LEWIS-TAKU NÉVÉ, 6000 FEET (1825 m), SEPTEMBER,1961

Part 1

Site 8B (Hand Auger Cores)

Depth		Density	Remarks[1]
Feet	Meters	(gm/cc)	
1.8	0.6	0.434	
3.4	1.0	0.384	
7.1	2.2	0.600	1 in. (2.5 cm) ice stratum
9.8	3.0	0.531	Two small ice layers
10.7	3.3	0.572	0.75 in. (2 cm) ice stratum
13.0	4.0	0.580	0.75 in. (2 cm) ice stratum
14.1	4.3	0.596	1 in. (2.5 cm) ice stratum
16.3	5.0	0.580	
17.7	5.4	0.560	0.25 in. (0.6 cm) ice stratum
19.7	6.0	0.616	0.25 in. (0.6 cm) ice stratum
20.7	6.3	0.660	
20.8	6.3	0.497	
23.2	7.1	0.564	0.5 in. (1.3 cm) ice stratum
24.9	7.6	0.528	
26.9	8.2	0.576	
29.3	8.9	0.576	
30.1	9.2	0.544	
32.2	9.8	0.584	
34.0	10.4	0.531	3 in. (7.6 cm) ice stratum (very clear ice)[2]
35.9	10.9	0.528	0.5 in. (1.3 cm) ice stratum
39.0	12.0	0.549	
40.6	12.4	0.553	
42.3	13.0	0.557	
44.5	13.6	0.583	
46.3	14.1	0.579	0.4 in. (0.9 cm) ice stratum
47.4	14.4	0.566	2 in. (5 cm) ice stratum
48.1	14.7	0.590	
49.3	15.0	0.557	
50.3	15.3	0.658	
52.0	15.8	0.631	Ice layer
54.1	16.5	0.631	
55.8	17.0	0.629	3 in. (7.6 cm) ice stratum[2]
57.4	17.5	0.658	Ice strata[2] and laminae
59.0	18.0	0.607	

[1] Stratigraphic terminology from Miller (1955).
[2] These ice layers were not used in the density determinations.

Part 2

Site 8B (Test Pit, 250-500 cc Hand Corer)

Firn samples taken with 250-500 cc hand corer from east and west walls of test pit.

Depth		Density (gm/cc)
Feet	Meters	
1	0.3	0.518
2	0.6	0.540
3	0.9	0.550
4	1.2	0.556
5	1.5	0.551
6	1.8	0.558
7	2.1	0.565
8	2.4	0.563
9	2.7	0.563
10	3.0	0.586
11	3.4	0.560
12	3.7	0.558
13	4.0	0.574
14	4.3	0.572
15	4.6	0.578
16	4.9	0.534
17	5.2	0.516
18	5.5	-----[1]
19	5.8	0.542

[1] Two in. (5 cm) ice layer. 1959-1960 Ablation Surface.

APPENDIX C

FIRN DENSITY MEASUREMENTS AND UPPER FIRN STRATIGRAPHY OF THE VAUGHAN LEWIS-TAKU NÉVÉ, 6000 FEET, (1825 m), AUGUST, 1963

Part 1

Site 8B Firn Stratigraphy (Hand Auger Cores)

Depth: Feet	Depth: Meters	Remarks[1]
1.2	0.4	0.34 in. (0.9 cm) ice stratum
1.3	0.4	0.47 in. (1.2 cm) ice stratum
2.8	0.9	0.79 in. (2.0 cm) ice stratum
4.3	1.3	0.43 in. (1.1 cm) ice stratum
5.4	1.6	0.08 in. (0.2 cm) ice stratum
5.5	1.7	0.20 in. (0.5 cm) ice stratum
12.1	3.7	0.43 in. (1.1 cm) ice stratum
12.6	3.8	0.35 in. (0.9 cm) ice stratum
13.3	4.0	1.02 in. (2.5 cm) straticulated firn-ice
14.4	4.4	0.35 in. (0.9 cm) ice stratum
14.5	4.4	soft zone, drilling rate lower
15.4	4.7	1.51 in. (4.0 cm) ice stratum
16.4	5.0	Drill jammed after soft zone
17.4	5.3	
18.0	5.5	3.93 in. (10.0 cm) ice stratum
23.0	7.0	1.18 in. (3.0 cm) ice stratum
26.3	8.0	3.14 in. (8.1 cm) ice stratum
28.1	8.6	0.39 in. (1.0 cm) ice stratum
28.5	8.7	1.57 in. (4.0 cm) ice stratum
29.2	8.9	0.39 in. (1.0 cm) ice stratum
34.5	10.5	1.97 in. (5.0 cm) ice stratum
35.1	10.7	0.78 in. (1.9 cm) ice stratum
36.4	11.1	0.78 in. (1.9 cm) ice stratum
42.7	13.0	0.39 in. (1.0 cm) ice stratum
44.3	13.5	1.57 in. (3.9 cm) ice stratum
46.3	14.1	0.39 in. (1.0 cm) ice stratum
47.9	14.6	0.39 in. (1.0 cm) ice stratum
49.2	15.0	

[1] Stratigraphic terminology from Miller (1955).

Part 2

Site 8B (Test Pit, 250-500 cc Hand Corer)

Densities determined from samples taken from test pit walls with 250-500 cc hand corer

Depth		Density (gm/cc)	Remarks[1]
Feet	Meters		
0.2	0.1	0.502	
0.7	0.2	0.510	.13 to .25 in. (0.3 to 0.6 cm) ice stratum
1.3	0.4	0.562	.5 in. (1.3 cm) ice stratum
2.0	0.6	0.528	.5 and 3.0 in. (1.3 and 7.6 cm) ice strata
2.6	0.8	0.514	
3.3	1.0	0.508	
3.9	1.2	0.544	
4.6	1.4	0.538	
5.3	1.6	0.556	
5.9	1.8	0.552	
6.5	2.0	0.558	
7.2	2.2	0.612	
7.9	2.4	0.580	
8.5	2.6	0.582	
9.2	2.8	0.602	
9.8	3.0	0.582	
10.5	3.2	0.500	
11.2	3.4	0.610	.25 in. (0.6 cm) ice stratum
11.8	3.6	0.592	
12.5	3.8	0.652	.13 and .25 in. (0.3 and 0.6 cm) ice strata
13.1	4.0	0.596	.25 in. (0.6 cm) ice lens
13.8	4.2	0.612	.13 to 2.0 in. (0.3 to 5 cm) ice lens
14.4	4.4	0.522	
15.1	4.6	0.542	.13 to 1.0 in. (0.3 to 2.5 cm) ice lens
15.7	4.8	0.576	.13 to 1.0 in. (0.3 to 2.5 cm) ice lens
16.4	5.0	0.552	
17.1	5.2	0.548	
17.7	5.4	0.584	.13 to 1.0 in. (0.3 to 2.5 cm) ice lens
18.4	5.6	0.586	4 in. (10.2 cm) blue ice stratum

[1]Stratigraphic terminology from Miller (1955).

APPENDIX D

FIRN DENSITY MEASUREMENTS AND UPPER FIRN STRATIGRAPHY OF THE VAUGHAN LEWIS-TAKU NÉVÉ, 6000 FEET (1825 m), JULY 1962

Part 1 - Site 8A

Density determinations from hand auger cores.

Depth Feet	Depth Meters	Density (gm/cc)	Remarks[1]
3.3	1.0	0.614	Two 0.6 in. (1.5 cm) and one 1.22 in. (3.0 cm) ice strata
5.3	1.6	0.629	0.47 in. and 2.36 in. (1.0 cm and 5.9 cm) ice strata
6.7	2.0	0.569	
8.2	2.5	0.642	Ice gland and a .98 in. (2.5 cm) ice stratum
10.5	3.2	0.585	
11.5	3.5	0.614	0.16 in. (0.3 cm) ice stratum
12.6	3.8	0.658	
13.9	4.2	0.772	
16.9	5.2	0.607	Irregular ice lenses
19.7	6.0	0.662	0.51 in. (1.3 cm) ice stratum
24.3	7.4	0.693	1.41 in. (3.5 cm) ice stratum
26.9	8.2	0.649	
30.8	9.4	0.583	0.3 in. (0.8 cm) ice stratum
31.8	9.7	0.578	0.3 and 0.4 in. (0.8 and 1.0 cm) ice strata
32.2	9.8	0.583	0.5, 1.0, and 1.6 in. (1.3, 2.5 and 4.0 cm) ice strata

Part 2 - Site 8B

Depth Feet	Depth Meters	Density (gm/cc)	Remarks[1]
2.6	0.8	0.756	0.31 and 0.12 in. (0.8 and 0.3 cm) ice strata
3.6	1.1	0.681	0.12 and 0.24 in. (0.3 and 0.6 cm) ice strata
6.2	1.9	0.552	
8.2	2.5	0.719	2.28 in. (5.7 cm) ice stratum
10.2	3.1	0.642	0.42 and 1.02 in. (1.0 cm and 2.5 cm) ice strata
12.5	3.8	0.640	0.51 in. (1.3 cm) ice stratum
13.5	4.1	0.653	0.12 to 0.51 in. (0.3 to 1.3 cm) ice strata
14.8	4.5	0.690	0.55 and 0.47 in. (1.4 and 1.2 cm) ice strata
15.8	4.8	0.644	
22.0	6.7	0.595	0.08, 0.12, 0.28, 0.59, 0.94, 1.10, 1.38 and 2.48 in. (0.2, 0.3, 0.7, 1.5, 2.4, 2.8, 3.5, and 6.3 cm) ice strata
23.3	7.1	0.662	0.16 in. (0.4 cm) ice stratum
27.2	8.3	0.688	
27.6	8.4	0.693	
28.9	8.8	0.657	Two 0.24 in. (0.6 cm) and one 0.51 in. (1.3 cm) ice strata

[1] Stratigraphic terminology from Miller (1955).

APPENDIX E

CAMP 8A - THERMAL BORE DRILLING-RATE READINGS, 1961
Elev. 5950 Feet (1813 m)

		Advance		Depth		Remarks
Date	Time	In.	Cm	Ft.	Meters	
8/29/61	1815			22.0	6.7	Starting point in bottom of hand auger hole.
	1845	17	43	23.4	7.1	
	1915	22	56	25.3	7.7	
	1945	19	48	26.9	8.2	
	2015	18	46	28.4	8.7	
	2045	20	51	30.0	9.2	
	2115	23	58	31.9	9.7	
	2145	26	66	34.1	10.4	
	2215	23	58	36.0	11.0	
	2245	04	10	36.4	11.1	
	2315	24	61	33.4	11.7	
	2345	05	13	38.8	11.8	
8/30/61	0015	32	81	41.4	12.6	
	0045	29	74	43.9	13.4	
	0115	24	64	45.9	14.0	
	0145	32	81	48.6	14.8	
	0215	07	18	49.2	15.0	These two readings obscured by rope being caught.
	0245	36	91	52.2	15.9	
	0315	21	53	53.9	16.4	
	0345	26	66	56.1	17.1	
	0415	32	81	58.8	17.9	
	0445	20	51	60.4	18.4	
	0515	26	66	62.6	19.1	
	0545	32	81	65.3	19.9	
	0615	08	20	65.9	20.1	
	0645	19	48	67.5	20.6	
	0715	21	53	69.3	21.1	
	0745	23	58	71.2	21.7	
	0815	24	61	73.2	22.3	
	0845	13	33	74.3	22.7	
	0915	20	51	75.9	23.1	
	0945	15	38	77.2	23.5	
	1015	22	56	79.0	24.1	
	1045	20	51	80.7	24.6	
	1115	24	61	82.7	25.2	
	1145	09	23	83.4	25.4	
	1245	12	30	85.9	26.2	
	1315	15	38	87.2	26.6	
	1345	08	20	87.9	26.8	
	1415	13	33	88.9	27.1	

Date	Time	Advance In.	Advance Cm	Depth Ft.	Depth Meters	Remarks
8/30/61	1445	06	15	89.4	27.3	
	1515	10	25	90.3	27.5	
	1545	07	18	90.9	27.7	
	1615	15	38	92.1	28.1	
	1645	19	48	93.7	28.6	
	1715	17	43	95.1	29.0	
	1745	06	15	95.6	29.2	
	1815	05	13	96.0	29.3	
	1845	03	08	96.3	29.4	
	1915	07	18	96.9	29.6	
	1945	10	25	97.7	29.8	
	2015	06	15	98.2	29.9	
	2045	07	18	98.8	30.1	
	2115	07	18	99.4	30.3	
	2145	07	18	99.9	30.5	Generator left running, no
	2215	07	18	100.5	30.7	reading taken, for a total
	2245	07	18	101.1	30.8	advance of 4 feet.
	2315	07	18	101.7	31.0	
	2345	06	15	102.2	31.2	
8/31/61	0015	0	0	102.2	31.2	Generator not running
	0045	0	0	102.2	31.2	during this period.
	0115	08	20	102.9	31.4	
	0145	04	10	103.2	31.5	
	0215	07	18	103.8	31.7	
	0245	04	10	104.1	31.8	
	0315	04	10	104.4	31.8	
	0345	06	15	104.9	32.0	
	0415	05	13	105.4	32.1	
	0445	01	03	105.4	32.1	
	0515	05	13	105.9	32.3	
	0545	05	13	106.3	32.4	
	0615	10	25	107.1	32.7	
	0645	04	10	107.4	32.8	
	0715	0	0	107.4	32.8	
	0745	06	15	107.9	32.9	
	0815	01	03	108.0	32.9	
	0845	06	15	108.5	33.1	
	0915	01	03	108.6	33.1	
	0945	04	10	108.9	33.2	
	1015	03	08	109.2	33.3	
	1045	04	10	109.5	33.4	
	1115	04	10	109.9	33.5	
	1145	03	08	110.1	33.6	
	1215	06	15	110.6	33.7	
	1245	03	08	110.9	33.8	
	1315	04	10	111.2	33.9	
	1345	04	10	111.5	34.0	
	1415	04	10	111.9	34.1	
	1445	03	08	112.1	34.2	

Date	Time	Advance In.	Advance Cm	Depth Ft.	Depth Meters	Remarks
8/31/61	1515	04	10	112.4	34.3	
	1545	04	10	112.8	34.4	
	1615	04	10	113.1	34.5	
	1645	06	15	113.6	34.6	
	1715	03	08	113.9	34.7	
	1745	04	10	114.2	34.8	
	1815	04	10	114.5	34.9	
	1845	06	15	115.0	35.1	
	1915	04	10	115.4	35.2	
	1945	03	08	115.6	35.3	
	2015	03	08	115.9	35.3	
	2045	03	08	116.1	35.4	Generator left running
	2115	03	08	116.4	35.5	for total advance of one
	2145	03	08	116.6	35.6	foot eight inches.
	2215	03	08	116.9	35.7	
	2245	02	05	117.0	35.7	
	2315	0	0	117.0	35.7	Generator not running
	2345	0	0	117.0	35.7	during this period.
9/1/61	0015	03	08	117.3	35.8	
	0045	03	08	117.5	35.8	
	0115	01	03	117.6	35.9	
	0145	01	03	117.7	35.9	
	0215	03	08	117.9	36.0	
	0245	06	15	118.4	36.1	
	0315	02	05	118.6	36.2	
	0345	03	08	118.9	36.3	
	0415	02	05	119.0	36.3	
	0445	06	15	119.5	36.5	
	0515	03	08	119.8	36.5	
	0545	02	05	119.9	36.6	
	0615	05	13	120.4	36.7	
	0645	04	10	120.7	36.8	
	0715	04	10	121.0	36.9	
	0745	04	10	121.4	37.0	
	0815	01	03	121.4	37.0	
	0845	03	08	121.7	37.1	
	0915	04	10	122.0	37.2	
	0945	01	03	122.1	37.2	
	1015	02	05	122.3	37.3	
	1045	04	10	122.6	37.4	
	1115	04	10	122.9	37.5	
	1145	02	05	123.1	37.5	
	1215	02	05	123.3	37.6	
	1245	02	05	123.4	37.6	
	1315	05	13	123.9	37.8	
	1345	03	08	124.1	37.9	
	1415	03	08	124.4	37.9	
	1445	04	10	124.7	38.0	
	1515	03	08	124.9	38.1	
	1545	01	03	125.0	38.1	

Date	Time	Advance In.	Advance Cm	Depth Ft.	Depth Meters	Remarks
9/1/61	1615	04	10	125.4	38.2	
	1645	03	08	125.6	38.3	
	1715	04	10	125.9	38.4	
	1745	02	05	126.1	38.5	
	1815	02	05	126.3	38.5	
	1845	04	10	126.6	38.6	Generator left running for total advance of two feet six inches.
	1915	05	13	127.0	38.7	
	1945	04	10	127.4	38.9	
	2015	05	13	127.8	39.0	
	2045	04	10	128.1	39.1	
	2115	04	10	128.4	39.2	
	2145	04	10	128.8	39.3	
	2215	0	0	128.8	39.3	Generator not running during this period
	2245	0	0	128.8	39.3	
	2315	0	0	128.8	39.3	
	2345	0	0	128.8	39.3	
9/2/61	0015	03	08	129.0	39.3	
	0045	03	08	129.3	39.4	
	0115	02	05	129.4	39.5	
	0145	02	05	129.6	39.5	
	0215	02	05	129.8	39.6	
	0245	03	08	130.0	39.7	
	0315	03	08	130.3	39.7	
	0345	02	05	130.4	39.8	
	0415	03	08	130.7	39.9	
	0445	04	10	131.0	40.0	
	0515	02	05	131.2	40.0	
	0545	06	15	131.7	40.2	
	0615	0	0	131.7	40.2	
	0645	02	05	131.9	40.2	
	0715	03	08	132.1	40.3	
	0745	02	05	132.3	40.4	
	0815	02	05	132.4	40.4	
	0845	02	05	132.6	40.4	
	0915	02	05	132.8	40.5	
	0945	04	10	133.1	40.6	
	1015	02	05	133.3	40.7	
	1045	05	13	133.7	40.8	
	1115	02	05	133.9	40.8	
	1145	04	10	134.2	40.9	
	1215	0	0	134.2	40.9	
	1245	03	08	134.4	41.0	
	1315	06	15	134.9	41.1	
	1345	03	08	135.2	41.2	
	1415	02	05	135.4	41.3	
	1445	02	05	135.5	41.3	
	1515	01	03	135.6	41.4	
	1545	02	05	135.8	41.4	
	1615	02	05	135.9	41.5	
	1645	02	05	136.1	41.5	

Date	Time	Advance In.	Advance Cm	Depth Ft.	Depth Meters	Remarks
9/2/61	1715	02	05	136.3	41.6	
	1745	04	10	136.6	41.7	
	1815	03	08	136.9	41.8	
	1845	03	08	137.1	41.8	
	1915	03	08	137.4	41.9	
	1945	03	08	137.6	42.0	
	2015	05	13	138.0	42.1	
	2045	05	13	138.4	42.2	
	2115	05	13	138.9	42.4	Generator left running
	2145	05	13	139.3	42.5	for total advance of two
	2215	05	13	139.7	42.6	feet eleven inches.
	2245	05	13	140.1	42.7	
	2315	05	13	140.5	42.9	
	2345	0	0	140.5	42.9	Generator not running.
9/3/61	0015	0	0	140.5	42.9	
	----	-	-	-----	----	No advance, rope frozen
	0745	0	0	140.5	42.9	in hole.
	0815	06	15	141.0	43.0	
	0845	04	10	141.4	43.1	
	0915	02	05	141.5	43.2	
	0945	02	05	141.7	43.2	
	1015	02	05	141.9	43.3	
	1115	02	05	142.2	43.4	
	1145	02	05	142.4	43.4	
	1215	02	05	142.5	43.5	
	1245	03	08	142.8	43.6	
	1315	03	08	143.0	43.6	
	1345	01	03	143.1	43.6	
	1415	04	10	143.4	43.7	
	1445	06	15	143.9	43.9	
	1515	05	13	144.4	44.0	
	1545	04	10	144.7	44.1	
	1615	02	05	144.9	44.2	
	1645	05	13	145.3	44.3	
	1715	04	10	145.6	44.4	
	1745	01	03	145.7	44.4	
	1815	01	03	145.8	44.5	
	1845	02	05	145.9	44.5	
	1915	02	05	146.1	44.6	
	1945	03	08	146.4	44.7	Generator left running
	2015	02	05	146.5	44.7	for total advance of one
	2045	03	08	146.8	44.8	foot four inches.
	2115	02	05	146.9	44.8	
	2145	02	05	147.1	44.9	
	2215	0	0	147.1	44.9	Generator not running
	2245	0	0	147.1	44.9	during this period.
	2315	0	0	147.1	44.9	
	2345	04	10	147.4	45.0	
9/4/61	0015	02	05	147.6	45.0	
	0045	02	05	147.8	45.1	

		Advance		Depth		Remarks
Date	Time	In.	Cm	Ft.	Meters	
9/4/61	0115	03	08	148.0	45.1	
	0145	04	10	148.4	45.3	
	0215	04	10	148.7	45.4	
	0245	04	10	149.0	45.4	
	0315	01	03	149.1	45.5	
	0345	01	03	149.2	45.5	
	0415	0	0	149.2	45.5	
	0445	02	05	149.4	45.6	
	0515	02	05	149.5	45.6	
	0545	02	05	149.7	45.7	
	0615	02	05	149.9	45.7	
	0645	02	05	150.0	45.8	
	0715	02	05	150.2	45.8	
	0745	02	05	150.4	45.9	
	0815	01	03	150.4	45.9	
	0845	02	05	150.6	45.9	
	0915	01	03	150.7	46.0	
	0945	02	05	150.9	46.0	
	1015	02	05	151.0	46.1	
	1045	02	05	151.2	46.1	
	1115	-	-	-----	----	Rope frozen in hole; drilling completed.

APPENDIX F

CAMP 8B - THERMISTOR MEASUREMENTS - 151-FOOT (46 m) BORE-HOLE

Elev. 5950 Feet (1810 m)   Cable 333   T=°C R=ohm

	DATE	9/5/61				9/6/61				9/8/61			
	TIME	1600 Hrs.		1900 Hrs.		0900 Hrs.		1900 Hrs.		1230 Hrs.		1830 Hrs.	
	Therm. No.	R	T	R	T	R	T	R	T	R	T	R	T
1	4300	2580	+4.16	5070	-8.35	1512	+15.49	3903	-3.57	1741	+12.52	2809	+2.80
2	4301	3207	-0.42	3218	-0.49	3340	- 1.21	3303	-1.00	3134	+ 0.02	3138	-0.01
3*	4302	3865	-1.41	3785	-1.01	3831	- 1.24	3727	-0.71	3633	- 0.22	3633	-0.22
4	4303	3491	-1.57	3434	-1.25	3381	- 0.95	3352	-0.79	3311	- 0.55	3310	-0.55
5	4304	3663	-2.18	3595	-1.81	3492	- 1.26	3465	-1.11	3431	- 0.92	3430	-0.92
6	4305	3713	-2.77	3638	-2.38	3494	- 1.60	3466	-1.44	3399	- 1.06	3392	-1.02
7	4306	3445	-1.28	3399	-1.02	3315	- 0.55	3310	-0.52	3285	- 0.36	3284	-0.36
8	4307	3311	-0.74	3270	-0.50	3210	- 0.14	3212	-0.16	3207	- 0.13	3206	-0.12
9	4308	3423	-0.68	3377	-0.41	3319	- 0.09	3321	-0.10	3315	- 0.07	3314	-0.06
10	4309	3351	-0.69	3303	-0.42	3241	- 0.05	3244	-0.06	3242	- 0.05	3242	-0.05
11	4310	3387	-0.75	3333	-0.43	3275	- 0.09	3279	-0.11	3274	- 0.08	3273	-0.08
12	4311	3452	-0.71	3396	-0.40	3335	- 0.05	3337	-0.06	3334	- 0.05	3334	-0.05
13	4312	3331	-0.72	3275	-0.40	3216	- 0.05	3214	-0.04	3216	- 0.05	3213	-0.03
14	4313	3374	-0.73	3330	-0.48	3259	- 0.05	3264	-0.08	3256	- 0.04	3257	-0.04
15	4314	3352	-0.72	3316	-0.51	3233	- 0.04	3238	-0.07	3235	- 0.05	3234	-0.04
16	4315	3537	-0.74	3501	-0.55	3420	- 0.09	3424	-0.11	3416	- 0.07	3420	-0.09
17	4316	3496	-0.75	3457	-0.51	3372	- 0.04	3375	-0.05	3374	- 0.05	3373	-0.05
18	4317	3355	-0.75	3301	-0.44	3232	- 0.03	3238	-0.07	3234	- 0.04	3234	-0.04

*Top of bore hole.

	DATE	9/9/61				9/10/61				9/11/61			
	TIME	0900 Hrs.		1850 Hrs.		1100 Hrs.		1800 Hrs.		1130 Hrs.		1805 Hrs.	
	Therm. No.	R	T	R	T	R	T	R	T	R	T	R	T
1	4300	2148	+8.18	3876	-3.44	0896	+27.05	1738	+12.55	1203?	+20.44	1731	+12.64
2	4301	3135	+0.01	3140	-0.02	3092	+ 0.28	3129	+ 0.05	3043	+ 0.59	3124	+ 0.08
3*	4302	3632	-0.22	3626	-0.19	3618	- 0.15	3618	- 0.15	3616	- 0.13	3606	- 0.08
4	4303	3307	-0.53	3326	-0.64	3301	- 0.49	3303	- 0.51	3296	- 0.47	3302	- 0.50
5	4304	3422	-0.87	3414	-0.83	3407	- 0.79	3408	- 0.79	3403	- 0.76	3405	- 0.77
6	4305	3381	-0.96	3377	-0.94	3366	- 0.88	3364	- 0.87	3356	- 0.82	3357	- 0.82
7	4306	3282	-0.35	3281	-0.35	3280	- 0.34	3278	- 0.33	3276	- 0.31	3280	- 0.34
8	4307	3208	-0.13	3208	-0.13	3208	- 0.13	3206	- 0.12	3207	- 0.13	3211	- 0.15
9	4308	3317	-0.08	3317	-0.08	3317	- 0.08	3315	- 0.07	3316	- 0.07	3319	- 0.09
10	4309	3243	-0.06	3243	-0.06	3243	- 0.06	3242	- 0.05	3243	- 0.06	3246	- 0.08
11	4310	3274	-0.08	3273	-0.08	3274	- 0.08	3273	- 0.08	3274	- 0.08	3278	- 0.11
12	4311	3338	-0.07	3336	-0.06	3338	- 0.07	3335	- 0.05	3336	- 0.06	3340	- 0.08
13	4312	3214	-0.04	3215	-0.04	3215	- 0.04	3215	- 0.04	3216	- 0.05	3218	- 0.06
14	4313	3257	-0.04	3258	-0.05	3258	- 0.05	3259	- 0.05	3259	- 0.05	3262	- 0.07
15	4314	3236	-0.06	3234	-0.04	3236	- 0.06	3235	- 0.05	3236	- 0.06	3238	- 0.07
16	4315	3421	-0.09	3421	-0.09	3423	- 0.11	3423	- 0.11	3422	- 0.10	3426	- 0.12
17	4316	3375	-0.05	3373	-0.05	3375	- 0.05	3374	- 0.05	3374	- 0.05	3377	- 0.07
18	4317	3235	-0.05	3234	-0.04	3235	- 0.05	3235	- 0.05	3235	- 0.05	3238	- 0.07

*Top of bore hole.

	DATE	9/12/61		9/13/61	
	TIME	1500 Hrs.		1100 Hrs.	
	Therm. No.	R	T	R	T
1	4300	1359	+17.78	1561	+14.82
2	4301	3021	+ 0.73	3041	+ 0.60
3*	4302	3600	- 0.05	3598	- 0.04
4	4303	3306	- 0.52	3293	- 0.44
5	4304	3394	- 0.71	3391	- 0.71
6	4305	3349	- 0.78	3341	- 0.75
7	4306	3277	- 0.32	3274	- 0.30
8	4307	3209	- 0.14	3207	- 0.13
9	4308	3318	- 0.08	3316	- 0.07
10	4309	3244	- 0.06	3242	- 0.05
11	4310	3276	- 0.09	3274	- 0.08
12	4311	3338	- 0.07	3336	- 0.06
13	4312	3217	- 0.05	3215	- 0.04
14	4313	3260	- 0.06	3259	- 0.05
15	4314	3237	- 0.06	3235	- 0.05
16	4315	3426	- 0.12	3423	- 0.11
17	4316	3376	- 0.06	3374	- 0.05
18	4317	3236	- 0.06	3235	- 0.05

*Top of bore hole.

APPENDIX G

CAMP 8B - THERMISTOR MEASUREMENTS - 60-FOOT (18 m) BORE-HOLE

Elev. 5950 Feet (1810 m) Cable 332 T=°C R=ohms

	DATE	9/5/61				9/6/61		9/9/61		9/10/61	
	TIME	1600 Hrs.		1900 Hrs.		0900 Hrs.		1850 Hrs.		1130 Hrs.	
	Therm. No.	R	T	R	T	R	T	R	T	R	T
9	4259									2642	+ 3.65
10	4260									1509	+14.74
11*	4261	4394	-5.26	4037	-3.67	1432	+17.26			1825	+12.11
12	4262	3269	+0.38	3944	-3.23	3043	+ 1.77	3338	-0.04	3338	- 0.04
13	4263	3528	-0.25	3501	-0.10	3503	- 0.12	3500	-0.10	3499	- 0.09
14	4264	3441	-0.21	3415	-0.06	3411	- 0.03	3414	-0.06	3412	- 0.03
15	4265	3222	-0.20	3196	-0.05	3196	- 0.05	3192	-0.03	3192	- 0.03
				8.980		8.671		2.401		2.77	
				8.960		8.645		2.414		2.78	

*Top of bore hole.

	DATE	9/10/61		9/11/61				9/12/61		9/13/61	
	TIME	1730 Hrs.		1300 Hrs.		1730 Hrs.		1530 Hrs.		1030 Hrs.	
	Therm. No.	R	T	R	T	R	T	R	T	R	T
9	4259	2975	+1.30	2289	+ 6.53	3041	+0.89	2819	+2.37	2924	+1.65
10	4260	2819	+1.98	1906	+ 9.85	2947	+1.12	2704	+2.80	2221	+6.73
11*	4261	3102	+1.40	936	+26.69	3044	+1.78	2457	+6.02	2171	+8.53
12	4262	3336	-0.03	3338	- 0.04	3340	-0.05	3336	-0.03	3336	-0.03
13	4263	3497	-0.08	3500	- 0.10	3501	-0.10	3500	-0.10	3499	-0.09
14	4264	3412	-0.03	3416	- 0.07	3416	-0.07	3415	-0.06	3414	-0.06
15	4265	3190	-0.01	3193	- 0.03	3193	-0.03	3193	-0.03	3193	-0.03
16		2.502		4.34		3.381		3.192		3.56	
17		2.508		4.35		3.365		3.172		3.57	

*Top of bore hole.

APPENDIX H

SURFACE MOVEMENT OF THE VAUGHAN LEWIS GLACIER, 1961 AND 1961 TO 1963

Part 1 - Wave-Band Zone

Surveyed on 8 and 10 September 1961 and 31 August 1963.

		Position Coordinates						Velocities					
Movement Stake No.	Date	X-Axis Feet	X-Axis Meters	Y-Axis Feet	Y-Axis Meters	Z-Axis Feet	Z-Axis Meters	X-Axis Ft/Day	X-Axis M/Day	Y-Axis Ft/Day	Y-Axis M/Day	Z-Axis Ft/Day	Z-Axis M/Day
	9/8/61	3232.97	985.42	2270.22	691.97	-758.39	-231.16	---	---	---	---	---	---
F-1	9/10/61	3285.69	1001.49	2308.47	703.63	-772.01	-235.31	28.74	8.76	20.85	6.36	7.42	2.26
	8/31/63	3572.92	1089.74	2992.68	912.77	---	---	0.47	0.14	1.00	0.30	---	---
F-2	9/8/61	3167.88	965.58	3473.09	1058.61	-883.95	-269.43	---	---	---	---	---	---
	9/10/61	3245.27	989.17	3557.08	1084.21	-907.24	-276.53	42.71*	13.02	45.82*	13.97	12.70	3.87
F-3	9/8/61	2209.42	673.44	3276.60	998.72	-807.44	-246.11	---	---	---	---	---	---
	9/10/61	2255.62	687.52	3342.35	1018.76	-825.61	-251.65	25.19	7.68	35.87	10.93	9.90	3.02
F-4	9/8/61	2682.61	817.67	2880.41	877.96	-852.42	-259.82	---	---	---	---	---	---
	9/10/61	2713.88	827.20	2913.65	888.09	-863.74	-263.27	17.05	5.20	18.12	5.52	6.17	1.88
F-6	9/8/61	2261.19	689.22	2174.84	662.90	-799.66	-243.74	---	---	---	---	---	---
	9/10/61	2294.40	699.34	2206.77	672.63	-812.85	-247.76	18.53	5.65	17.82	5.43	7.36	2.24
F-7	9/8/61	1878.55	572.59	864.62	263.54	-686.35	-209.35	---	---	---	---	---	---
	9/10/61	1888.63	575.66	871.81	265.73	-691.82	-210.87	5.51	1.68	3.92	1.19	2.71	0.83
	9/8/61	1751.95	534.00	285.17	86.92	-616.30	-187.85	---	---	---	---	---	---
F-8	9/10/61	1760.15	536.50	290.02	86.40	-620.33	-189.08	4.47	1.36	2.65	0.81	2.19	0.67
	8/31/63	1858.70	566.90	1436.50	438.13	---	---	0.15	0.05	1.59	0.48	---	---
	9/8/61	1888.95	575.76	233.07	71.04	-610.29	-186.02	---	---	---	---	---	---
F-9	9/10/61	1896.89	578.18	235.79	71.87	-613.05	-186.86	7.31	2.23	2.51	0.77	2.55	0.78
	8/31/63	2013.13	614.00	1387.32	423.13	---	---	0.17	0.05	1.60	0.49	---	---

*Questionable: Possibly instrument error due to small angles from base line.

		Position Coordinates						Velocities					
		X-Axis		Y-Axis		Z-Axis		X-Axis		Y-Axis		Z-Axis	
Movement Stake No.	Date	Feet	Meters	Feet	Meters	Feet	Meters	Ft/Day	M/Day	Ft/Day	M/Day	Ft/Day	M/Day
	9/8/61	1698.11	517.59	152.33	46.43	-595.89	-181.63	---	---	---	---	---	---
F-10	9/10/61	1709.20	520.97	157.22	47.92	-600.94	-183.17	6.04	1.84	2.67	0.81	2.74	0.84
	8/31/63	1799.26	548.77	1341.68	409.21	---	---	0.14	0.04	1.65	0.50	---	---
	9/8/61	1584.36	482.92	337.20	102.78	-624.89	-190.47	---	---	---	---	---	---
F-11	9/10/61	1586.23	483.59	340.02	103.64	-628.01	-191.42	1.02	0.31	1.53	0.47	1.70	0.52
	8/31/63	1653.29	504.25	1491.78	454.99	---	---	---	---	---	---	---	---

Part 2 - Icefall Zone

No movement stakes were placed in the icefall, measurements were made on prominent ice pinnacles

Ice Pinnacle No.	Date	Feet	Meters	Feet	Meters	Feet	Meters	Ft/Day	M/Day	Ft/Day	M/Day	Ft/Day	M/Day
P-1	9/6/61	1274.43	388.45	-1138.93	-347.15	-150.49	- 45.87	---	---	---	---	---	---
	9/10/61	1295.98	395.02	-1115.47	-340.01	-167.94	- 51.19	5.23	1.59	5.68	1.73	4.22	1.29
P-2	9/6/61	292.55	89.17	-1727.18	-526.45	375.85	114.56	---	---	---	---	---	---
	9/10/61	302.16	92.10	-1686.86	-514.16	363.25	110.72	1.54	0.47	9.78	2.98	3.06	0.93
P-3	9/6/61	462.30	140.91	-1783.74	-543.69	380.18	115.88	---	---	---	---	---	---
	9/10/61	468.66	142.85	-1730.69	-527.52	373.06	113.71	1.54	0.47	12.90	3.93	1.73	0.53
P-6	9/9/61	773.38	235.73	- 666.89	-203.27	-221.52	- 67.52	---	---	---	---	---	---
	9/10/61	779.52	237.60	- 666.79	-203.24	-226.79	- 69.15	5.89	1.80	0.10	0.03	5.14	1.57
P-7	9/9/61	1279.58	390.02	- 862.16	-262.79	-275.82	- 84.07	---	---	---	---	---	---
	9/10/61	1293.40	394.23	- 864.82	-263.60	-281.43	- 85.78	13.26	4.04	2.55	0.78	5.39	1.64
P-8	9/9/61	1401.59	427.21	- 247.54	- 75.45	-497.11	-151.52	---	---	---	---	---	---
	9/10/61	1411.24	430.15	- 246.39	- 75.10	-501.70	-152.92	9.24	2.82	1.09	0.33	4.39	1.34

APPENDIX I

SURFACE MOVEMENT AND STRESS TENSOR IN THE WAVE-BAND ZONE OF THE VAUGHAN LEWIS GLACIER, 1964

1964 movement measurements (Havas, 1965) surveyed 22 days in August and September 1964.

	Y-Movement		X-Movement	
Movement Stake No.	Feet Per Day	Meters Per Day	Feet Per Day	Meters Per Day
4	1.38	0.42	0.36	0.11
5	1.15	0.35	0.36	0.11
6	1.15	0.35	0.30	0.09
7	1.28	0.39	0.13	0.04
8	1.38	0.42	0.07	0.02

APPENDIX J

SURFACE MOVEMENT MEASUREMENTS ALONG PROFILE VIII, NORTH BRANCH TAKU GLACIER IN THE CAMP 8 SECTOR

Part 1 - 1960 Measurements
(after D. McLane, J.I.R.P., 1960)

Surveyed on 21 July and 30 July 1960

	Position Coordinates				Velocity	
	X-Axis		Y-Axis		Y-Axis	
Movement Stake No.	Feet	Meters	Feet	Meters	Ft/Day	M/Day
1	5514.00	1680	0	0		
	5514.00	1680	2.57	0.8	0.26	0.08
2	6197.00	1889	0	0		
	6197.00	1889	4.75	1.5	0.48	0.15
3	6295.00	1919	0	0		
	6295.00	1919	2.64	0.8	0.26	0.08
4	7035.00	2144	0	0		
	7035.00	2144	4.81	1.5	0.48	0.15
5	7665.00	2336	0	0		
	7665.00	2336	5.29	1.6	0.53	0.16
6	8402.00	2561	0	0		
	8402.00	2561	7.63	2.3	0.76	0.23
7	9250.00	2819	0	0		
	9250.00	2819	8.52	2.6	0.85	0.26
8	10225.00	3117	0	0		
	10225.00	3117	7.61	2.3	0.76	0.23
9	10871.00	3313	0	0		
	10871.00	3313	9.09	2.8	0.91	0.28
10	11730.00	3575	0	0		
	11730.00	3575	7.96	2.4	0.80	0.24
11	13490.00	4112	0	0		
	13490.00	4112	7.26	2.2	0.73	0.22

Part 2 - 1961 Measurements

Surveyed on 19 August and 5 September 1961

	Position Coordinates				Velocity	
	X-Axis		Y-Axis		Y-Axis	
Movement Stake No.	Feet	Meters	Feet	Meters	Ft/Day	M/Day
1	5959.15	1816	0	0		
	5959.15	1816	7.12	2.2	0.40	0.12
2	7177.73	2188	0	0		
	7177.73	2188	7.68	2.3	0.43	0.13
3	8347.08	2544	0	0		
	8347.08	2544	9.06	2.8	0.50	0.15
4	9626.98	2934	0	0		
	9626.98	2934	8.89	2.7	0.49	0.15
5	11035.86	3364	0	0		
	11035.86	3364	7.19	2.2	0.40	0.12
6	12654.08	3857	0	0		
	12654.08	3857	6.63	2.0	0.37	0.11
7	14298.97	4358	0	0		
	14298.97	4358	4.20	1.3	0.23	0.07
8	15866.38	4836	0	0		
	15866.38	4836	2.17	0.7	0.12	0.04

APPENDIX K

SURFACE MOVEMENT MEASUREMENTS ALONG PROFILE VII, NORTH BRANCH TAKU GLACIER IN THE CAMP 9 SECTOR, 1961

Surveyed on 17 August and 12 September 1961.

	Position Coordinates				Velocity	
	X-Axis		Y-Axis		Y-Axis	
Movement Stake No.	Feet	Meters	Feet	Meters	Ft/Day	M/Day
1	3249.83	990	0	0		
	3249.83	990	3.77	1.15	0.15	0.05
2	4151.49	1265	0	0		
	4151.49	1265	9.15	2.79	0.34	0.10
4	6073.25	1851	0	0		
	6073.25	1851	26.31	8.02	0.98	0.30
5	7422.45	2262	0	0		
	7422.45	2262	28.61	8.72	1.06	0.32
6	8522.99	2598	0	0		
	8522.99	2598	30.68	9.35	1.14	0.35
7	10409.26	3173	0	0		
	10409.26	3173	29.82	9.09	1.10	0.34
8	12055.04	3674	0	0		
	12055.04	3674	19.82	6.04	0.73	0.22

APPENDIX L

SURFACE MOVEMENT MEASUREMENTS ALONG PROFILE IV, MAIN BRANCH TAKU GLACIER IN THE CAMP 10 SECTOR

Part 1 - 1960 Measurements

Movement stakes surveyed on 20 July and 6 August 1960.

Movement	Position Coordinates				Velocity			
	X-Axis		Y-Axis		X-Axis		Y-Axis	
Stake No.	Feet	Meters	Feet	Meters	Ft/Day	M/Day	Ft/Day	M/Day
1	0	0	1343.8	410	-	-		
	0	0	1418.5	433	-	-	2.41	0.73
2	0	0	2206.0	672	-	-		
	0	0	2206.2	672	-	-	0.16	0.05
3	0	0	3384.5	1031	-	-		
	0	0	3382.0	1030	-	-	0.74	0.23
4	0	0	4654.4	1419	-	-		
	0	0	4652.4	1418	-	-	1.43	0.44
5	0	0	5782.2	1762	-	-		
	0	0	5778.7	1761	-	-	1.83	0.56
6	0	0	6982.7	2128	-	-		
	0	0	6974.5	2126	-	-	2.02	0.62
7	0	0	8240.2	2512	-	-		
	0	0	8229.4	2508	-	-	2.08	0.63
8	0	0	9528.2	2904	-	-		
	0	0	9498.8	2895	-	-	2.65	0.81
10	0	0	12013.4	3662	-	-		
	0	0	12000.9	3658	-	-	1.78	0.54
11	0	0	13250.4	4039	-	-		
	0	0	13244.7	4037	-	-	1.19	0.36
12	0	0	14262.0	4347	-	-	0.66	0.20

Part 2 - 1961 Measurements

Movement stakes surveyed on 25 July and 12 September

	Position Coordinates				Velocity				XY Direction (Downglacier)	
Movement	X-Axis		Y-Axis		X-Axis		Y-Axis			
Stake No.	Feet	Meters	Feet	Meters	Ft/Day	M/Day	Ft/Day	M/Day	Feet	Meters
1	1635.5	499.	627.0	191						
	1633.0	498	629.6	192	0.05	0.02	0.05	0.02	0.07	0.02
2	4746.3	1447	606.6	185						
	4734.5	1443	689.6	210	0.24	0.07	1.66	0.51	1.69	0.52
3	7398.9	2255	613.2	187						
	7379.8	2249	716.2	218	0.38	0.12	2.06	0.63	2.09	0.64
4	10215.1	3114	623.7	190						
	10211.8	3113	713.6	218	0.07	0.02	1.79	0.55	1.79	0.55
5	12951.6	3948	642.1	196						
	12962.4	3950	696.2	212	0.22	0.07	1.08	0.33	1.11	0.34

GLOSSARY

Arched bands. See wave-bands.

Ablation. The wasting or surface-lowering of a glacier by the combined processes of melting, evaporation, and sublimation. (Also some avalanching and calving.)

Bergschrund. The crevasse occurring at the head of a glacier or margins of an icefield, which separates the moving firn and ice of the glacier from the relatively immobile firn and ice adhering to the headwall or nunatak. This crevasse commonly penetrates to the headwall or bed of the glacier. It usually has a lower lip on the down-valley side.

Bubbly glacier ice. The main material of glaciers variably containing air pockets and entrapped water bubbles, and having a density approximating 0.88-0.90 gm/cc.

Cirque. A deep, steep-walled "amphitheater" or recess in a mountain, caused by glacial erosion.

Depth-hoar. Stratum of relatively softer autumn "snow" lying just above the annual ablation surface, characterized by low density and cupshaped crystals.

Diagenesis. A process of across-stratum changes which take place in firn due to accumulation above it, or percolation of rain and melt-water through it; e.g., compaction and recrystallization, the latter by metamorphism and refreezing.

Firn. Compacted, granular, but still pervious material metamorphosed from old snow, and in transition to glacier ice. Characterized by a density approximating 0.50-0.75 gm/cc.

Forbes' bands. See wave-bands.

Icefold. A fold of ice, anticlinal in shape, with its long axis across glacier in the lower Vaughan Lewis icefall.

Mean névé-line. The average elevation of the névé-line taken over a period of 10 years.

Névé. The net accumulation area of a temperate glacier.

Névé-line. The elevation of the most stable position of the lower limit of firn or the névé. The demarcation line dividing the areas of net accumulation and negative dissipation or wastage.

Ogive. See wave-band.

Regime. The material balance (budget) of a glacier involving the total accumulation and the gross wastage in one or more budget year. The long-term state of health of a glacier.

Seasonal névé-line. The elevation of the lower geographical limit of the firn or névé at the end of a specific ablation season. Usually the year involved is prefixed.

Wave-band. The curved light and dark bands, arched or convex in plan view downglacier, that in cross-section have surface wave length and amplitude and are found below icefalls on some glaciers. Actually these also include a pattern of englacial folia which become accentuated downglacier by the process of ablation. The accentuation of the ogive character (plan) parallels the attenuation of the surface wave (cross-section), hence these terms can be used together or separately. However, where the wave character dominates, the term wave-band is applied; and where the inlaid structures dominate, the term ogive is applied. The term arched bands is sometimes applied for general reference, where it is desired not to detail the geometry of the plan view. The descriptive term Forbes' bands is general, and applies to the feature as a combination of wave-bands and ogives (arched bands).

Wave-ogive. Same as wave-band but more pointed in plan view.

White-ice. White, fine-grained, non-foliated glacier ice that is in sharp contrast to fabric-oriented bubbly glacier ice.

White-ice anticline. The surface expression of two white-ice layers that join and continue as a single layer thus giving a "canoe-shaped" or eroded anticlinal appearance.

White-ice layer. The near vertical inlays of white-ice found associated with ice folds in the icefall and in the wave-bands of the Vaughan Lewis Glacier.