FIRN STRATIGRAPHY AND NÉVÉ REGIME TRENDS ON THE JUNEAU ICEFIELD, ALASKA, 1925-65

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ABSTRACT

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By Christopher P. Egan

The Taku Glacier, an advancing valley glacier complex originating in the Juneau Icefield of the Boundary Range northeast of Juneau, Alaska, has been the focus of glaciological and related studies conducted as part of the Juneau Icefield Research Program since 1946. The névé regime investigations for the years 1962 to 1965 and their relationship to the sequence of earlier observations and to possible future trends are discussed.

Ablation measurements made during these and earlier field seasons indicate that at successively higher elevations, lower rates of ablation and correspondingly shorter annual melting seasons pertain. At representative lower-névé and upper-névé stations, accumulation records for the period 1946-65 reveal a strongly positive regime trend, with relatively greater amounts of retained accumulation on the higher névé...i.e. above 5000 feet. A downward migration of the accumulation zone, indicated by increased net accumulation on the névés below 1500 meters (ca. 5,000 feet), as well as by a downward shift in the seasonal névé-line, has occurred over the past half decade. The regime trends of this icefield are shown to be more directly a function of secular temperature changes, rather than a simple function of geographical position or elevation.

Precipitation and temperature trends during the past quarter century are analyzed from coastal weather data, recorded at five sea-level stations on the southern and western periphery of the Juneau Icefield. A fair correlation is demonstrated between these and corresponding trends in annual accumulation on the lower and upper Taku névés. Results from this climatologically-sensitive glacier system point up the possibilities for teleconnection analyses with regimen data from glacier systems in other middle to high-middle latitude cordillera. The particular significance of continuing systematic observations at the same annually-visited field sites over the next several decades is discussed.

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PREFACE

This study was undertaken as a part of the field program of the Glaciological Institute, Department of Geology, Michigan State University, in cooperation with the Juneau Icefield Research Program of the Foundation for Glacier Research, Inc., Seattle, Washington.

The author is indebted to the Glaciological Institute and the Foundation for Glacier Research for providing the logistical support by which this study was made possible. The author also wishes to acknowledge his debt to earlier workers on the Juneau Icefield, whose published and unpublished data greatly aided the present study. The author especially appreciates the generous assistance given by members of the 1962, 1963 and 1964 field programs. Special thanks are given to Peter Kakela, Fred Fisher, Fred Dunham, Dave Potter, Barry Prather, Tom Cochrane, Dave Morris, Rolf Wesche and Jim Whitaker.

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I. INTRODUCTION AND BACKGROUND

A. Location and Description of Area

The Juneau Icefield is located on a segment of the Coast Mountains (Alaska-British Columbia Boundary Range) near Juneau, Alaska (Fig. 1). The icefield is approximately 130 km. (80 miles) long, and 50 to 80 km. (30 to 50 miles) wide. It is bounded on the north by White Pass, and on the south by Taku Inlet. The western side of the icefield is bordered by Lynn Canal, a prominent fiord paralleling the north-northwest trend of the Coast Mountains. Lake Atlin and the Talsekwe Trench lie along the eastern periphery of these mountains. A large percentage of the Juneau Icefield is occupied by broad high level areas of snow accumulation (névés), predominantly between elevations of 900 to 2,000 meters (3,000 to 6,500 feet).[1] Several peaks in this section of the Coast Mountains attain elevations of 2,300 to 2,600 meters (7,500 to 8,500 feet) range, the highest being Devils Paw (8,584 feet). These peaks, and a large number of lesser ranges and nunataks, divide the névé complex into numerous ice drainage systems.

Field work for the present report was conducted mainly on the accumulation area of the North Branch of Taku Glacier (this branch is also referred to as Matthes Glacier), lying entirely in Alaska; and to a lesser extent, on Llewellyn Glacier in Northern British Columbia. These two glaciers form a transection glacier system aligned approximately in a north-south direction. A crestal névé at an elevation of 1,890 meters (6,200 feet) forms the drainage divide between these glaciers. The

1. The term névé as used in this paper denotes the general zone of net accumulation for a given glacier system, and as such has an areal connotation. This use is in conformity with earlier Juneau Icefield Research Program (JIRP) reports.

southward-flowing Taku Glacier is the largest outlet draining the icefield. This large valley glacier is nearly 64 km. (40 miles) long and is joined by four major tributaries above the 915-meter (3,000-foot) mean névé-line elevation. Approximately 21 km. (13 miles) from the névé-line, Taku Glacier terminates at sea level in Taku Inlet. The northward-moving Llewellyn Glacier is nearly 32 km. (20 miles) long, and terminates near Lake Atlin on the continental side of the Coast Mountains at an elevation of about 625 meters (2,500 feet). The Llewellyn terminus at present is continuing a recession which began about 1925 (Miller, 1963a). In contrast, and particularly relevant to the following discussion, Taku Glacier has maintained a continuous advance since the mid-1890's (Miller, 1963a).

B. Previous Work and Present Study

1. Background Information

Glaciological studies of the Juneau Icefield were begun in 1946 (Miller, 1947). The first investigations on the upland accumulation zones were made in 1948 with the support of the American Geographical Society and other agencies, supplemented in 1949 by a contract project (Task Order N9onr-83001) via the Office of Naval Research. In 1953, American Geographical Society support and the ONR project terminated. Most of the results of this early work were published by the American Geographical Society in a series of nine Juneau Icefield Research Project reports issued between 1949 and 1954. Since 1953, long-term continuation of the main icefield studies has been undertaken as the Juneau Icefield Research Program (JIRP), sponsored by the Foundation for Glacier Research, Inc., of Seattle, Washington. A continuing series of reports is being

published on the icefield studies by this Foundation.

Beginning in 1961, the research program has also been affiliated with a program of graduate-level summer field courses offered by the Michigan State University Glaciological Institute. Since 1963 this phase of the program has been supported by the National Science Foundation. Institute personnel utilize the Foundation's equipment and field station facilities. The combined academic activity of the Glaciological Institute and the research activity of the Foundation for Glacier Research are directed by Dr. Maynard M. Miller of the Michigan State University Geology Department.

The present report comprises data collected during the writer's participation in the 1962, 1963 and 1964 Glaciological Institute programs, with brief reference to a few additional measurements obtained in 1965. Pertinent aspects of the field program for these four seasons are discussed in later sections of this report.

2. Pertinent Earlier Studies

Several of the early Juneau Icefield Research Program reports are relevant to the present study. The first is JIRP Report No. 6, Scientific Observations of the Juneau Icefield Research Project, Alaska, 1949 Field Season, edited by M. M. Miller (1952), containing a particularly relevant section, Investigations in the Taku Glacier Firn, by F. Beach Leighton. Also useful is JIRP Report No. 7, Juneau Icefield Research Project, Alaska, 1950 Summer Field Season by M. M. Miller (1954). JIRP Report No. 9, Snow Studies on the Juneau Icefield, by E. R. LaChapelle (1954, is particularly pertinent to the present study. In Névé Studies on the Juneau Icefield, Alaska, 1961, with Special Reference to Glacio-

Hydrology on the Lemon Glacier to be published as JIRP Report No. 16, E. C. Andress (1962) reports on the 1961 season of glaciological work on the upper Taku Glacier. Andress' effort was focused on problems of meltwater percolation and runoff, and incorporated stream gage records of the runoff from Lemon Creek Glacier, at the southern extremity of the icefield (v. Fig. 1). A further comprehensive report, Taku Glacier Evaluation Study, prepared by M. M. Miller (1963a) for the State of Alaska, Department of Highways, contains complete summary data through the 1962 field season.

The regional pattern of glacier behavior is described by D. B. Lawrence (1950) in Glacier Fluctuation for Six Centuries in Southeastern Alaska and its Relation to Solar Activity, and also by M. M. Miller (1963b) in The Regional Pattern of Alaskan Glacier Fluctuations. Historical Variations of Lemon Creek Glacier, by C. J. Heusser and M.G. Marcus (1964b) contains results of a detailed study of a single glacier. In Climate-Glacier Studies in the Juneau Icefield Region, Alaska, M. G. Marcus (1964) also discusses the interactions between climate and glaciers, emphasizing mass budget studies conducted on Lemon Creek Glacier in the five-year period 1953-58. A summary of the recent (1948-64) terminal changes in the Taku Glacier is given in JIRP Report No. 21 by A. Al-Naqash (1965) entitled, "Application of Terrestrial Photogrammetry to Glacier Surveys in the Taku District, Alaska."

3. Scope and Objective of the Present Investigations

The primary objectives are to assess changes in recent accumulation and ablation at specific sites on the Juneau Icefield, and to examine the relationships of these elements to geographic position and elevation.

The annual trends of accumulation observed at key Taku Glacier sites during the last two decades are compared with corresponding precipitation records from low-elevation U. S. Weather Bureau stations on the icefield's southern and western periphery. It is hoped that this report will extend the interpretations presented in earlier JIRP reports concerning the complex and often seemingly anomalous behavior of adjoining glacier systems.

For the present report, accumulation and ablation measurements made by the writer during the 1962, 1963 and 1964 field seasons are described and interpreted with a few statistics from the summer of 1965 added. These measurements are liberally supplemented by the published and unpublished data of other workers.

In elevation, the field sites occupied during this study are distributed from immediately above the Taku Glacier's 915-meter (3,000-foot) mean névé-line to the 1,890-meter (6,200-foot) crest of the Taku-Llewellyn transection glacier system. Geographically, the test sites are located on four of the five main branches of Taku Glacier, and on the upper Llewellyn Glacier (Fig. 2). In nearly all cases, mid-glacier positions on broad, low-gradient areas were selected for test sites. To maintain long-term continuity with JIRP records, the most detailed work has been focused on two key sites on Taku Glacier. These are mid-glacier sites, designated as 8B (at 1,814 meters, or 5,950 feet) and 10B (at 1,082 meters, or 3,550 feet). These sites are located respectively near Camps 8 and 10, the main permanent FFGR field research stations.

C. Recent Terminal Fluctuations

With the exception of Taku Glacier, the Juneau Icefield glaciers are at present characterized by recessional or near-equilibrium conditions.

This predominantly negative regime trend has persisted since a significant regional glacier advance which culminated in the middle eighteenth century (Lawrence, 1950). On the basis of dendrochronological studies conducted at low elevations on the coastal periphery of the icefield, Lawrence (1950) reports that "... the glaciers emanating from the southern part of the Juneau Icefield, including Eagle, Herbert, Mendenhall, Norris, Taku and its distributary arm, Hole-in-the-Wall, and Twin Glaciers, seem to have advanced in unison to a maximum sometime in the early or middle eighteenth century, which surely had not been exceeded since before the 1300's and from which recessions of 1.3 miles to 5 miles beginning by 1765 at the latest subsequently occurred."

A similar conclusion was reached by Heusser and Marcus (1964b) with respect to the Lemon Creek Glacier, a small valley glacier at an intermediate elevation range on the southern periphery of the Juneau Icefield, where both dendrochronological and radiocarbon dating techniques have been applied: "Lemon Creek Glacier has not advanced more than 375 m. (1,230 feet) beyond the maximum of c. 1750, if at all, during the last 10,000 yr." Heusser and Marcus also report that the earliest recession of Gilkey Glacier, a deeply entrenched valley glacier on the western side of the icefield, began about 1783.

The presence of several heavily forested lateral moraines above the west side of Taku Glacier near its present terminus clearly shows that at some time in the last few centuries its thickness was substantially greater, and its terminal position was perhaps a mile or more farther into Taku Inlet than at present. This maximum extension is believed to have occurred during the eighteenth-century period of regional glacier advance.

After a period of thinning and recession, during which the terminus withdrew at least several miles, Taku Glacier again began to advance in the mid-1890's (Miller, 1963a). The pre-1890 history of this glacier is obscure, largely as a result of its having had a tidal terminus, rather than a terminus on land. The post-1890 advance has continued to the present time. The terminal position is no doubt influenced by the protective outwash apron and broad moraine embankment which has developed along the terminus in recent years, replacing the former tidal icefront (v. photo sequence since 1948 in Al-Naqash, 1965).

This minimal historical framework outlines the regional pattern of the last two centuries only in a general way. In detail, the pattern is of course complicated by variations in the rates of advance and recession of individual glaciers. Major complications have been introduced by the readvances of several Juneau Icefield glaciers since the maximum eighteenth-century advance. Of these, the Taku Glacier is most significant. Another important example, however, is the Norris Glacier, located a short distance west of Taku Glacier (v. Fig. 1). Beginning at an unknown date, Norris Glacier advanced until about 1910-1916 (Lawrence, 1950). The Norris terminus has continued to recede since 1916 (v. photographs in Lawrence, 1950, and in Al-Naqash, 1965).

D. Former Phases of Glaciation

Morphogenetically, the icefield is at present in a Retracted Icefield Phase (Miller, 1964), with the main snow accumulation areas restricted to intermediate and high elevations. This phase corresponds to Kerr's (1936) "Alpine Stage", and to Davis and Mathews' (1944) "Phase I." The segment of the Coast Mountains occupied by the Juneau

Icefield has been subjected to repeated phases of glaciation during the Pleistocene. In order of increasing magnitude of glaciation, these gradational phases are designated the Local Glacier Phase, the Retracted Icefield Phase, the Extended Icefield Phase, the Lesser, Intermediate, and Greater Mountain Ice-sheet Phases, and the Intermontane Icecap Phase (Miller, 1964). Miller regards the Intermontane Icecap Glaciation as pre-Wisconsin in age, and to correspond to Kerr's (1936) "Continental Ice-sheet Stage."

The contrast between the decreasing glacier thicknesses and receding termini of the present phase,and the much greater quantities of ice and more extended terminal positions of former phases of glaciation, clearly shows that important changes in factors affecting glacier regime have occurred. As in the case of main source areas of continental glaciation during the Pleistocene Epoch, lateral shifts in centers of ice outflow were associated with the various phases noted above. The regional ice center of the pre-Wisconsin Intermontane Icecap Glaciation is considered by Miller (1964) to have been located approximately "...ten to twenty miles east of the present International Boundary and to have run parallel to the structural axis of the range between Mount Nesselrode, Mount Nelles, and Mount Lester Jones east of Tulsequah." This postulated ice center differs significantly from the present location of maximum snow accumulation patterns on the Juneau Icefield. In this region of high relief, pronounced orographic influences complicate the analysis of snow accumulation patterns. It is reasonable to assume, however, that a changing sequence of factors affecting the glacier regime (including precipitation, atmospheric and englacial temperatures, ablation, and prevailing storm tracks) were associated with the phase sequence of glaciation.

II. THERMAL CHARACTER OF THE TAKU GLACIER

A. Thermal Classification of Glaciers

A classification of glaciers on the basis of sub-surface temperature was first proposed by M. Lagally (1932). This classification distinguishes between Kalt glaciers characterized by pronounced sub-freezing englacial temperatures, and Warmen glaciers having a temperature corresponding to the pressure-melting point. An intermediate category was termed transitional (Ubergangstyp).

H. W. Ahlmann (1933, 1935, 1948) independently presented a similar classification, using the terms high-Polar and Temperate, with an intermediate type designated sub-Polar. Ahlmann's high-Polar and Temperate categories correspond, respectively, to Lagally's Kalt and Warmen types.

Following the introduction of the Lagally and Ahlmann proposals, lack of consistency in usage led to efforts to develop a standard terminology. Refinements were particularly necessary because although both terms are applied to an intermediate category, Lagally's "transitional" type is not identical with Ahlmann's "sub-Polar" type. J. W. Glen (1957) pointed out that Lagally's "transitional" glacier is sub-freezing in its upper levels, but at the pressure-melting point in its basal zone. The Ahlmann "sub-Polar" category, however, refers to a predominantly sub-freezing glacier having an upper zone of seasonal melting. M. M. Miller (1957) drew attention to the fact that in the Ahlmann "sub-Polar" type, the penetration of seasonal warmth is restricted to a relatively thin layer, while Lagally's "transitional" type is characterized by a relatively thick annual melt zone.

To maintain consistency with earlier reports of the Juneau Icefield Research Program, a terminology suggested by M. M. Miller (1957, 1964) is used in this paper. This terminology is based on those of Lagally and Ahlmann, but provides useful refinements in terms applied to glaciers of intermediate thermal types.

As in the Ahlmann classification, a Polar glacier is defined (Miller, 1964) as "... perennially sub-freezing, except for a shallow surface zone which may be warmed for a few weeks each year by seasonal atmospheric variations." The Temperate type is one in which "... internal ice temperatures, below a recurring winter chill zone, are always at the pressure-melting point."

The refinements proposed by Miller relate principally to thermal conditions between true Polar englacial temperatures known to exist in Greenland and Antarctic ice-sheets (arbitrarily, -10° to -70° C), and the Temperature category. For this intermediate range, Miller suggests the definition of two categories, designated Subpolar and Subtemperate. In this system, the term Subpolar refers to glaciers in which "... the ice is essentially 'cold', but where the intensity of chilling is not extreme. To facilitate application of the terms arbitrary limits have been set at -12° to -1° C." The term Subtemperate refers to glaciers which are "... essentially Temperate but which have some tendency towards Polar characteristics...seasonal changes from winter to summer cause development of isothermal conditions in the surface zone to a much greater depth than in either of the previous (i.e., Polar and Subpolar) types."

B. Regime Significance of Thermal Type

In a Temperate glacier, meltwater and rainfall percolating into the firn-pack at the pressure-melting point is regarded as eventually lost through englacial or subglacial drainage. In a Subtemperate glacier segment, however, rainfall may be refrozen in the firn-pack and become part of the accumulation increment. In addition, meltwater from the surface may be refrozen at depth, and therefore cannot be regarded as a deficit.

Englacial temperature measurements made on the Taku Glacier system reveal significant thermal differences between névés at different elevations. On the lower névé, Temperate conditions predominate (Miller, 1965a). On the higher elevation segments of the Taku Névé, Subtemperate conditions exist (Miller, 1955a; Andress, 1962). The elevation range in which the transition between Temperate and Subtemperate categories occurs has not yet been investigated in detail, and undoubtedly varies somewhat depending on geographical position and proximity to bedrock. The suggested upper elevation limit of Temperate character is 1,372 to 1,524 meters (4,500 to 5,000 feet), but this, of course, must be considered provisional. Add to this the probability that such a limit will, of course, shift in consequence of climatic trends.

An analysis of the quantitative disposition of liquid water in terms of budgetary gain or loss is not an objective in the present study. In detailed mass balance studies, however, liquid water (produced either by surface melting or by direct rainfall) is obviously of significance, particularly in the case of Subtemperate or colder glaciers. For detailed discussions of englacial water of the Juneau Icefield, reference is made to Leighton (1952), Andress (1962), and Miller (1962 and 1963a).

C. Glacio-thermal Measuring Techniques

Englacial temperature data cited in this paper were obtained with thermistor cables installed in holes drilled by hand augers, thermal

drills, and a motor-driven rotary borer. The drill units, thermistor cables and field procedures used are described in detail by M.M. Miller (1955a) and E. C. Andress (1962).

The thermistor cables used by Miller and Andress are considered accurate to 0.01° to 0.03° C (Miller, 1955a). Hole diameters vary from ca. 1.25 inches (3.18 cm.) when drilled by a small hand auger, to as much as 6 to 8 inches (ca. 15 to 20 cm.) when a 5-inch (12.70 cm.) O. D. coring auger is used. The motor-driven rotary borer and thermal drills produce holes ca. 3 inches (7.62 cm.) and 2.5 inches (6.35 cm.) respectively (Miller, 1955a). It is obvious that large-diameter holes, even though sealed at the surface, can allow substantial convection, and therefore the available accuracy of the thermistor is not fully utilized. Additional loss of accuracy results from the lack of intimate contact between individual thermistor units and the adjacent ice wall. In practice, holes of small diameter are preferred. After installation of the cable, the hole may be filled with snow or other material in order to minimize the convection. At the surface, the hole is tightly covered and marked. Temperature readings are made subsequently over a period of days or weeks by means of a modified Wheatstone Bridge.

D. Temperature Measurements in the Taku Glacier Firnpack

In recent decades the Temperate thermal character of the lower Taku Glacier (i.e., below the provisional elevation range of ca. 1,370 to 1,525 meters, or 4,500 to 5,000 feet) has been established by mid-summer thermistor measurements. These have indicated essentially 0° C temperatures to depths of about 60 meters (200 feet) (Miller, 1964, personal communication). A mid-glacier site at an elevation of 1,100 meters (3,550 feet),

designated 10B, is considered to be representative of this lower Taku Glacier accumulation zone (v. Fig. 2). This site has been reoccupied a number of times since 1949. To determine the depth of winter chill at site 10B, thermistor readings to 51.8 meters (170 feet) were obtained on 28 February, 1951, using a cable that had been in place for five months. These measurements revealed a winter cold wave penetration of nearly 20 meters (65 feet), with a minimum recorded temperature of -9.5° C (15°F) (Miller, 1963a). The 1950-51 snowpack and underlying firn to a depth of six meters was recorded as isothermal (at 0° C) between the 7th and 16th of June, 1951. Similarly, between 27 May and 17 June, 1952, and between 20 June and 25 June, 1953, the upper three to four meters of the snowpack reached 0°C (Miller, 1963a). Complete dissipation of the cold wave at site 10B is therefore indicated to occur normally before the end of June, though possibly, in some years, as late as early July.

In contrast to the lower névé, the Taku Glacier crestal névé is characterized by slightly sub-freezing temperatures throughout the ablation season, except for a shallow surface zone which becomes raised to 0°C during the summer. Incomplete dissipation of the winter cold wave at greater depths has been recorded at all mid-glacier stations located on or near the crest of the Taku Glacier during each of the summer field seasons in which deep thermal measurements were obtained (i.e., 1952, 1953, 1958, 1961, 1962 and 1963). Thermal amelioration during the summer appears to be limited on the upper névé to depths of about ten meters. At the key record site (8B) located at an elevation of 1814 meters (5,950 feet), the preceding winter's snowpack was observed to reach a fully Temperate condition by late July during the 1951, 1952, 1958, 1960, 1961 and 1962 field seasons (Miller, 1963a). In each of these years, 0°C temperatures ended at the surface during August or early September (Miller, 1963a). For example, late-summer measurements made on 8 September, 1952, detected the onset of the winter cold wave in a firnpack which had previously been at 0°C to a depth of nearly 8 meters (26.3 feet). On the same date, sub-freezing temperatures were measured at the 8 meter and 9.5 meter (31 foot) levels. In view of the presence of warmer overlying material, these cold zones are interpreted as remnants from the preceding winter chill.

In 1961, Andress (1962) detected subfreezing temperatures in a 46 meter (151 foot) hole at site 8A, at an elevation of ca. 1,814 meters (5,950 feet). This site was located between the margin of the eastern side of Taku Glacier and the mid-glacier site 8B. Andress (1962) also recorded subfreezing temperatures at depth on the upper Llewellyn Glacier, at a site (19A) located about 9.7 km. (6 miles) northwest of 8A, at an elevation of ca. 1,980 meters (6,500 feet). Andress found nearly identical depth vs. temperature curves at sites 8A and 19A, with a minimum temperature of -0.9°C at a depth of ca. 9 meters (30 feet). A relatively constant temperature of -0.05°C was recorded below the 18.3 meter (60 foot) level, and a zone of relict cold was detected at the 36.7 meter (120 foot) and 42.7 meter (140 foot) levels.

Late-summer thermistor measurements made near the edge of Taku Glacier, at elevations of 2,040 to 2,135 meters (6,700 to 7,000 feet), suggest that even at high elevations Temperate conditions exist locally

along the margins of the upper Taku Glacier, despite the predominantly Subtemperate character of the main central body of the glacier at these elevations (Andress, 1962).

III. THE ABLATION RECORD

A. Introduction and Application of Terms

In glaciological literature, the term ablation is generally taken to include "...all processes by which ice and snow are lost from the glacier...ablation is caused by such phenomena as melting, evaporation, calving, wind erosion, and removal of snow and ice by avalanches (Meier, 1962, p. 253)." At present, calving and avalanching do not constitute significant processes of ablation on Taku Glacier. Evaporation is minimized by the normally high humidity and abundant rainfall associated with the maritime climate of this region. Wind erosion is negligible during the summer months, but deflation and transfer of new snow does occur during the winter (Miller, 1953, p. 16-17). Therefore, the term, as generally used in this study, refers to ablation as a result of melting. To permit consistent comparisons ablation is expressed in water equivalent.

R. C. Hubley (1957, p. 68) in his investigation of ablation on the southwestern part of the Juneau Icefield, found that "...turbulent transfer of heat is the most important factor in causing ablation on the Lemon Creek Glacier. This turbulent transfer of energy becomes very large during summer storm periods. As a result, the number of warm storms passing over the glacier in a single ablation season can largely determine whether the glacier will end the season with a positive or negative mass budget." On the basis of physical proximity and comparable elevations,[1] it may

1. Lemon Creek Glacier is a small valley glacier located at the southwestern extremity of the Juneau Icefield. Its surface area is 9.21 km., its elevation range is ca. 500 m. (1,640 feet) to 1,500 m. (4,920 feet) and its mean névé-line elevation is ca. 1,145 m. (3,750 feet) (Marcus, 1964).

be presumed that this conclusion holds for the generally maritime sectors of the Juneau Icefield.

Ablation measurement is complicated by many factors, several of which have been discussed by LaChapelle (1959) who measured ablation at several sites on the upper Taku Glacier. LaChapelle (1959, p. 458) points out that "ablations measured over long periods for glacier regimen studies are subject to a settlement error in even dense snow, corrections for which may be made by simultaneous measurements with stakes of different lengths." With respect to sub-surface temperature conditions, LaChapelle notes that "when sub-freezing temperatures exist near the surface of the annual accumulated snow layer, the refrozen melt water may again be remelted later in the summer as the zone of redeposition later becomes exposed to melting processes."

The complications of meltwater refreezing at depth in a snowpack has been discussed in broader terms by E. Etienne (1940) and H.W. Ahlmann (1942). Ahlmann (p. 18) suggested that the term "<u>gross</u> ablation" be used to refer only to "...ablation due to superficial melting and evaporation." The term "<u>net</u> ablation" was defined by Ahlmann (1942, p. 18) as "...the total amount of water actually lost to the glacier by drainage." On Kårsa Glacier in Swedish Lappland (68° 20' N, 18° 20'E), C. C. Wallén (1948, p. 81) found that the gross ablation, recorded at ablation stakes and calculated by the use of different values of specific gravity of the surface snow, was <u>larger</u> than the net ablation. Wallén had calculated the net ablation by measuring changes in depth and specific gravity in snow pits. On the Juneau Icefield in 1952, LaChapelle (1954, p. 26) observed an opposite relationship. He found that "... in all cases the net

ablation was equal to or greater than the gross ablation of the 1952 snow cover." It should be noted, however, that for general application he regarded this conclusion as provisional.

A related problem involves the penetration and dissipation of the winter cold wave. The extensive accumulation area of the Temperate segment of the Taku Glacier becomes fully isothermal at 0° C only after a period of several weeks of mean ambient surface temperatures above 0° C. The ablation season on the lower névés may therefore be viewed both in terms of an annual melting period (when atmospheric temperatures exceed 0°C), and a somewhat shorter effective ablation season, defined as "... that part of the annual melting period when the snowpack of the previous winter's accumulation is isothermal at 0°C" (Miller, 1963a). During the effective ablation season most, if not all, meltwater and rainfall is assumed to percolate downward and eventually to drain from the glacier.

For the main névés lying at different elevations on the Juneau Icefield, the approximate dates of the beginning and end of the annual melting period may be extrapolated from Juneau Airport temperatures. For this purpose the analyses have been made in conjunction with lapse rates determined from RAOBS (radiosonde) data obtained at Juneau Airport between January, 1946, and May, 1953. For detailed discussion of these extrapolations, reference is made to Miller (1963a, p. 81-84) and Marcus (1964, p. 52-65.) The length of the important transition period preceding and following the effective ablation season is also discussed by Miller (1963a).

As stated earlier in this discussion, the highest elevation of Taku Glacier is classified as Subtemperate (Miller, 1963a).[1] The obvious implication is that the concept of an "effective ablation season" would have little meaning if it is assumed that all meltwater (and rainfall) is refrozen at depth in the higher névé zone of the Taku Glacier system. Actually the assumption becomes untenable when we consider the impounding of water in the bottom of crevasses which the writer has investigated near the margins of these highest névés. Instead, the assumption is made that some meltwater probably drains from these high glacier segments via englacial channels particularly along the bedrock margin where side-wall percolation and small streams have been observed to enter the glacier. It is probably not safe to make the assumption that all surface meltwater and rainfall refreezes in a sub-freezing firnpack because some water loss may occur through englacial drainage systems. The observation of fluctuating water levels in crevasses at and above the 1,740 meter (5,700 foot) level on this glacier system indicates that at least some downward movement of water occurs. The question of the actual volume of meltwater lost in this way from the Subtemperate Taku Glacier zone has not yet been answered and probably may never be answered beyond an order of magnitude estimate. In terms of the glaciothermal measurements previously cited, however, this volume is assumed to be relatively small.

In the present study, the gross ablation data have been derived through measurements of surface lowering. These are converted to water equivalent when the density of the surface material is known. In cases where the

1. Provisionally, the central portion of Taku Glacier higher than ca. 1,700 meters (5,600 feet) is taken to be Subtemperate (Miller, 1964, personal communication). In the proximity of exposed bedrock, however, Temperate thermal conditions probably occur at substantially higher elevations.

density determinations were not made directly at the ablation record sites, approximations are used. These are based on mean bulk densities measured at or near the surface. The mean mid-summer bulk density is ca. 0.50 gm/cm^3. Late-summer bulk densities of the annual snowpack generally range between 0.50 and 0.60 gm/cm^3 (Marcus, 1964, p. 32). Therefore, a value of 0.55 gm/cm^3 is adopted as the mean late-season bulk density of the annual snowpack. This value corresponds to that adopted by Marcus (1964, p. 32) for the end-of-season firn density on the Lemon Creek Glacier. The mean values here suggested are applied with additional confidence, as they represent a composite of measurements made by a number of other workers on the main Juneau Icefield (cf. Marcus, 1964, p. 32, and also previous JIRP reports.)

B. Measurement Techniques and Accuracies

The gross ablation records cited in this report were obtained by periodically measuring the lowering of the snow surface with respect to stakes driven vertically to depths of one to two meters. As discussed below, small-diameter stakes were used for ablation measurements in order to minimize the disturbance of natural conditions. Regardless of size, material, or color, all stakes were found to produce ablation craters around the base of the stake. After a few days, these craters generally attained a depth of several centimeters. Ablation crater development, and consequent loss of record accuracy, can be reduced by implanting the stakes so that their tops are initially level with the snow surface, and also by resetting the stakes daily. In snow, the errors produced by settling of stakes can be minimized by driving the stakes to the top of a thick ice stratum or other diagenetic inhomogeneity.

Additional consideration of the accuracy of ablation measurements based on the use of stakes has been given by previous investigators. For example, during the 1952 summer season on the icefield, LaChapelle (1954) tested the suitability of several materials, in different colors, for ablation stakes. These included wood, steel tubing, aluminum tubing, aluminum strips and steel strips. He noted that "the size of the ablation crater around a given stake appeared to bear little relation to the material, color, or reflectivity of the stake, but was almost entirely a function of stake diameter." For ablation measurements, he used unpainted 0.476 cm. (3/16 in.) dowels approximately three meters long and driven to depths of about 2.5 meters. LaChapelle obtained additional measurements by driving a 0.95 cm. diameter (3/8 in.) steel rod to the upper surface of an ice stratum, and placing a short wooden plug at the base of the hole, which was otherwise left empty. Subsequent ablation measurements were made by means of a pointed dowel with which the lowering of the snow surface relative to the wooden plug could be measured; about the nearest mm. (LaChapelle, 1954, p. 3). The objective of the writer's measurements, however, was gross regional, rather than micro-meteorological analysis, and therefore, such accuracy was not essential.

But even for gross measurements, pronounced surface irregularities, such as suncups, can substantially lessen the accuracy of stake measurements. Suncup relief increases at successively lower elevations, reaching a maximum near the névé-line. The relief between adjacent crests and troughs on a late-summer surface may be in excess of 10 to 15 cm. (4 to 6 in.). In earlier field seasons, it was found that the most representative

surface lowering values could be obtained by placing stakes on inter-suncup divides (Miller, 1954, p. 15-18). In general this procedure was followed in the present study.

The stakes used in the 1962, 1963 and 1964 field seasons were unpainted wooden stakes of the smallest cross section available. These were 0.64 cm. (1/4 in.) diameter dowels, and 3.2 by 0.64 cm. (1-1/4 by 1/4 in.) cross-section laths. Each was at least 1.2m. (4 ft.) in length. In addition, several unpainted 1.80 cm. (3/4 in.) square stakes ranging from 2.45 to 3.35 m. (8 to 12 ft.) in length were driven as deeply as possible into the snow or firn, in an effort to measure components of surface lowering due to compaction.

The time interval between ablation measurements was about 24 hours. Daily readings were taken, when possible, each evening. In many cases, however, several days elapsed between measurements, particularly at outlying sites and during periods of unusually poor weather. In the present analysis, generally only the more continuous records are used.

In summary, the magnitude of error in daily stake measurements varies primarily with the degree of surface irregularity, and with the carefulness of the individual recorder. Measured values cited in the following discussions are considered to be accurate to within 0.2 to 0.5 cm/day.

C. Selection and Location of Record Sites

Unless otherwise noted, cited ablation data are from stakes at representative sites in mid-glacier, selected to minimize the effects of heat radiation from adjacent bedrock surfaces. The most complete gross ablation records are from two mid-glacier sites, designated 8B (1,814 m., or 5,950 ft.) and 10B (1,082 m., or 3,550 ft.). Site 8B lies near the

1,890 m. (6,200 ft.) drainage divide of the Taku and Llewellyn Glaciers. Site 10B is located on the lower Taku Glacier névé, ca. 27 km. (17 miles) from the terminus, and only about 5 to 8 km. (ca. 3 to 5 miles) from the mean névé-line position at the end of the ablation season. At these key sites, from 5 to 10 stakes were employed in order to obtain representative mean values. Less complete data are available from other mid-glacier sites representing different elevations on the Taku Glacier system.

Marginal ablation moats along the lower Taku Glacier indicate that surface melting rates increase significantly in the vicinity of exposed bedrock. To measure the cross-glacier variation, ablation stake transects were placed on upper, intermediate and lower Taku Glacier accumulation areas. Data from transects located opposite Camps 8, 9 and 10 are included in this report (cf. map, Fig. 2).

D. Ablation on Cross-Glacier Transects

Although in previous JIRP reports other designations have been applied to the transects described below, for the direct purposes of this particular study the names "8B transect", "9B transect", and "10B transect" are used. These transects are on the main trunk of the Taku Glacier (Fig. 2). They represent cross-glacier profiles passing through or within a few tens of meters of Sites 8B, 9B and 10B. Each transect is approximately perpendicular to the direction of glacier movement.

Gross ablation data with respect to each transect were measured during the summers of 1962, 1963 and 1964 on a number of movement stakes of the kind previously described. The large stake sizes used in these measurements, plus the generally long intervals between measurements,

prevent the breakdown of these data into representative daily values. The measurements do, however, permit the depiction of relative cross-glacier variations in rates of gross ablation during the effective ablation seasons of the years noted above.

1. Transect 8B

The alignment of movement stakes on transect 8B, with a mean elevation of approximately 1,830 meters (6,000 ft.) is from the flank of Governor's Ridge and Mt. Moore on the east toward an azimuth of 275°T. This bearing transects the Vaughan Lewis Glacier-Taku Glacier drainage divide south of Blizzard Peak (Fig. 3). For purposes of volume transfer comparison this transect has been referred to as Profile VIII in earlier JIRP reports. Site 8B (1,814 meters; 5,950 ft.) is located about one-third of the way out from the glacier's eastern margin on this transect.

In Fig. 6a, 1962 summer measurements from a 7-stake line are plotted for two different time intervals. In the mid-summer period, 9 July - 6 Aug., the gross ablation rate is seen to be consistently greater than the earlier summer rate over the interval 23 June - 9 July. For the 23 June - 9 July period, the mean ablation rate was 2.02 cm/day, which is only 75% of the 2.72 cm/day ablation rate for the period 9 July - 6 Aug. The mean daily surface lowering for the entire 44-day (23 June - 6 Aug. 1962) period is calculated as 2.39 cm/day.

In each plot, the ablation rate is seen to be progressively greater toward the eastern end of the transect, i.e., as the Mt. Moore nunatak is approached. In each plot later in the season, the rate of increase in ablation, with respect to proximity of the nunatak, also increases.

These observations corroborate the fact that more nearly representative values can be obtained at mid-glacier locations than at sites near the glacier margin.

2. Transect 9B

The 9B transect (designated as Profile VII in previous JIRP volume transfer analyses) extends northwestward from the slopes adjacent to Camp 9 (Fig. 4). This line trends toward Centurian Peak, on the western side of the North Branch of Taku Glacier. The transect azimuth in this case is approximately 300° T., with a mean elevation of about 1,356 meters (4,450 ft.)

The gross ablation plotted in Fig. 6b is also from early and mid-summer intervals during the 1962 field season - i.e., 23 June - 7 July and 7 July - 23 July. As on the 8B transect, the later of these intervals is characterized by greater mean daily ablation. Also, as previously shown for the crestal névé, during the later period (7 July - 23 July), the mean daily rate increases more conspicuously as the Camp 9 nunatak is approached on a line from the glacier's center.

The mean daily ablation rate over this overall 30-day period in 1962 (23 June - 23 July) was 3.65 cm.of firn per day. For 23 June - 7 July the rate was 3.45 cm/day, or 89% of the 3.85 cm/day rate for 7 July - 23 July. The mean mid-summer 1962 ablation rate was, therefore, about 1.52 times that indicated for the corresponding period for transect 8B.

3. Transect 10B

The 10B movement stake transect has, for volume transfer comparisons, also been designated as Profile IV (earlier JIRP reports). This transect (Fig. 4) extends from near the base of Camp 10 nunatak on the

east, to the base of the east ridge of Shoehorn Peak on the west (azimuth) ca. 230° T). The mean elevation of this transect is about 1,113 meters (3,650 feet). Because in its proximity to the main F.F.G.R. field station, gross ablation records on this transect are more complete than for the two higher transects (i.e., 8B and 9B) previously described.

Measurements from comparable intervals in three summer field seasons (1961, 1962 and 1964) are plotted in Fig. C. Representative mean daily gross ablation rates on transect 10B are tabulated below:

Measurement period:	Gross ablation of firn, cm/day:
24 July - 5 Aug. '61 (12 days)	4.09
20 June - 10 Aug. '62 (51 days)	3.59
31 July - 20 Aug. '64 (20 days)	3.91

The mean value is 3.86 cm. of firn/day, which is assumed as a reasonable mid-summer average for the Taku Glacier's lower névé sector. This value is about 1.05 times the 1962 mean on the 9B transect, and about 1.61 times the 1962 mean on the 8B transect. Although some difference is to be expected because the periodsof comparison are not entirely the same, these relative values give a fair idea of the early to mid-summer differences to be expected under conditions of the present decade.

E. Daily Gross Ablation of Firn at Site 10B and Relationship to Camp 10 Meteorological Records

From the plotted data in Fig. 7, a continuous 20-day (1 Aug. - 20 Aug. 1964) gross ablation record from Site 10B (1,082 meters, or 3,550 ft.) is compared with meteorological observations during this same interval at Camp 10, located ca. 2 km. (1.25 miles) ENE of Site 10B. The 10B record represents a 6-stake mean. The Camp 10 weather observations plotted

in this figure include the 0700, 1000, 1300, 1600, 1900 and 2200 hours readings of temperature, wind direction, wind velocity and cloud cover.

Also plotted as daily means are the Camp 10 temperature and relative humidity records for this 20-day period.

The available temperature data from Site 10B are also included in this figure. The 10B temperature record, however, is too intermittent for valid correlation with the surface ablation record at this site. Thus, for this comparison the Camp 10 records are used. It must be recognized, however, that these indicate higher temperatures and sometimes lower relative humidities. Also because of katabatic wind effects, a substantially different wind direction and velocity would be synoptically recorded at Site 10B than at Camp 10. Previous detailed records of mid-summer conditions have shown that the mean temperature at Camp 10 is about 20° F. higher than at Site 10B (Miller, 1952, 1954, 1963a). For the 12 synoptic temperature measurements available from Site 10B for the 20-day period in 1964, the Camp 10 temperature was also consistently higher, with a mean temperature difference of approximately 8° F, and a range of 2° to 17° F. In general, the greatest temperature differences between these two sites (in the summer of 1964) occurred on days during which relatively high temperatures were recorded at Camp 10. The least temperature difference was recorded on days of relatively low temperature at Camp 10.

In general, a direct relationship between the trends of mean daily Camp 10 temperature and the corresponding daily gross ablation at Site 10B is clearly shown in Fig. 7. Each of the high-temperature peaks (e.g., 3, 6, 11 and 17 Aug.) are associated with a relatively high peak in the plot of gross ablation.

The plot of wind direction during the period 1 - 20 August shows that the prevailing wind direction at Camp 10 was from the SE. During the same interval at Site 10B, however, a frequent, if not dominant down-glacier wind direction pertained. This wind is generally from the N or NW, at a velocity of 5 MPH or more, and is presumably katabatic air flow, often prevailing despite regional air movements in the opposite directions. It is of further significance that during the summer, regional winds across the icefield from the north frequently coincide with the low relative humidity, and generally higher ablation rates.

A discussion of the detailed relationships between meteorological factors and resulting gross ablation is not the province of the present study. The main significance of the above discussion is to point out that meteorological conditions at the mid-glacier site, (10B), while different in absolute value, are similar in trend to those observed at neighboring nunataks at levels above local katabatic flow - such as Camp 10.

F. Comparative Meteorological Records at Camps 8 and 10

Selected synoptic weather observations made at Camps 8 and 10 during the period of this study are plotted in Fig. 8. As stated previously, Camps 8 and 10 are the two main F.F.G.R. camps, and from these the most complete meteorological records are available. These camps are located on bedrock, and stand respectively 3,935 meters (1,200 feet) and 1,312 meters (400 feet) above the general level of the surrounding ice. Camp 8 is at an elevation of 2,195 meters (7,200 ft.) and Camp 10 is at 1,220 meters (4,000 ft.). Camp 8 is located about 18.5 km. (11.5 miles) north of Camp 10 (v. maps, Figs. 2, 3 and 4).

At these main icefield stations, summer meteorological observations have been made at 0700, 1000, 1300, 1600, 1900 and 2200 hours. The Fig. 8 plots represent daily temperature, relative humidity and cloud cover. Much of the difference in mean daily temperature reported at each camp over the period 1 - 12 Aug. 1964 may be attributed to the 975-meter (3,200 ft.) elevation difference between these two camps. Mean daily temperature at Camp 8 for the 1 - 12 Aug. 1964 period was about 11° F. less than at Camp 10. The mean temperature difference between camps over these 12 days of record varied from 8° to 14° F. daily.

Mean relative humidity reported at Camp 8 for 1 - 12 August was 96%, versus 75% for Camp 10. This difference is somewhat greater than expected. The consistently higher relative humidity at Camp 8 is related largely to orographic effects. In other words, the prevailing summer winds are from the south and southeast and should result in a relative humidity increase as the air mass lowers its temperature in rising to the crest of the Coast Mountains. Miller (1966, personal communication) has suggested that there may be a significant layering effect from regional flow, or more maritime air moving in at higher level from the outer coast in a cyclonic pattern.

The least difference in mean daily relative humidity between the two camps occurred on 12 August, on which date a mean of 98.3% humidity was registered at Camp 8, versus a 95% value for Camp 10. This small difference, however, could be purely local, or due to some variation in observer technique. The greatest difference occurred on 11 August, when 89% was recorded at Camp 8, compared to only 52% at Camp 10. This unusually large difference can possibly be explained by the fact that the winds reported at Camp 10 on 11 August were northerly, suggesting an overriding effect of a drier than normal pressure cell from the continental side of the Coast Mountains. This explanation, however, appears to conflict with the Camp 8 records on the same date, in that winds from the south were dominant that day. Again this explanation may be layer stratification, or local perturbation in the configuration of the opposing continental and maritime pressure cells at this time. Generally, during the summer when opposing wind directions occur at these camps the reverse is true - i.e., northerly flow at Camp 8, vs. southerly air movement at Camp 10 (Miller, 1966, personal communication).

The plot of cloud cover in Fig. 8 (rated on a scale from zero to ten, with zero indicating no cloud cover and ten indicating complete cloud cover) shows a general correlation between Camps 8 and 10. For the selected representative 12-day period, the mean cloud cover at Camp 8 was 8.25, some 106% of the value of 7.81 recorded at Camp 10.

Inspection of the plot in Fig. 8 also shows that for about 50% of this 12-day period, cloudiness was significantly greater at Camp 8 than at Camp 10. About 33% of the time, the opposite was true. About 17% of the record period was characterized by equal cloudiness reported at Camps 8 and 10. The dominance of cloudy conditions on the crestal névé, and its to-be-expected increase in radiation back-scatter during many summer weeks, provides some explanation for the greater relative humidity recorded at the higher camp, as discussed above.

It is essential to realize, however, that estimation of cloudiness, other than for the end-point values of 0 and 10, are subject to much individual error, particularly with untrained observers.

The weather data available during these period lend themselves to some further analyses, but these are outside the scope of the present treatment. However, the anomalies pointed out in this discussion demonstrate the need for systematic, prolonged and continuous synoptic records obtained by experienced personnel not merely over a few weeks, but for much longer periods of time -- preferably throughout consecutive seasons. Clearly these factors need to be investigated with respect to the long-term ablation characteristics of the higher and intermediate elevation zones of this icefield.

IV. STRATIGRAPHIC AND DENSITY RELATIONSHIPS IN THE ANNUAL FIRNPACK

A. Introduction

In this report, the terms névé and firn are not used synonymously. The German term firn is used in its original sense, and refers to snow which has lasted through one or more ablation seasons. The French term névé, as used here, is restricted to an areal connotation. The snow increment of the preceding winter is referred to as the snowpack of that winter, until the density attains 0.45 or greater. After this time, at greater densities, it is designated the firnpack of that budget year. Actually, in most sectors of the névé on this icefield the winter snowpack transmutes into a firnpack usually by mid-summer - that is, after July 15th (Miller, 1966, personal communication).

The term accumulation refers to processes resulting in the addition of ice to a glacier, as opposed to ablation, by which ice is lost from a glacier. Processes of accumulation include "... direct precipitation of snow and ice, refreezing of liquid water, condensation of the ice from vapor, and the transport of snow and ice to the glacier by avalanches or wind (Meier, 1962, p. 253)." Of these factors, vapor condensation is regarded as only of minor importance in the regime of the Juneau Icefield, mainly because of the extreme maritimity (humidity) of this climate. Avalanching is also an insignificant process in Taku Glacier accumulation, because the terrain is broad and not characterized by large avalanche slopes. The predominant process of accumulation on the Juneau Icefield is the heavy deposition of snow from late September through early June. As indicated previously, the refreezing of percolation at depth (meltwater plus rainfall) is considered to take place to a significant extent in the high-elevation

subtemperate sectors of the Taku-Llewellyn Glacier system.

Generally, accumulation measurements obtained during a summer field season represent values lying between the initial or gross accumulation present at the beginning of the ablation season, and the final, or net accumulation remaining at the end of the ablation season. The summer ablation season closes with the onset of autumn snowfall, representing the first accumulation increment of the next budget year. By measuring, at representative sites, the total amount and seasonal trend in ablation between successive accumulation seasons, an estimate of both gross and net accumulation can be made, based on records of the thickness and bulk density of the annual firnpack at known times during the ablation season.

A complication in evaluating deep stratigraphy results from the fact that deposition of successively deeper strata occurred progressively farther upglacier, at higher elevations. As an illustration, a 20-year old annual accumulation stratum exposed in a crevasse wall might have been deposited 9 to 10 km. (ca. 6 miles) upglacier. At the mean gradient (3%) of the Taku Glacier this could represent an elevation as much as 250 meters (ca. 800 ft.) higher than that at the measurement site. For detailed analysis, such results could not properly be compared with the initial accumulation trends at such a lower elevation location. In the present study, this factor is not regarded as important, because most measurements are from shallow depths, and the general comparisons attempted are based on measurements from broad, low-gradient areas.

B. Measurement Sites

In long profile, the Taku Glacier surface exhibits several long, low-gradient segments separated by relatively short, steep-gradient segments.

Measurement sites were selected on the assumption that accumulation would be most representative near thecenter of each of these longer segments. On the flattest mid-glacier segments, local orographic effects on accumulation and ablation are regarded as minimal.

Logistical limitations in the field prevented a dense concentration of record sites. The range of local variation in accumulation is consequently not well documented, although some comparisons were made from stratigraphic measurements in three closely-spaced crevasses examined in 1964. During the 1962-64 field seasons, Sites 10B (1,082 meters) and 8B (1,814 meters) were given priority in order to maintain continuity with the long-term records obtained at these locations in preceding field seasons.

The 21 measurement sites of the 1962 field season were distributed over most of the main branches of the Taku Glacier system. Firnpack stratigraphic information during the 1962 field season was obtained primarily from 3-inch diameter hand auger cores. The 1963 stratigraphic measurements were obtained on pit and crevasse walls at the 1,082-meter elevation, on walls of two crevasses at the 1,737-meter elevation, and in a test pit at 1,814 meters. In 1964, measurements were made in three crevasses at the 1,082-meter elevation, and in single crevasse and test-pit sites at 1,737 meters. The most useful sequential accumulation data obtained for the present study consist of depths and thicknesses of ice strata associated with annual ablation surfaces, supplemented with bulk density measurements of firn. Except for depth-hoar horizons, crystal types and sizes were not noted, as this information is not essential in

interpreting annual accumulation increments in Temperate glaciers. Data from earlier field seasons incorporated in this paper were also obtained from test-pits, crevasse walls, and drill holes.

Rammsonde (ram penetrometer) profiles were made near each of the main record sites. This provided corroborative stratigraphic information, at least, to shallow depths (i.e., to 3 meters). These data are not essential for the present purpose, and are not included in this report.

Ablation stakes were also emplaced at nearly all of the drilling and pit sites, in the hope that subsequent ablation measurements could be made. In many cases, it was not possible to revisit or relocate these stakes, particularly in the case of the widely dispersed 1962 record sites.

C. Criteria for Delineating Annual Accumulation Increments

Buried summer ablation surfaces, which separate annual accumulation increments, were recognized in the field by several criteria. A list of possible methods for such differentiation follows. The first ten criteria have been listed previously (Miller, 1955, p. 295). The remainder have been suggested during the course of the M.S.U. Glaciological Institute program.

1. Presence of dirty layer or dust sheet.
2. Presence of undulations, usually representing a relict suncupping of wind-rippled surface.
3. Presence of unusually thick ice stratum.
4. Sudden or persistent density change at depth.
5. Presence of basal depth-hoar stratum (Schwimmschnee).
6. Abnormal concentration of pollen in a single horizon or zone.
7. Marked change in chloride content of firn.
8. Considerable increase in firmness characteristics as indicated by ram resistance technique.

9. Definite difference in drill rate with low speed thermal or mechanical boring apparatus.

10. Well-differentiated englacial temperature change in firn at depth.

Additional criteria include:

11. Increase in radioactivity level attributable to atmospheric nuclear testing.

12. Natural and man-made tritium content.

13. Oxygen-isotope content.

14. Concentrations of inorganic microscopic particulates.

15. Grain size.

16. Discontinuity in crevasse-wall profile.

17. Icicle zones on crevasse walls.

18. Stratigraphic discontinuity determined by shallow seismic or other geophysical methods.

19. Local and regional correlation with other established profiles.

20. Petrographic evidence denoting significant stratigraphic change.

21. Strata differentiation by chemical analysis of organic and inorganic content.

Several of these indications of buried ablation surfaces may be directly observed on the walls of crevasses or deep pits. Where crevasses are absent, ram penetrometer and thermal or mechanical drilling techniques can be used. The main identification criteria used in the present study were: (1) the presence of a dirty layer; (2) an unusually thick ice stratum; (3) a marked change in density trend; (4) presence of a basal depth-hoar stratum (or strata); and (5) marked increase in firmness, as detected by penetrometer or hand auger methods.

Buried ablation surfaces generally become more difficult to identify at depth, as the firn becomes more homogeneous in physical characteristics.

On Temperate glaciers, in the vicinity of the mean névé-line, stratigraphic relations are further complicated by the presence of multiple ablation surfaces. At the higher elevations on the Juneau Icefield, many of these identification criteria become progressively well developed, an observation previously noted by LaChapelle (1954, p. 23).

D. Field Techniques and Results

1. The 3-Inch I.D. Hand Auger

Much of the stratigraphic data for this study was obtained by drilling with a standard type of 3-inch (I.D.) hand auger. The drill sites involved are noted in the accompanying maps (Fig. 2, 3, 4 and 5). This excellent coring auger was designed and developed by SIPRE, the former Snow, Ice and Permafrost Research Establishment of the U.S. Army Corps of Engineers, now reorganized as CRREL, the Cold Regions Research and Engineering Laboratory, headquartered at Hanover, New Hampshire. This type of drill has been used extensively in glaciological work during and since the I.G.Y. It is available from the General Mechanical Corp. at Chicago, Illinois.

For the purposes of the present study, coring depths of 7 to 10 meters were used, insuring the penetration of at least the previous winter's accumulation segment. The maximum depth reached was 22.5 meters (74 ft.), near Site 20A on the crestal névé. Ice strata thicknesses and depths below the fiducial surface were recorded as soon as possible after the cores were brought to the surface. Occasionally small gaps in the record resulted from breakage and disaggregation of the cores in the core barrel. The frequency of such breaks was minimized by careful drilling and handling. Ice strata thicknesses were measured to the nearest mm. The measurement of depths below the surface are considered accurate to about 5.0 cm.

Density measurements were made by sawing the cores into segments of known length, and then weighing them on a spring balance. To facilitate density calculations, a standard core length of 10.0 cm. was used. Each segment consisted either of firn without ice strata, or of continuous ice from a single ice stratum. A serious objection to calculating firnpack density from such cores resulted from the fact that soft snow or firn became crushed and compacted in the core barrel during drilling. This error was further increased because the main section of the core barrel is slightly greater in diameter than the diameter of the core, as originally cut. In the case of sufficiently cohesive firn, compaction usually does not take place, but in the easily compacted firn which is common on Temperate glaciers in the summer, anomalously high density values are likely to result. This situation is believed to have affected at least the upper few meters of the core measurements made in this study. These errors are discussed later.

2. Test-pit Records

The locations of pertinent test-pits in this study are shown in Figs. 2, 3, 4 and 5.

Most of these pits were excavated to the depth of the previous annual ablation surface -- in most cases, at 3 to 5 meters. Pit excavation was most efficiently done by digging on the site of a large crevasse, into which the loosened snow could be shoveled. In this way, disturbance of the fiducial surface was minimized, and in deep pits the amount of labor involved was greatly reduced.

In order to reduce melting effects from solar radiation, pits were oriented to keep at least two walls shaded during most of the day.

During excavation, the snow surface around part of the pit perimeter was left undisturbed, so that it could be used as a reference surface for depth measurements. As excavation progressed, density measurements were taken at regular intervals on the shaded sides of the pit. Density measurements were obtained by rotating or driving hollow cylindrical metal corers into the pit wall, and weighing the extracted 250 or 500 cc. samples. The samplers have been described by Miller (1954, v. Fig. 10).

Certain types of corers cause a loss in accuracy because of the inward bevel of the cutting edge, which tends to compress the snow as coring progresses. The magnitude of this error is difficult to evaluate, as it varies with the type and compressibility of the snow (or firn) being sampled. An analysis of these errors has been given by LaChapelle (1954, p. 4-5). For detailed density evaluations, these errors are of course significant. In this present report, in which gross comparisons are made with data from previous studies, the same techniques have been applied.

3. Crevasse-wall Stratigraphy

Crevasse stratigraphy was measured from wire cable ladders, with a steel tape measure suspended alongside for depth measurements. For safety, all persons entering crevasses were protected by standard mountaineering belay techniques.

Wherever possible, and to insure maximum consistency in observations, most of the 1962-64 stratigraphic measurements used in this study were made or field-checked by the writer. Among the difficulties leading to subjective error is the fact that stratigraphic details seen on crevasse walls become increasingly obscure at depth, both because of the poor

light available, and because often a thick sheath of ice covers the crevasse walls.

As in the case of the pit records, density measurements were made with toothed coring tubes of known volumes. Below the previous summer's ablation surface, the firn and ice was generally too compact to be sampled with coring tubes not having cutting teeth. Emphasis was placed on density measurements in the previous winter's firnpack.

A major advantage in using crevasse walls for stratigraphic measurement is that local ranges of variation in thickness of ice strata can be readily observed, with the result that interpretations are more realistic than those based on a single hand-auger profile. The most representative stratigraphic data incorporated in this report are from crevasse measurements. The locations of key crevasse sites for this purpose are noted in Figs. 3 and 4.

4. Density Measurements

In this study, firn density measurements are used for two main purposes. First, as noted in the beginning of this section, changes in depth/density trend provided an excellent basis for delineation of the accumulation segments of successive budget years. This was aided by identification of the relatively low-density depth-hoar (Schwimmschnee) horizon commonly found at or near the base of an annual accumulation increment. It was also helped by recognition of marked increases in density in the accumulation increment representing the preceding year. In firn older than a few years, distinct density variations became attenuated at depth, largely as a result of firn diagenesis. Deeper segments proved to be of limited value in the interpretation of annual increments.

Firn density data are also essential for the conversion of annual firnpack thickness to water equivalent (w.e.). The water equivalent is calculated by averaging a suitable number of density measurements to approximate the firnpack's bulk density. Accumulation data expressed in terms of water equivalent provide a basis for comparison with annual precipitation trends at coastal U.S.W.B. stations. Such comparisons are discussed later.

A composite of 1961-62 firnpack density measurements to a depth of 11 meters is plotted in Figs. 10a and 10b. All of these density determinations were made by weighing known lengths (usually 10 cm.) of 3-inch hand auger cores.

As pointed out earlier in this paper, the 1962 density measurements from shallow depths (i.e., less than ca. 3 to 5 meters) are suspected to be anomalously high in value, as a result of the compression of firn in the hand auger core barrel during the drilling operation. For the present, all 1962 data are retained here because the main purpose of these particular density plots (Figs. 10 and 11) is to facilitate certain general comparisons between depth/density trends at lower elevations and those at higher elevations on the icefield.

In Fig. 10a, firnpack densities have been compiled from seven widely dispersed sites as the lower névé. The elevations of these sites range from 945 to 1,370 meters (3,100 to 4,500 feet). Fig. 10b depicts density measurements from ten sites on the upper névé, at elevations of 1,370 to 2,135 meters (4,500 to about 7,000 ft.). The measurements in these two diagrams were taken during July and August, 1962. They provide a general indication of the depth-density relationships as a function of elevation.

Although detailed effects of the time factor in the densification of snow and firn are not discussed, these composite diagrams do show significant differences in the rate of density increase with respect to depth. They also reveal the observed range of density variation. It is of interest that the rate of increase with respect to time and depth is greater at successively lower elevations on the Taku Glacier. This supports the concept of a Subtemperate geophysical character of the crestal firn-pack as previously described.

As a further illustration of the use of density values in differentiating annual accumulation increments, the 1951 density data at Site 10B are plotted to a depth of nearly 6 meters (Fig. 11a). Inspection of this plot reveals that the 1948-49 firnpack (bounded at the top by the 1949-50 multiple-ablation surface) is conspicuously denser than the overlying 1950-51 firnpack.

A notable decrease in density near the base of the 1950-51 firnpack (3 to 3.45 meters) indicates the presence of a well-developed depth-hoar stratum. This stratum corroborates the interpretation that the base of the 1950-51 firnpack at the time of measurement was at a depth of approximately 3.45 meters.

A composite of bulk density values measured on test-pit walls (Sites 8A and 8B) at 1,780 and 1,815 meters, respectively, is plotted in Fig. 11b.

Such measurements are fundamental in total mass budget evaluations because from such statistics unit volume calculations (in w.e.) can be made for the areas of accumulation between different contours.

F. Firn Stratigraphic Data

Stratigraphic measurements at five representative record sites obtained during successive field seasons are now described. The key sites are 8A, 8B, 10A and 10B. Most of these measurements were made on crevasse walls, but some are from the 3-inch diameter hand auger cores. In successive years comparable stratigraphic data were obtained at two to three crevasse sites in the same vicinity.

In Figures 16, 17 and 18, the stratigraphic sections are arranged so that the fiducial surface of a given section matches the corresponding buried ablation surface observed in the following year. This type of presentation facilitates sequential stratigraphic correlation.

1. Sites 8A, 8B and 8D

The 8A - 8B stratigraphic record is plotted in Fig. 16. Because large crevasses are absent in the 8A-8B area, most of the stratigraphic and density data are from hand-auger cores. Supplemental pit measurements were made in 1961 and 1963.

The pertinent data for Sites 8A and 8B are tabulated below:

Budget Year:	Stratigraphic Thickness (Meters):	Bulk Density: (g/cm^3)	Record Date:	Type of Measurement:
1960-61	5.26	0.555	early Sept. 61	8A pit
1960-61	5.26	0.537	early Sept. 61	8A hand auger
1961-62	6.90*		28 July 62	8B hand auger
1962-63	5.65		27 Aug. 63	8B hand auger
1962-63	5.60	0.562	27 Aug. 63	8B pit
1963-64	6.50*		22 July 64	8A hand auger

* Note: These are relatively high values because of the early (mid-summer) measurement date.

Ice samples collected in 1963 at Pit 8B were subjected to gamma radioactivity determination by Dr. Neil Farlow of the NASA Ames Research Center, California (1965, personal communication). Five values of specific activity (net counts/min/mg of residue) reported by Farlow as being "probably significant" are included in the 8B stratigraphic plot. These data are too few to permit interpretations useful to the present study, but are included here to facilitate future comparisons as more information of this type becomes available. It is noted that additional samples have been collected at Sites 8B, 9B and 10B during the 1964 and 1965 field seasons. These are also being tested for tritium concentration.

In Fig. 17, the crevasse stratigraphy from Site 8D at the 1,737 meters (5,700 foot) elevation of the north branch of Taku Glacier, is plotted. This record site is located at the upper part of a relatively steep glacier segment. The resulting transverse crevasses make it a favorable site for deep crevasse measurements.

The stratigraphy plotted in Fig. 17 was measured on crevasse walls in the summers of 1961, 1963, and 1964. The 1962 records are from the 3-inch hand-auger core data, and is not as representative as the crevasse data.

The stratigraphic thickness of each annual firnpack, as measured in the 8D area during the successive summers, is tabulated below:

Year	Stratigraphic Thickness (m):	Date of Record:	Type of Measurement:
1960-61	5.35 m	13 Sept. 61	Crevasse wall stratigraphy (8D)
1961-62	6.50*m	5 Aug. 62	Hand auger (8D)
1962-63	5.30 m	2 Sept. 63	Crevasse wall stratigraphy (8X)
"	5.10 m	3 Sept. 63	Crevasse wall stratigraphy (8Y)
1963-64	6.40*m	6 Aug. 64	Crevasse wall stratigraphy (8D-1)

* Note: These are relatively high values as a result of early (mid-summer) measurement.

The four-year record at this site provides a means for comparing thickness and the stratigraphic changes in the approximate annual accumulation increment during successive years. Particularly on the crestal névé, variation in original snowpack thickness may be expected to prevent accurate determination of compaction effects with time. But the order of magnitude differences are significant and in nearly all cases, the measured thickness of a given annual increment decreased significantly over successive years. The percentage of this decrease is greatest during the first year or two, and gradually diminishes as the firnpack becomes transformed into bubbly glacial ice. In a few cases, the annual stratigraphic thickness indicated a small increase, rather than the expected decrease, when measured the following year. This is attributed to local variations in accumulation and ablation in the record area, and to slight differences in the position of successive measurement profiles.

Several deep crevasses in the 8D sector of Taku Glacier were observed to contain water, giving a water-table relationship (Miller, 1962). The depth of this water table varies greatly between adjacent crevasses, but in the 8D sector, at least, only the deepest parts of crevasses were found to contain water. For example, the depth to the water level in crevasse 8D-1 was 32 meters (105 ft.) below the firn surface (Fig. 17). Water levels fluctuate in crevasses, and in some cases water will drain completely from a crevasse in a few hours. Apparently this drainage occurs to a great extent through channels in the ice deeper than the 35 to 45 meter (120 to 150 ft) depth. These channels may originate as fractures produced by stress, which are probably later closed by continuing adjustments within the glacier body. Despite the predominantly subfreezing englacial temperatures reported for the highest elevation levels of the Taku Glacier system, it is likely that some of the downward - and laterally - percolating water (meltwater and rainfall) in the firnpack escapes refreezing and enters englacial drainage channels.

2. Sites 10A and 10B

The 1962 through 1964 stratigraphic records from sites 10A and 10B on the lower Taku Glacier are assembled in Fig. 18. The 1962 data are from hand-auger core measurements and density determinations to 9 meters. The 1963 record consists of crevasse stratigraphy from two sites, 10B-1 and 10B-2, reaching respective depths of 17 and 30.5 meters. A density and stratigraphic study was made in a pit (pit 10B-A) excavated to a depth of 3.7 meters at the 10B-1 site. These data are included in the 10B-1 column. As at site 8A, residues from the 1963 ice samples from the 10B-1 and 10B-2 crevasse walls and from pit 10B-A were analyzed for gross gamma radioactivity level by Dr. Neil Farlow of NASA's Ames Research Center, Moffett Field, California. Mainly as a result of small sample sizes collected, this research yielded few interpretable data. Part of this problem may have resulted from diffusion by percolation. The three measurements of specific activity (net counts/min/mg of residue) regarded by Farlow (1965, personal communication) as "probably significant" are plotted in the 10B-1 column. The 1964 record consists of three crevasse stratigraphy profiles, 10A-1, 10A-2, and 10A-3.

In Fig. 18 it is possible to correlate some of the same buried annual ablation surfaces not only between crevasses examined in the same year but also between crevasses measured in successive years. Such correlations are made difficult for several reasons, one of the most obvious being the local variability of subsurface ice stratigraphy. This variability is

particularly evident when crevasses 10A-2 and 10A-3 are compared. These crevasses were located 20 meters apart.

In nearly all cases, a given annual increment will be seen to decrease substantially in thickness from year to year as a result of compaction. However, the horizontal variability pointed out above makes it doubtful that any meaningful results can be obtained by tracing the compaction of a particular annual horizon.

As mentioned earlier, the apparent decrease in stratigraphic detail with depth results mainly from ice sheathing the walls, and from poor visibility encountered by the observer while working at deeper levels in these crevasses.

In crevasses 10B-2 and 10A-2 water levels were encountered at 30.5 meters (100 ft.) and 19.2 meters (62.4 ft.) respectively. In regard to englacial drainage, it may be of interest that while the stratigraphy was being measured in crevasse 10B-2, a steady trickle of water could be heard at one end of the crevasse. On one occasion this was interrupted by a slight tremor of the glacier, after which a distinct increase in water volume could be heard pouring into the crevasse.

G. Accumulation Trends on the Lower and Upper Névés, 1926-65.

The annual trends of retained accumulation (w.e.) at the two main reference sites are depicted in Fig. 19. The estimated ablation (w.e.) has been added to the upper portion of each histogram. This estimate was made on the basis of the cumulative ablation curves in Fig. 9. For example, the measured values of ablation plotted in the cumulative curve for Site 10B represent records obtained during various periods in several field seasons. From these, a composite plot has been prepared which

represents an idealized reconstruction of gross ablation during the total melting season. Although it is realized that total ablation varies significantly from summer to summer, this procedure nevertheless allows at least an approximation or best estimate of the ablation which occurred both prior to, and subsequent to, the annual accumulation increment measured at known dates during the summer. The total histogram heights in Fig. 19 are referenced, therefore, as only a first approximation of the gross accumulation.

The retained firnpack statistics for the lower névé are plotted for a period of 39 budget years - i.e., since 1926. The first two decades of this record are based on deep crevasse-wall measurements at site 10B. As already shown, they represent approximate annual increments at locations which were formerly farther upglacier and up to several hundred meters higher in elevation. Thus the initial 20 years of record shown in Fig. 19 include values not representative of the present position of site 10B. They are considered, however, to represent values of mean accumulation in the central lower névé area and are used here as approximations for the stratigraphic column at 10B. As such, they add considerably to the interpretations based on those more reliable measurements which have been obtained nearer to this control site since the late 1940's.

A mean of the total precipitation over a period of nine months, as recorded at five coastal U.S. Weather Bureau stations (v. maps, Fig. 1 and 2) is also plotted in Figure 19. This permits some useful comparisons with the icefield accumulation records. By using only nine months of the record, precipitation during June, July and August is disregarded on the basis that during these summer months, when ablation dominates, net accumulation by snowfall is nil on the icefield's lower névés, and minimum

on the crestal névé. Thus, in the comparisons, attention can be focused more directly on the significant data relating to major variations in accumulation. The pertinent coastal weather stations and their elevations are listed as follows:

1) Annex Creek, 24 Ft.
2) Eldred Rock, 55 Ft.
3) Juneau City, 72 Ft.
4) Juneau Airport, 17 Ft.,
5) Point Retreat, 20 Ft.

Comparable 9-month precipitation totals for Annex Creek are also shown separately in Fig. 19. This U.S.W.B. station is the closest to the Taku Glacier, being 12 km. ($7\frac{1}{2}$ miles) from the terminus, and 37 km. (23 miles) from Site 10B.

There are certain inherent difficulties in any attempt to make direct comparisons between retained accumulation on the icefield and the sea-level precipitation records. The factors involved include inherent differences between station records, whether measured synoptically or averaged over long periods; the problem of deciding which low-elevation records most closely approximate the higher-elevation icefield data; and the problem of obtaining representative values of annual accumulation at specific sites on the icefield.

Additional points are that net accumulation is a function of both liquid precipitation and snowfall, and also of varying temperatures during the subsequent summer melting period. The combined affect of these factors makes it somewhat dangerous to attempt close and detailed correlation between the 8B and 10B icefield data and the weather records at low-

elevation coastal sites. Inspection of Fig. 19 suggests, however, some broad similarities in the occurrence of extremes as well as in the general trends. These similarities appear to be regionally significant. As an example, a decrease in 8B accumulation from 1948-51 appears to parallel a corresponding decrease in Annex Creek winter precipitation. A decrease in the accumulation at Site 10B also occurred during these years, and in 1949-50 and 1950-51, no net gain was recorded at 10B. Unusually high summer temperatures recorded at Annex Creek during the summer of 1950 undoubtedly played an important role in this relationship.

With the exception of the relatively low values reported in the budget years 1946-47, 1950-51 and 1951-52,the retained accumulation for site 8B averages 3 meters (9.8 ft.) w.e. The mean value of the ten annual increments for the budget years 1946-47 to 1952-53 and from 1960-61 to 1962-63, as plotted in Fig. 16, is about 2.8 meters (9.2 ft.). The corresponding value at 10B over these same years is 0.79 meters (2.6 ft.). Thus, during at least ten budget years in the recent past, retained accumulation at 8B has been over three and one-half times that at 10B. If the refreezing of rainfall and meltwater at depth in the 8B sector is also considered, the total retained accumulation at 8B must be significantly more than three and a half times that at 10B.

Variations in the records of retained accumulation at 8B appear to be of significantly larger amplitude than those at 10B. Despite this greater fluctuation, a generally closer correspondence in trend appears between the 8B annual accumulation records and the 9-month sea-level precipitation, because the 9 month interval was selected to correspond more closely with the duration of maximum accumulation by snowfall on

the upper névés. This correspondance may be further accounted for by the fact that much less total ablation takes place on the higher névés, with a consequently smaller and less variable quantity of ablation in different years than occurs on the lower névés. Thus a more regionally significant gross accumulation pattern may be expected on the highest névés. In this respect a higher percentage of the regional total precipitation over the 9-month period falls only as snowfall at high elevations than at successively lower and warmer levels.

A pertinent analysis has been made by Miller (1963a, p. 162) who shows that sea-level snowfall trends in the Taku District parallel ice-field accumulation trends on the lower névé, while total precipitation trends at sea level parallel the net accumulation trends on the crestal névé of the Taku Glacier system. The later data incorporated in this present study would appear to corroborate this conclusion.

The upper and lower névé plots in Fig. 19 suggest a fairly close and direct correspondence in trend on a year-to-year basis, particularly when strongly negative budget years are involved. The long-term pattern, however, is more difficult to discern, partly because of lack of full continuity in the 8B record. Clarification of the nature of trends on the order of a decade or more will require continued long-term field measurements, but these will be aided by the records already obtained.

Also, as discussed below, the data on the shifting névé-line on the Taku Glacier adds further corroboration to the trends indicated strictly by stratigraphic and precipitation statistics.

V. THE NÉVÉ-LINE AS AN INDICATOR OF MASS BUDGET CHANGE

A. Description and Terminology

At the beginning of each annual melting period, the preceding winter's snow cover is removed from the glacier's surface at low elevations, with the maximum rate of loss at the terminus. During the summer, as the snow cover is progressively removed at higher elevations, the steadily rising transition zone between snow and ice is termed the transient névé-line (or transient névé-line zone). This zone retreats upglacier during the ablation season until effective ablation ends with the accumulation of new snow and the low temperature of winter. At its highest position, this is termed the seasonal névé-line. On Taku Glacier, the seasonal névé-line since the 1940's has developed by mid-to-late September, at an elevation of about 915 to 975 meters (3,000 to 3,200 feet).

In previous JIRP reports, the lowest position over several years has been referred to as the semi-permanent névé-line. The mean névé-line has arbitrarily been defined as the mean elevation of the seasonal névé-line over the most recent 10-year period.

In plan view, the seasonal névé-line zone is usually several tens to a few hundreds of meters in width. The contrast in albedo between the firnpack and the glacier ice (or between firnpacks of different winter seasons) is easily seen from the air or on aerial photos. The seasonal névé-line positions cited below are, in most cases, based on late-summer observations from aircraft, and from aerial photos.

The general position of the mean névé-line on the glacier can usually be located on a contour map because the cross-glacier profile changes from convex-up in the ablation zone to slightly concave-up in the accumulation

zone. This, of course, means that down-glacier from the mean névé-line, contour lines crossing the ice surface tend to be convex toward the terminus, while in the accumulation zone the contour line pattern tends to be concave in the down-glacier direction. In the vicinity of the mean névé-line, the contour lines generally cross the glacier in a straight course. This relationship is well shown in the map, Figure 4.

Because névé-lines are partly a function of ablation, comparison of seasonal névé-line positions with the mean temperatures of corresponding ablation seasons should reveal a general accordance in trend. Theoretically, a high seasonal névé-line should result from an unusually warm summer melting period, and a low névé-line from relatively cooler summer conditions. In contrast, an inverse relationship may be expected between the amount of winter (and spring) snowfall and the elevation of the seasonal névé-line. In this case, an abnormally thick annual firnpack tends to be associated with a low seasonal névé-line. In other words, it is reasonable to expect that a trend toward lower seasonal névé-line elevations will be associated with a trend toward increasing mass budget. The comparison of such trends on the Taku Glacier is considered below.

B. Comparative Névé-Line and Net Accumulation Trends on the Taku Glacier, 1946-65.

Observed névé-line positions for the period since 1946 are tabulated in App. E., and plotted in Fig. 20. For comparison, retained accumulation data from site 10B (1,000 meters) for the same 20-year period are also plotted in Fig. 20.

During the past two decades of record, abnormally high seasonal névé-lines were observed in 1950 and 1951. In these two successive years, the

névé-line actually retreated upglacier to a higher elevation than Site 10B.

In contrast, in 1949, 1955, and 1964, unusually low positions were recorded (Miller, 1963a, and personal communication, 1965). In 1949 and 1964, greater than normal net accumulation was also reported at Site 10B, but for unknown reasons the unusually low 1955 seasonal névé-line does not appear to have been accompanied by heavy accumulation at Site 10B. A possible cause of this discrepancy may be that because of some local variation in the thickness, the retained accumulation recorded at Site 10B in 1955 was not representative of the lower Taku névé.

Referring to the plot of seasonal névé-line elevations from 1946 to 1965, we see an unmistakable correlation between these and the accumulation trends over the past 20 years. Significant shifts of the névé-line, corresponding to significant shifts in the net accumulation at Site 10B, are best illustrated by the plots of 5-year and 10-year running means in Fig. 20. The running means express the general increase in net accumulation previously documented for the lower névé, as well as the expected downward shift in the mean névé-line.

For this 20-year period of record, the Taku Glacier's mass budget is clearly one of increasingly positive character. If this trend is maintained for several more decades, continuing advance of the Taku Glacier may be expected. A further implication is that other maritime glaciers on the Juneau Icefield, at least those having large accumulation areas at or above the 10B level, may begin to readvance as a consequence of increasingly healthy regimes. Such an increase should also be reflected under present conditions by a commensurate lowering of seasonal névé-lines on other key glaciers of this icefield, for example, the Twin

Glaciers in Taku Valley, the Lemon Creek Glacier near Juneau, and the Vaughan Lewis Glacier west of Camp 8.

VI. EXTRAPOLATIONS AND CONCLUSIONS

A. General

The large quantity of retained accumulation in recent years on the extensive upper névés, resulting from low total ablation plus freezing of percolating water (meltwater plus rainfall) at depth, is of major importance to the present regime of the Taku Glacier system. This effect is regarded as primarily dependent on temperature trends, rather than being a simple function of elevation.

A trend toward a more positive regime is indicated by firn stratigraphy records on both the higher and lower névés. The increasingly heavy accumulation measured at lower elevations has resulted in a downward trend of the mean névé-line in the past decade. This suggests that the lower accumulation zone may now be playing a greater role in the overall mass budget of the Taku Glacier than it has in recent decades.

B. Regional Significance of the Results

Heusser and Marcus (1964b) have recently pointed out that on the basis of 10-year means, the post-1940 temperature trend at Juneau has been characterized by a general rise in July mean temperature, and a general decline in January mean temperature. A recent study by Hamilton (1965), who plotted mean annual temperature records from many widely separated Alaskan stations, indicates that the Juneau mean annual temperature plot (on the basis of 8-year running means) agrees fairly well with a comparable composite Alaskan plot. The Alaskan composite of mean annual temperatures shows that "...post - 1910 temperature trends for all stations are characterized by gradual warming from 1910 to 1935, then pronounced rises to maxima around 1941. Comparably sharp declines from the temperature peaks continued to 1947, and have been followed by relatively horizontal trends. Net temperature gain from 1902-10 temperature levels to those of the late 1950's has been ca. 0.7° F.

(Hamilton, 1965)." Miller (1963a, p. 165) has noted that "...at the latitude of Juneau there has been a net 5.5° F. rise in winter temperature since 1876, compared to the 2.2° F. world-wide rise. According to the Juneau curves in Fig. 68, this was expressed as a 7° rise in the 10-year <u>mean of winter temperatures</u> from 1918 to 1948, and as a 4.5° F. rise in <u>mean yearly temperature</u> from 1918 to the mid-1950's."

Miller (1963a) has also emphasized the high correlation between Juneau temperature records and those of 64 coastal U.S.W.B. stations in Southeastern Alaska, as well as a correlation between the Juneau and regional means of annual total precipitation and snowfall over the period 1907-61.

Hamilton (1965) also studied Alaskan precipitation trends, and concluded that "...fluctuations in annual precipitation totals of the principal stations are generally similar in number and spacing, but individual peaks and troughs show apparently random displacements in timing. Fluctuations are more numerous in the precipitation than in the temperature records, and show no direct correlations. There is little agreement among the stations in major precipitation trends, and net changes from 1910 to the present vary from negligible (Nome) to a gain of over 10% (U.E.S.). Precipitation and temperature trends do not appear to be related." It should be pointed out that Hamilton's data cover all of Alaska, not just the south coastal sector.

Miller (1963a, p. 164), however, has pointed out that in the Taku District, weather records indicate that "...in reverse manner, these temperature trends closely parallel the sea-level precipitation trends which have been described." Miller (1965, personal communication) suggests that "...an inverse relationship pertains with respect to this icefield which may not be as clearly seen throughout a region as large as all of

coastal Alaska. Also this icefield may be positioned more critically than others with respect to the interaction zone lying between the major continental and oceanic pressure cells of the North Pacific coast."

With respect to present conditions on the Taku Glacier, unless a strong decline in winter precipitation occurs, the present decreasing temperature trend (particularly for the melting-period months) may be expected to be of major importance in the maintaining or strengthening of the present positive regime of this glacier system.

The relationships between climatic trends and changing regime patterns over different elevations of the Juneau Icefield serve as a type situation for the clear understanding of processes and variations in process intensity once affecting the growth and decline of former valley glaciers and ice sheets in mid-latitude cordilleran regions. From this, interpretations of sequences of Pleistocene erosional and depositional forms in other regions can also be more effectively made.

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FIG. 1. MAP OF THE JUNEAU ICEFIELD REGION
ALASKA - B.C. COAST MOUNTAINS.

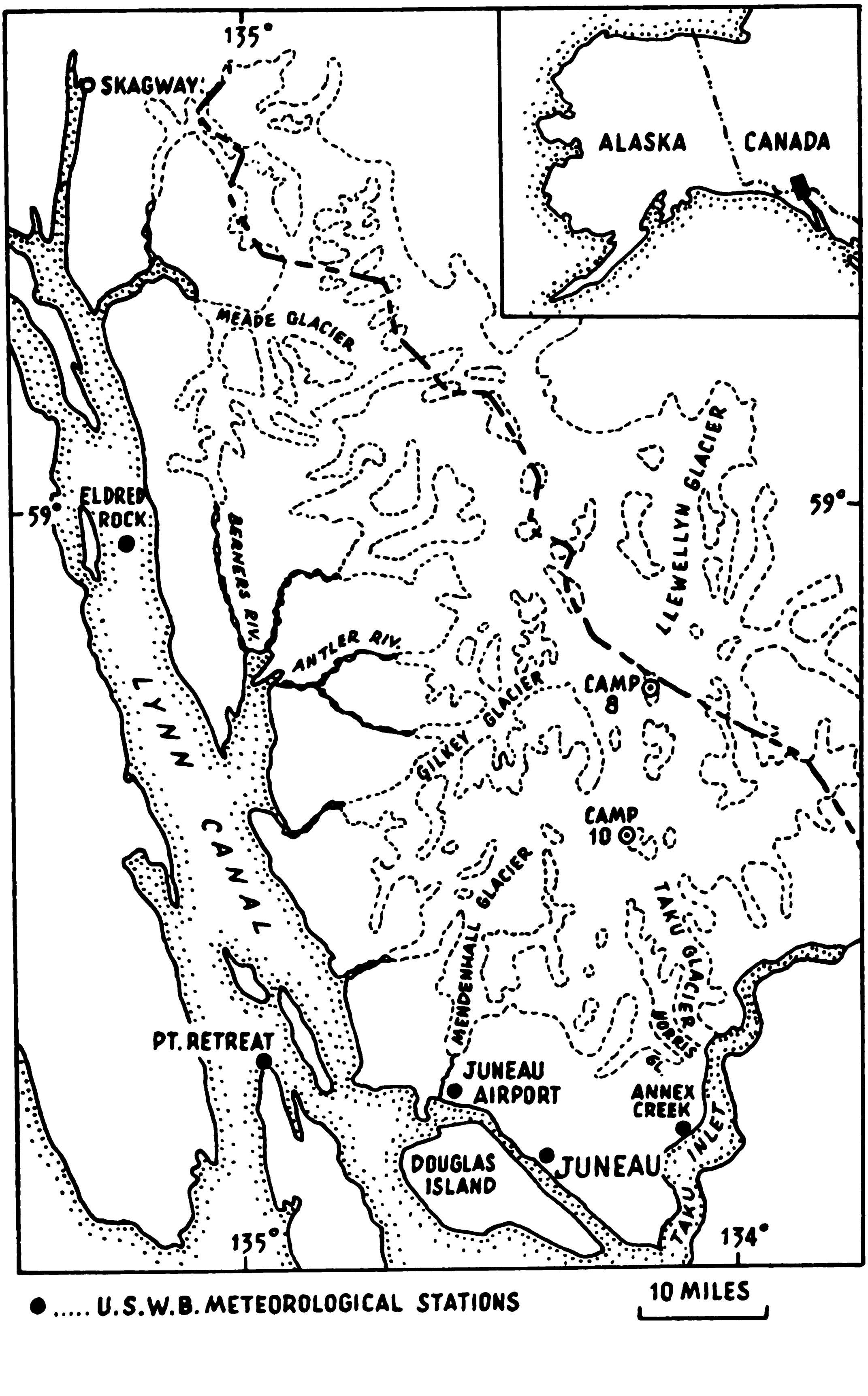
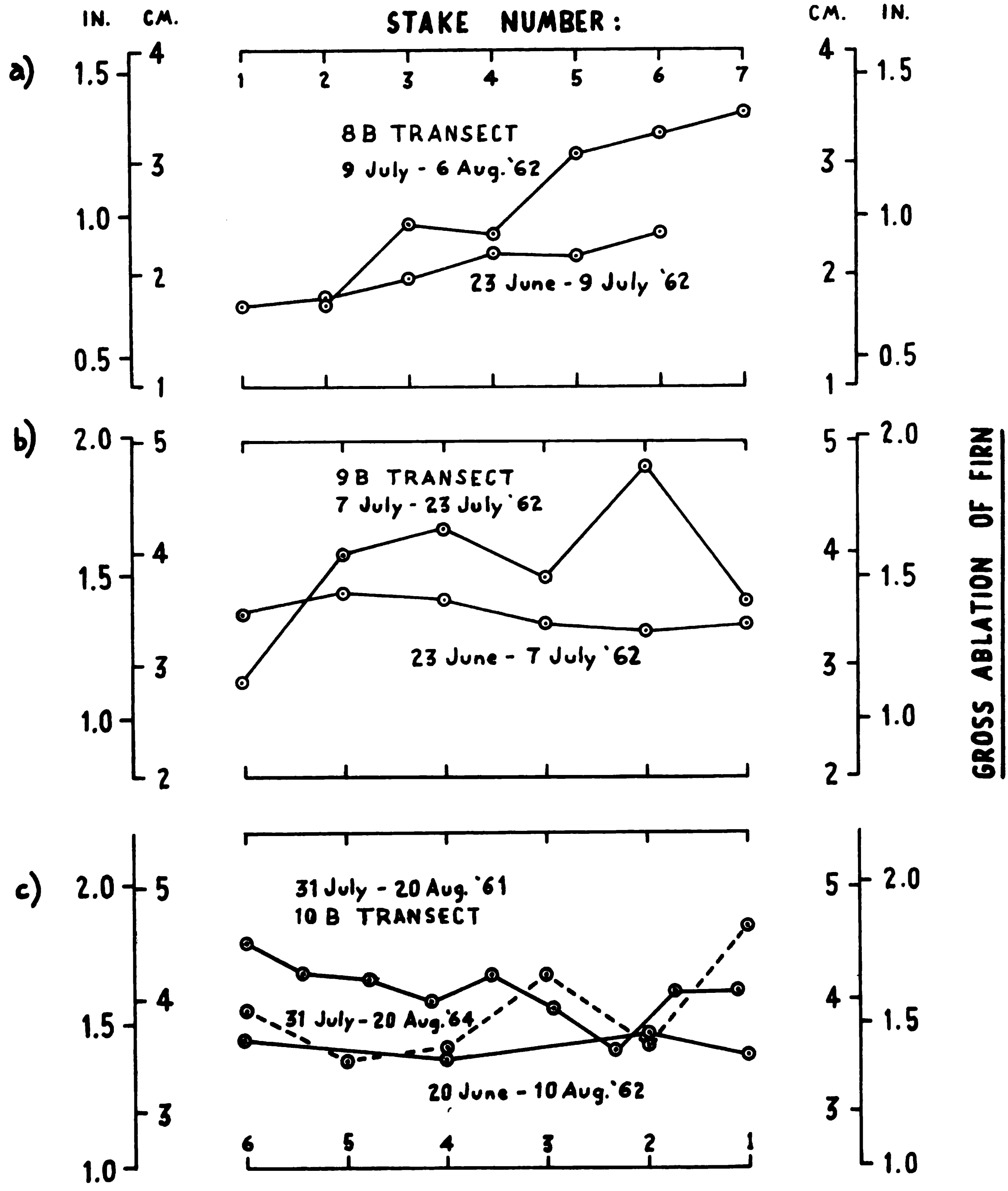


FIG. 6 MEAN DAILY GROSS ABLATION RATES ON SELECTED TAKU GLACIER TRANSECTS



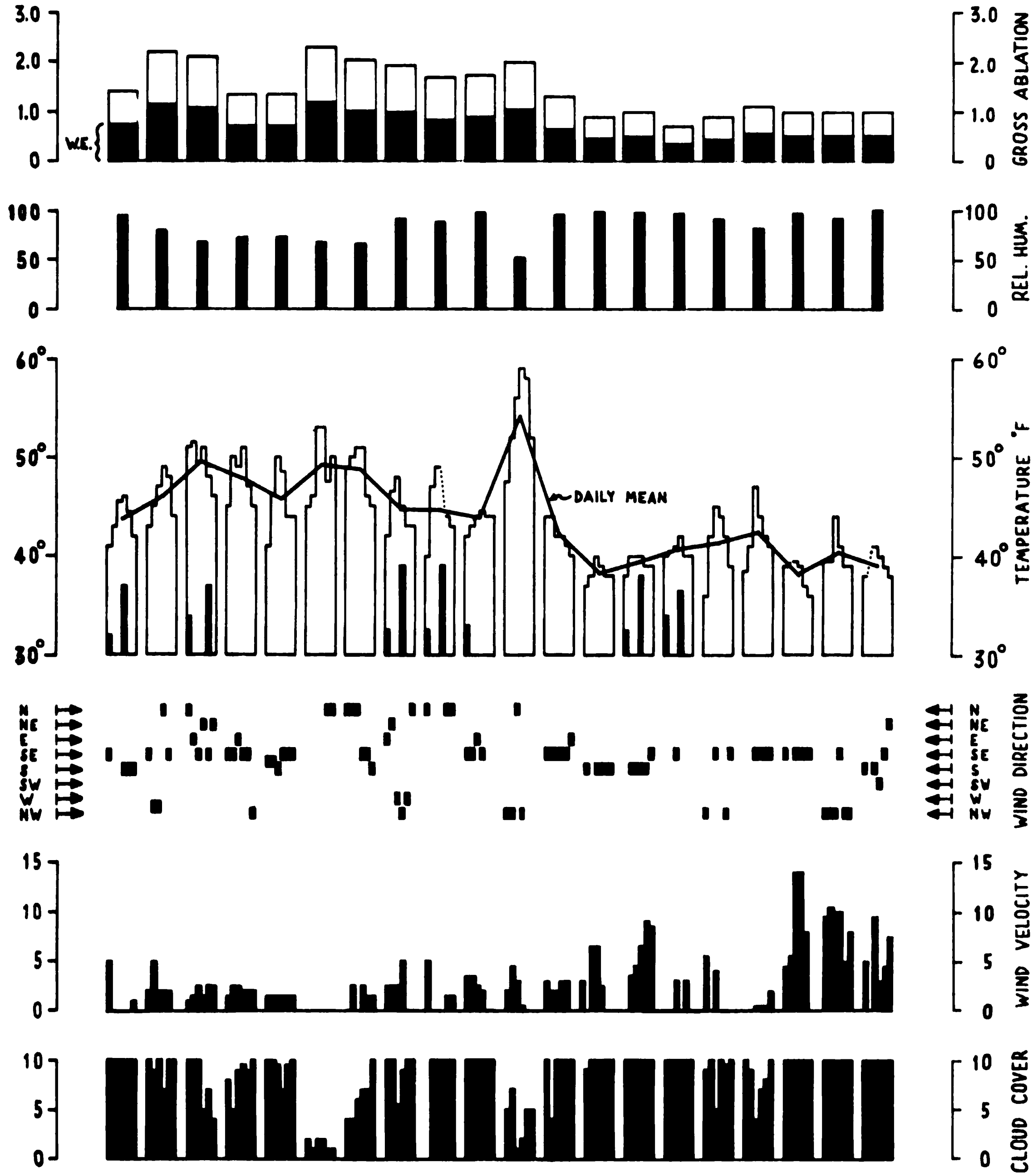


FIG. 7 THREE-HOURLY (0700 to 2200 h) METEOROLOGICAL OBSERVATIONS FROM CAMP 10 (1220 M), 1-20 AUG. 1964, WITH SUPPLEMENTARY TEMPERATURE DATA FROM SITE 10 B (1082 M)

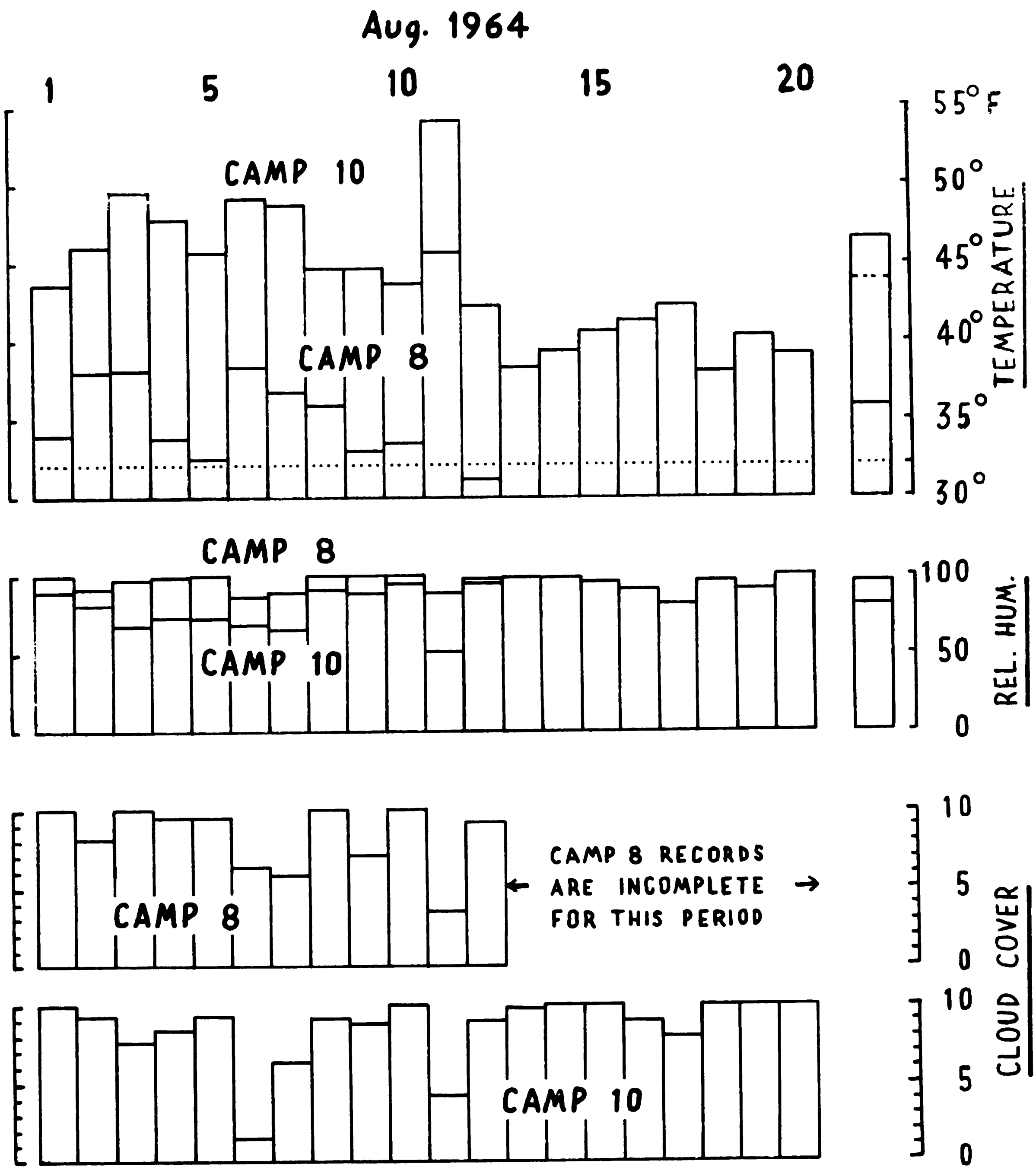


FIG. 8 MEAN DAILY TEMPERATURE, RELATIVE HUMIDITY, AND CLOUD COVER AT CAMPS 8 AND 10

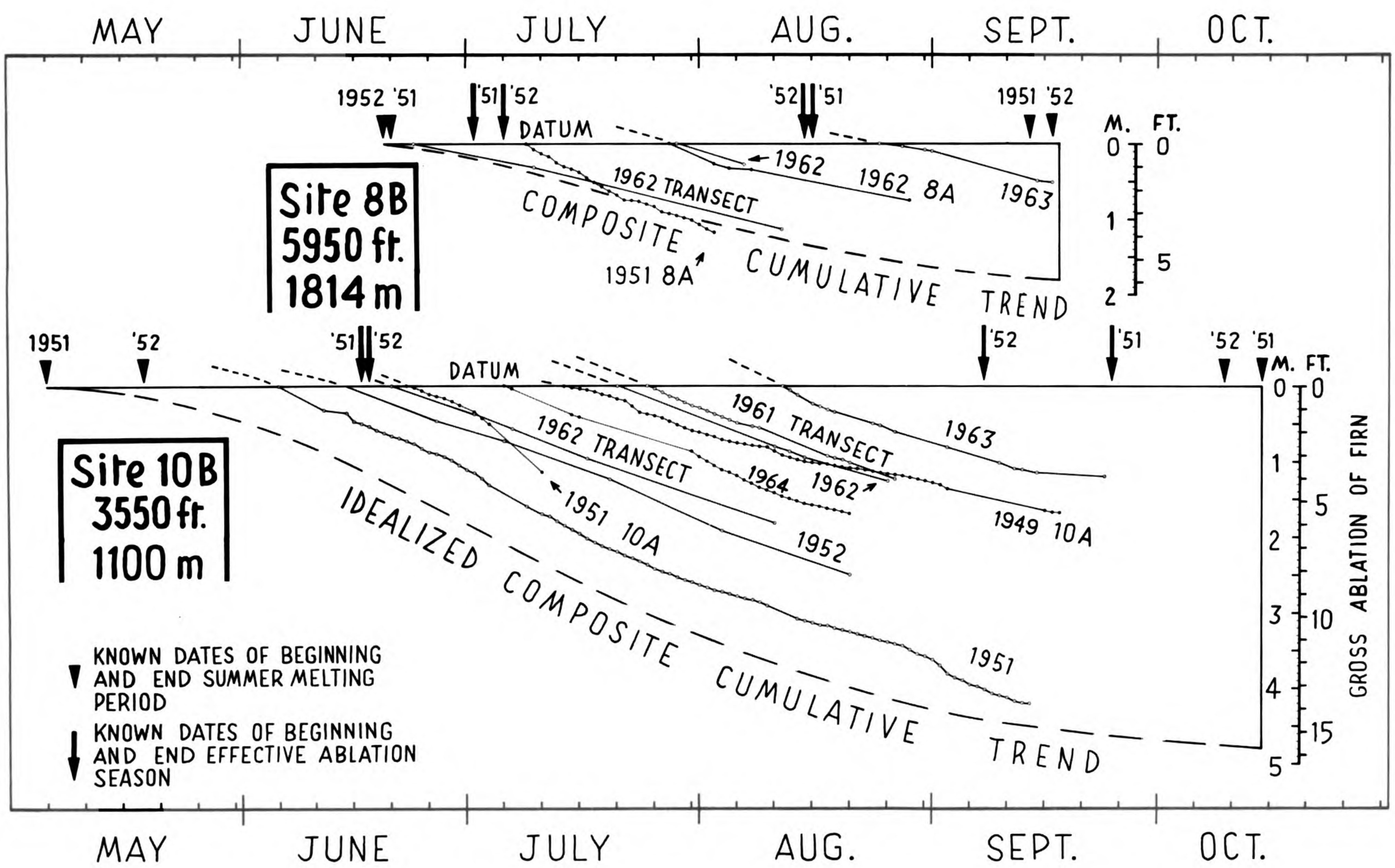


FIG. 9 CUMULATIVE CURVES OF DAILY ABLATION ON TAKU NÉVÉ
From J.I.R.P. data at sites 8B (5,950 ft) and 10B (3,550 ft).

FIG. 10 COMPOSITE PLOT OF FIRN DENSITY MEASUREMENTS, 1962

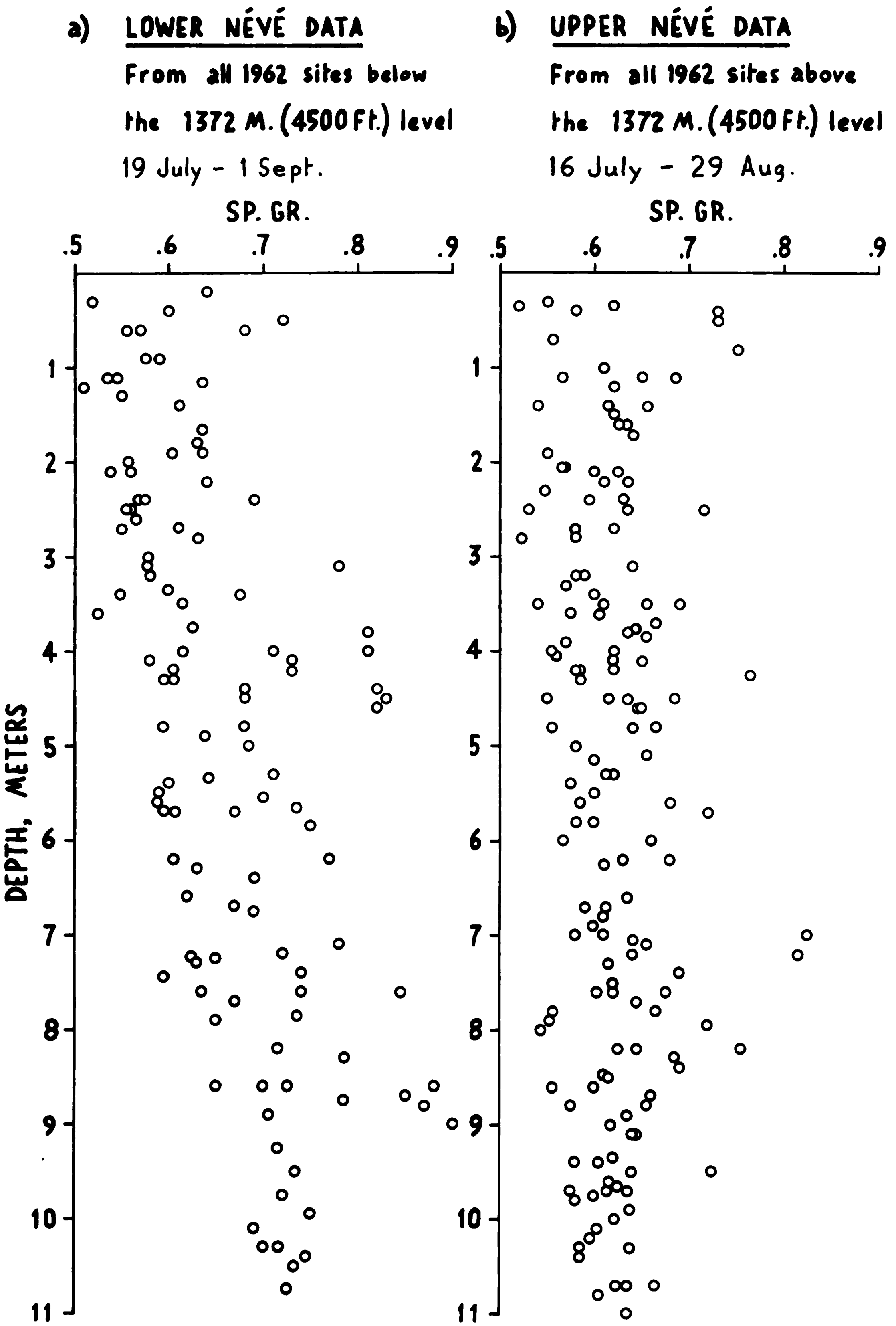


FIG. 11 FIRN DENSITY MEASUREMENTS, LOWER AND UPPER NÉVÉS

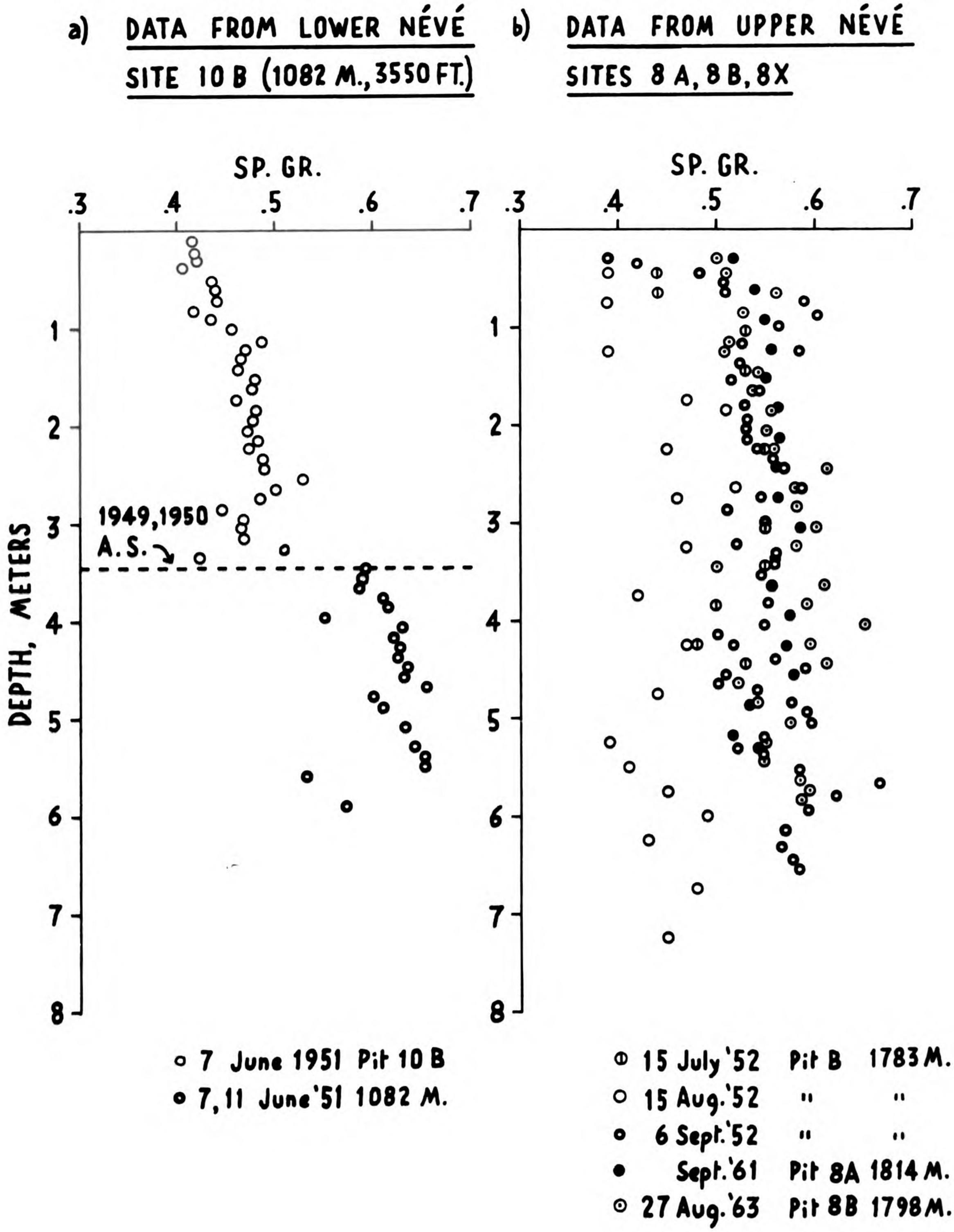
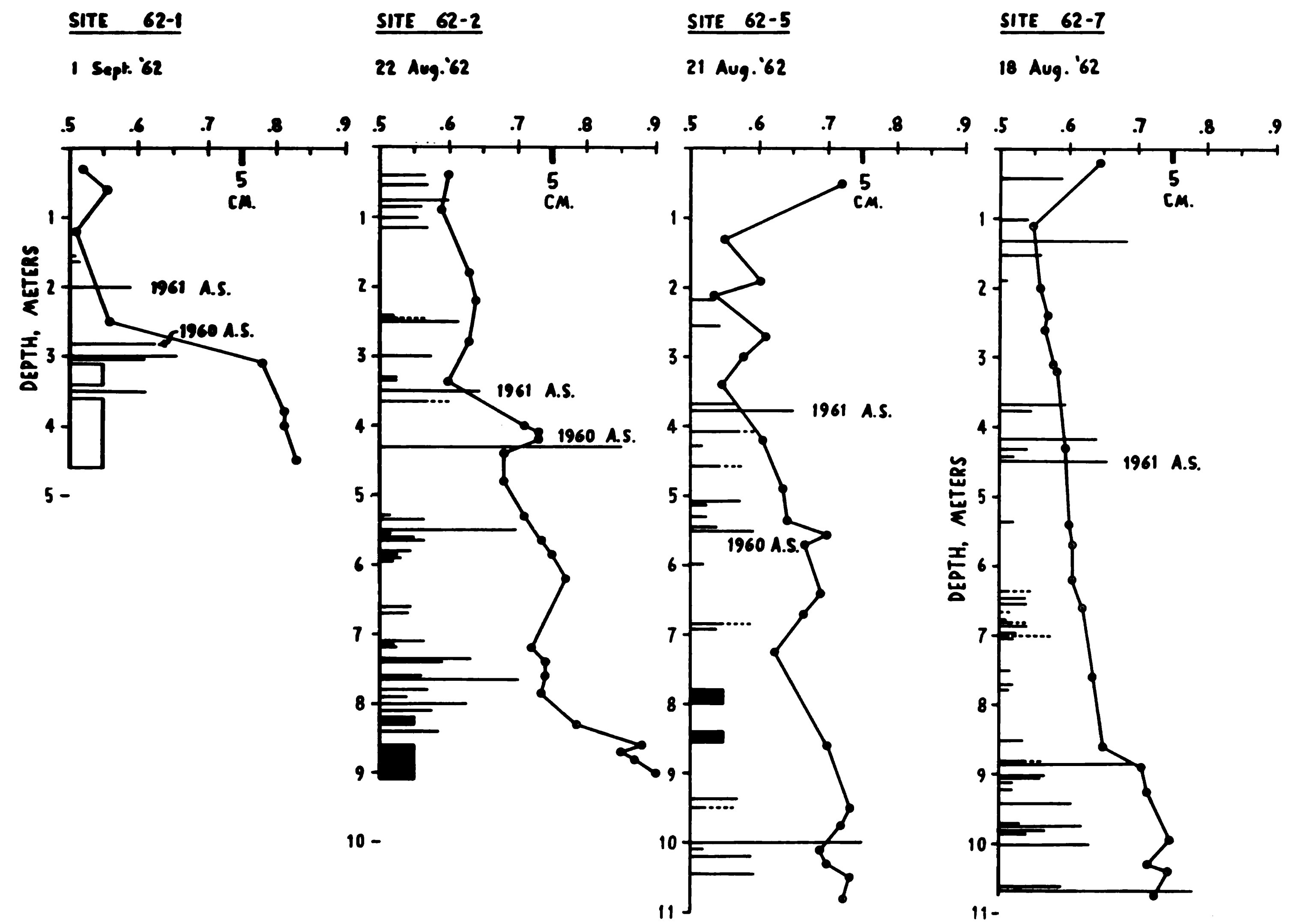


FIG. 12 TRANSECT A: FIRNPACK STRATIGRAPHY AND DENSITY FROM 1962 HAND AUGER CORES



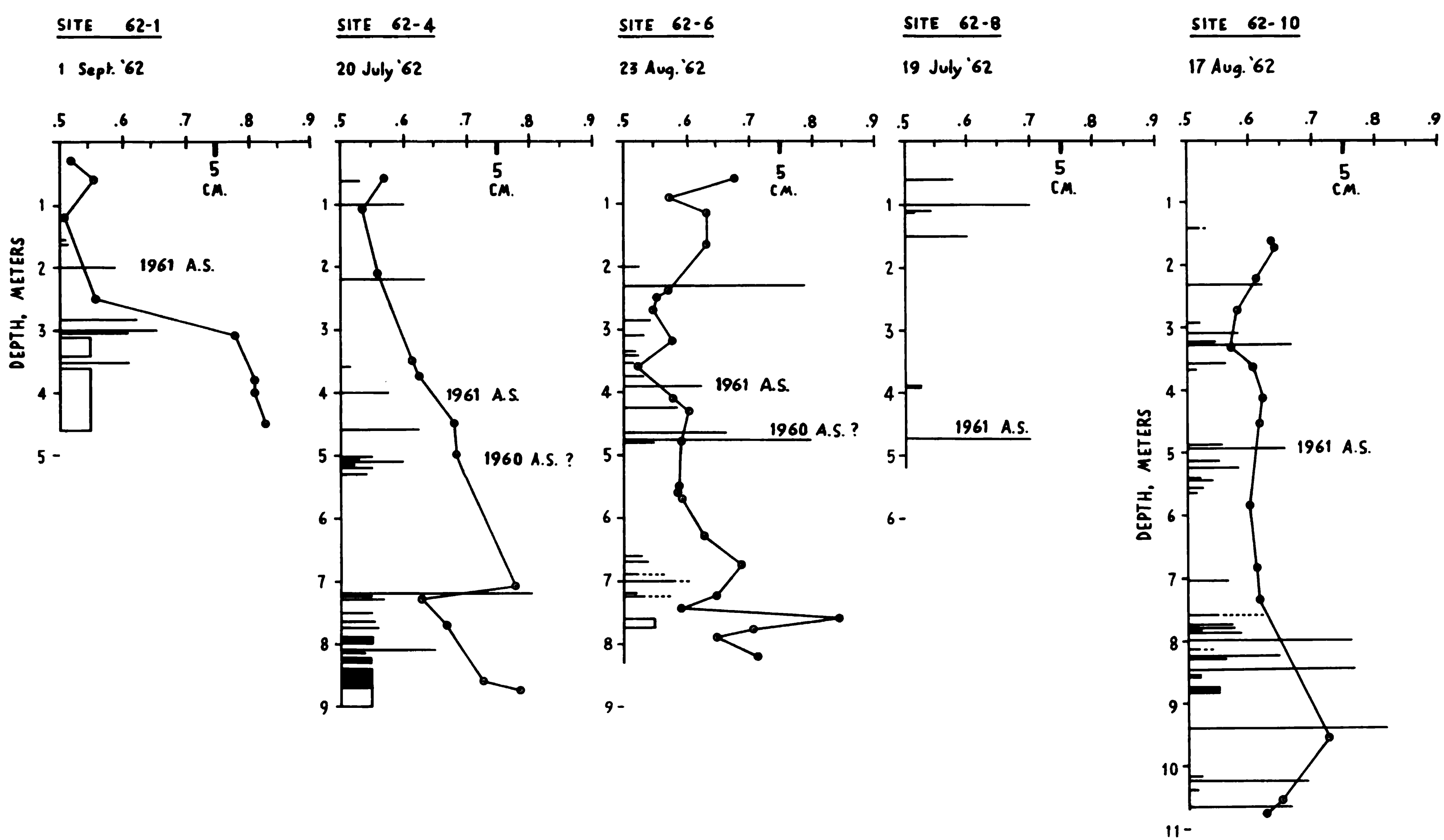


FIG. 13 TRANSECT B: FIRNPACK STRATIGRAPHY AND DENSITY FROM 1962 HAND AUGER CORES

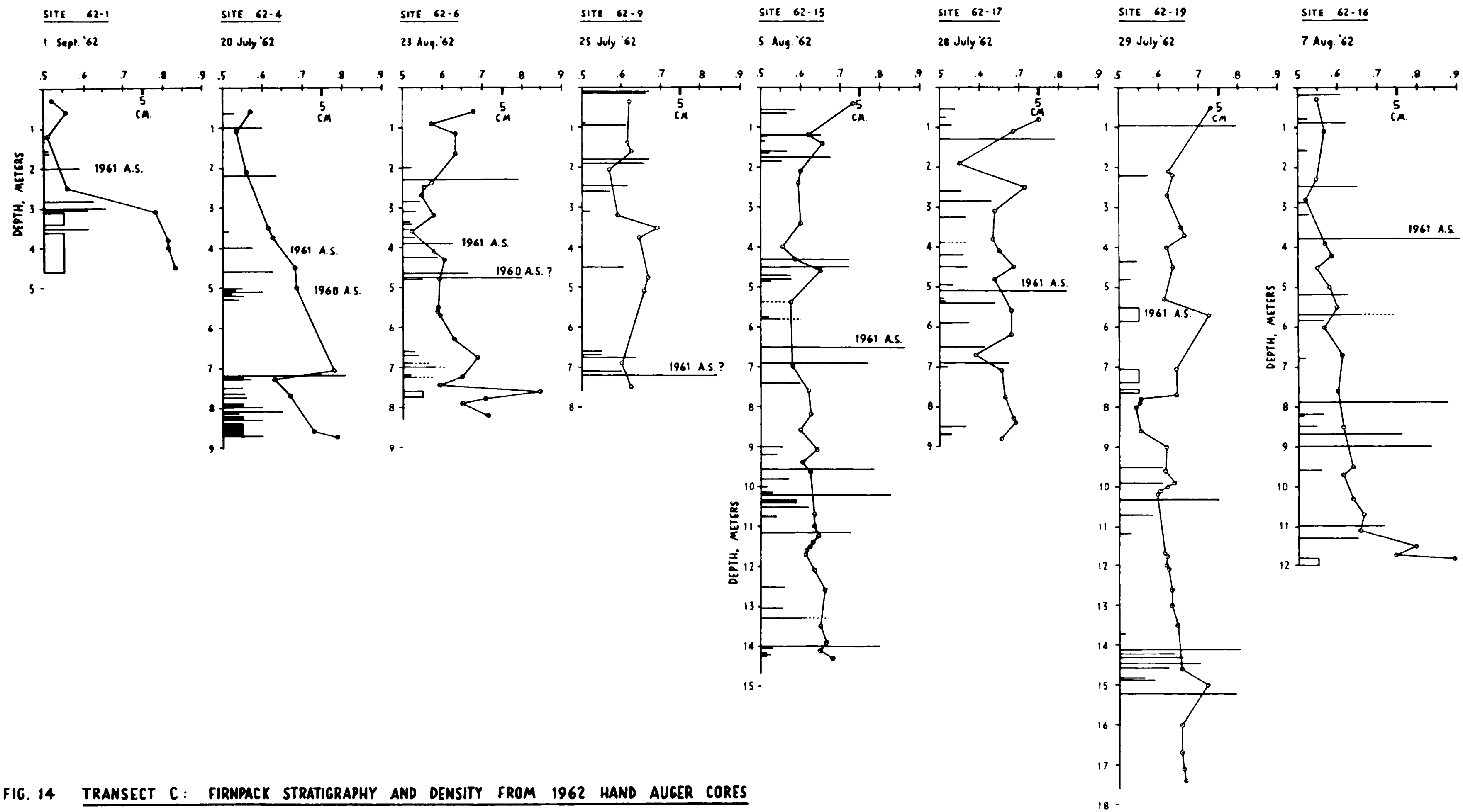


FIG. 14 **TRANSECT C: FIRNPACK STRATIGRAPHY AND DENSITY FROM 1962 HAND AUGER CORES**

FIG. 15: FIRNPACK STRATIGRAPHY AND DENSITY FROM 1962 HAND AUGER CORES (MISCELLANEOUS SITES)

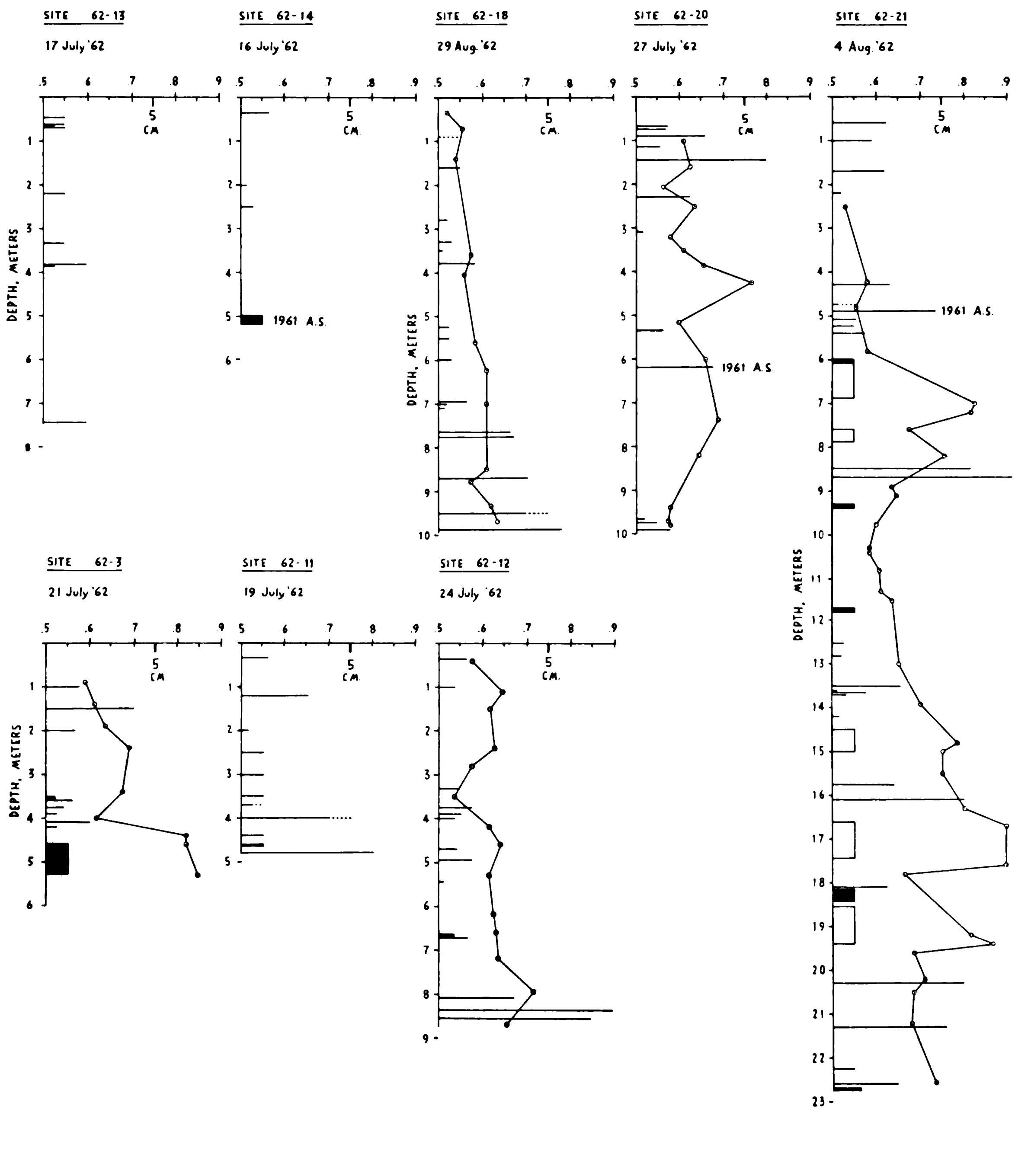


FIG. 16 FIRNPACK STRATIGRAPHY AND DENSITY FROM CREVASSES ON THE UPPER TAKU NÉVÉ

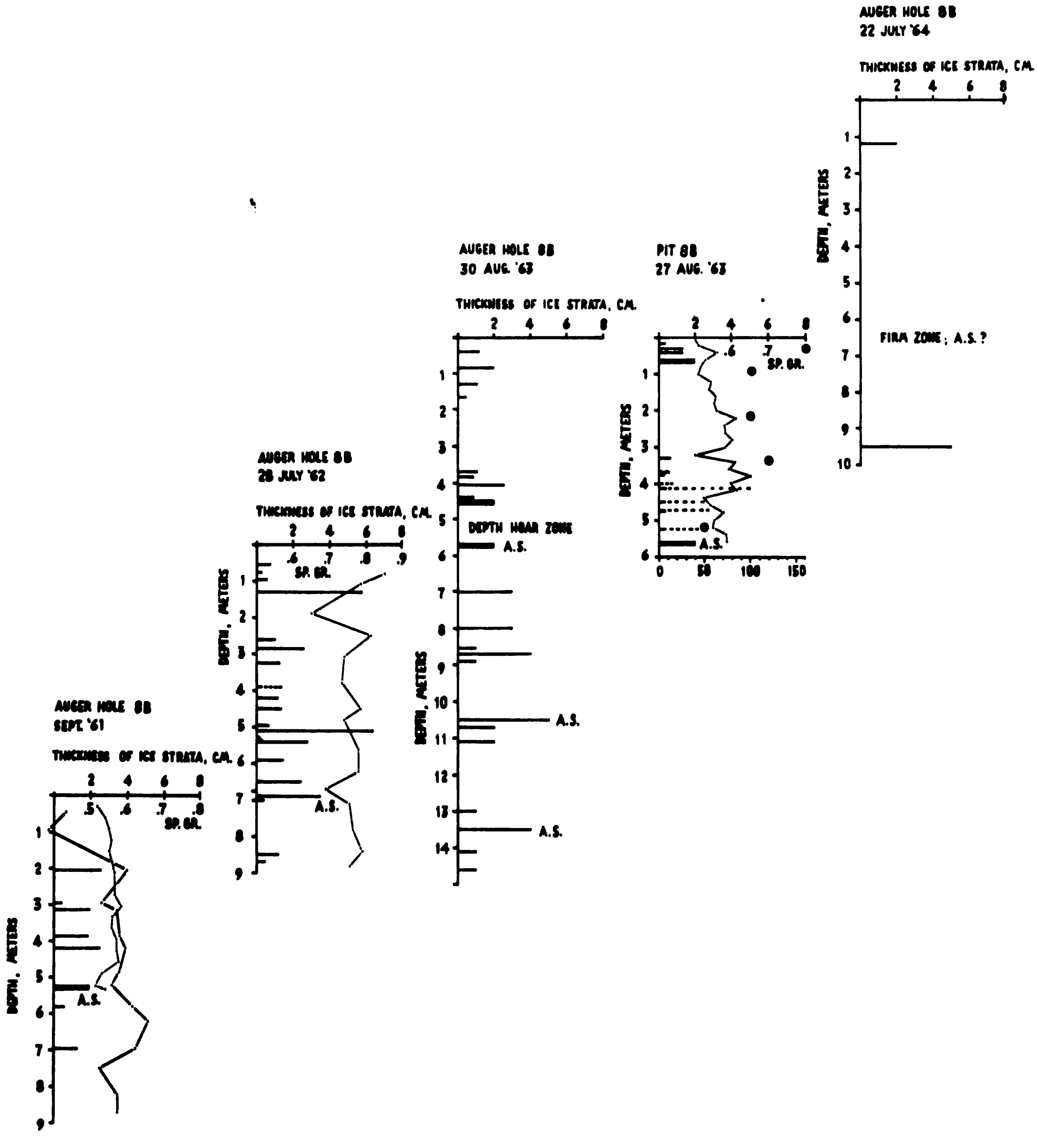


FIG. 17 FIRNPACK STRATIGRAPHY AND DENSITY FROM CREVASSES ON THE UPPER TAKU NÉVÉ

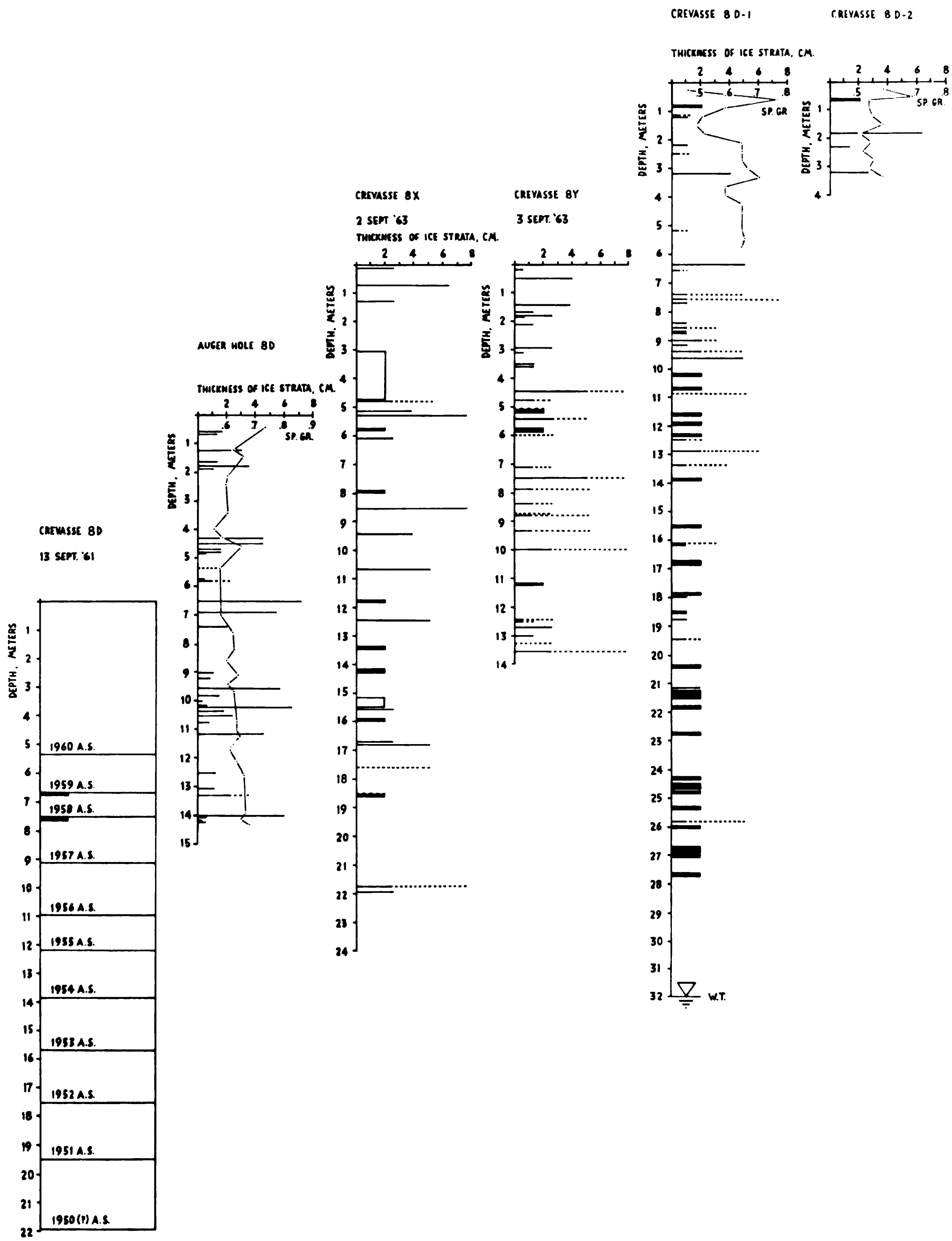
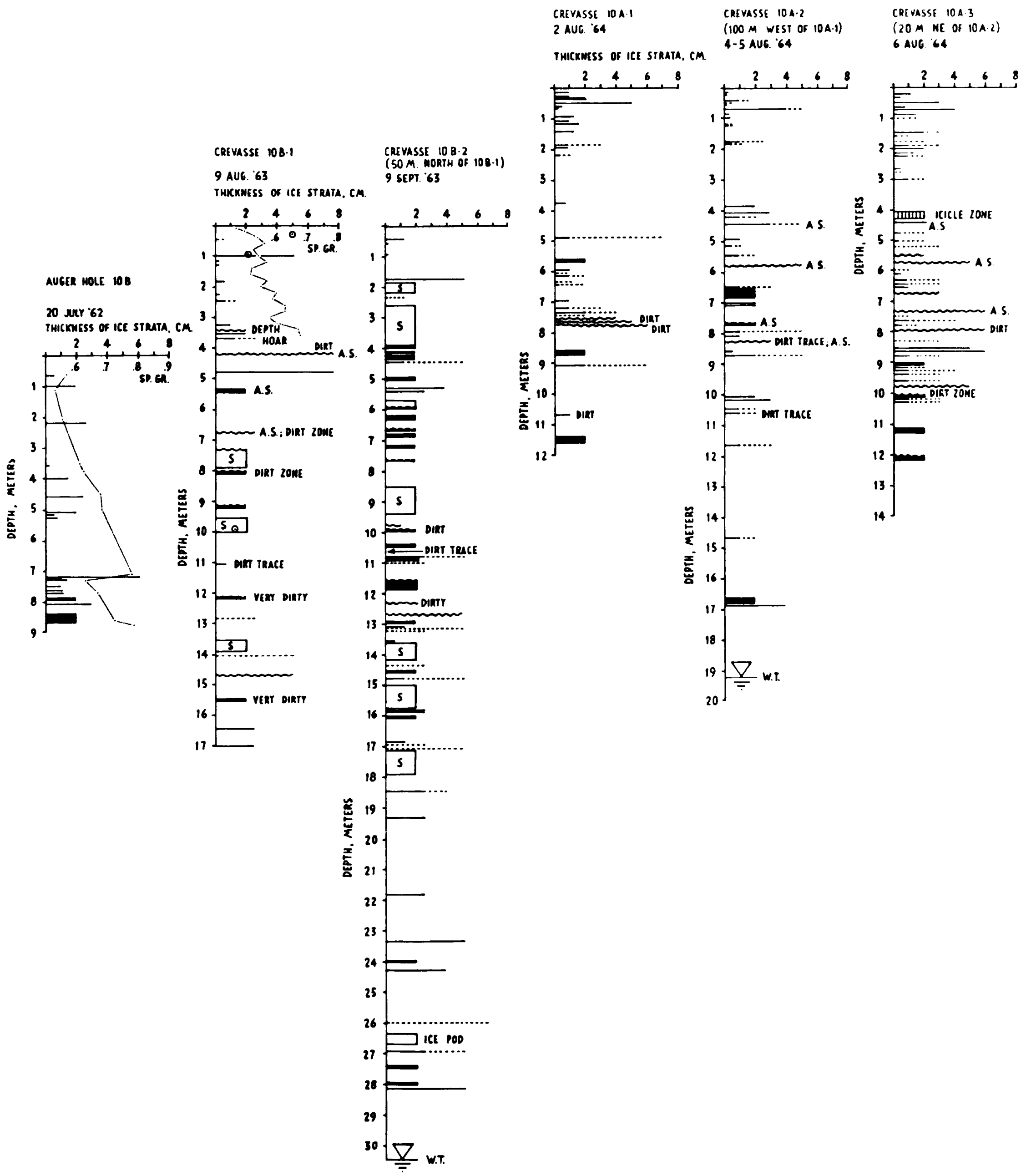


FIG. 18 FIRNPACK STRATIGRAPHY AND DENSITY FROM CREVASSES ON THE LOWER TAKU NÉVÉ



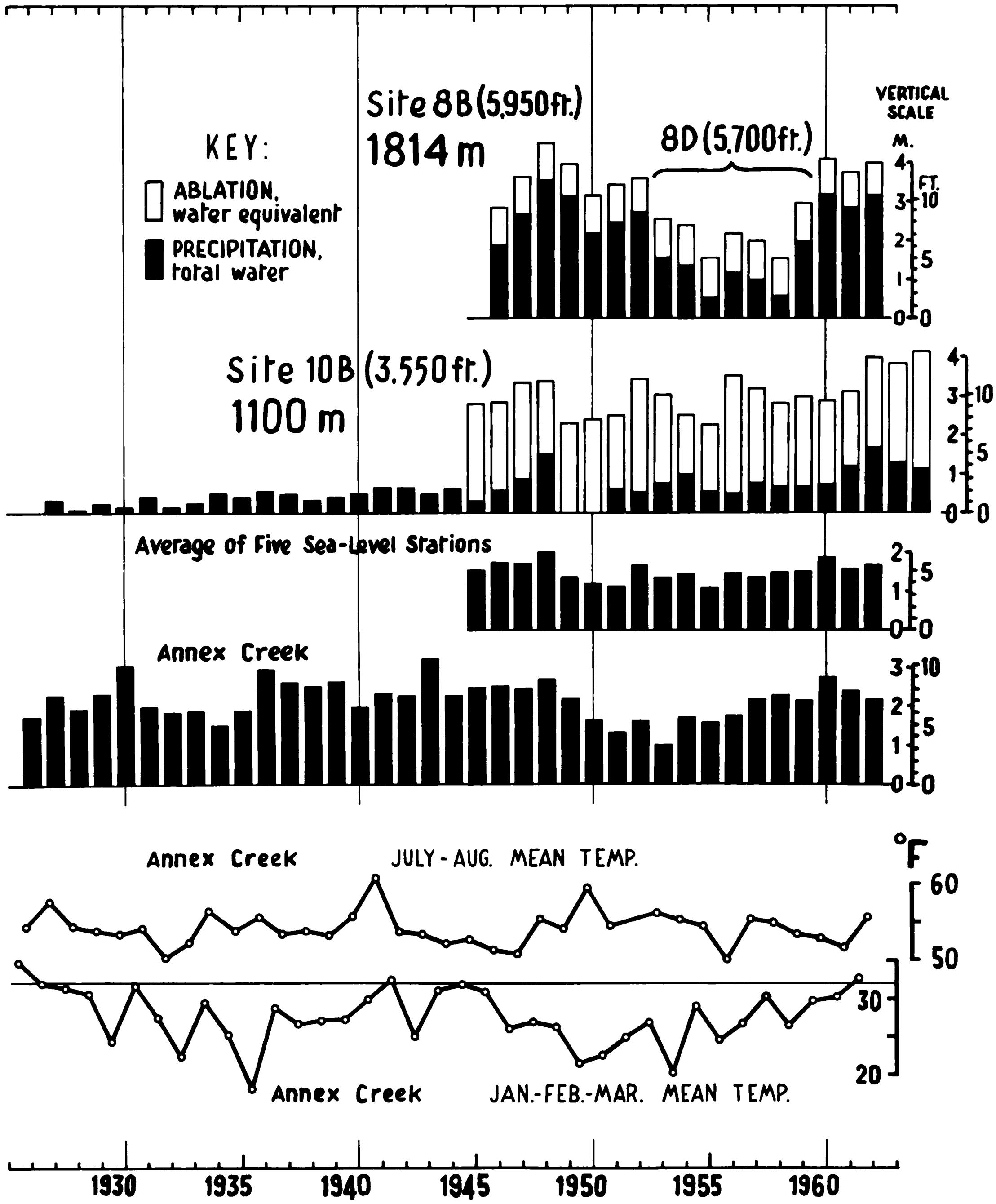


FIG.19 ANNUAL ACCUMULATION TRENDS ON TAKU GLACIER COMPARED WITH CORRESPONDING PRECIPITATION AND TEMPERATURE AT ADJACENT COASTAL STATIONS.

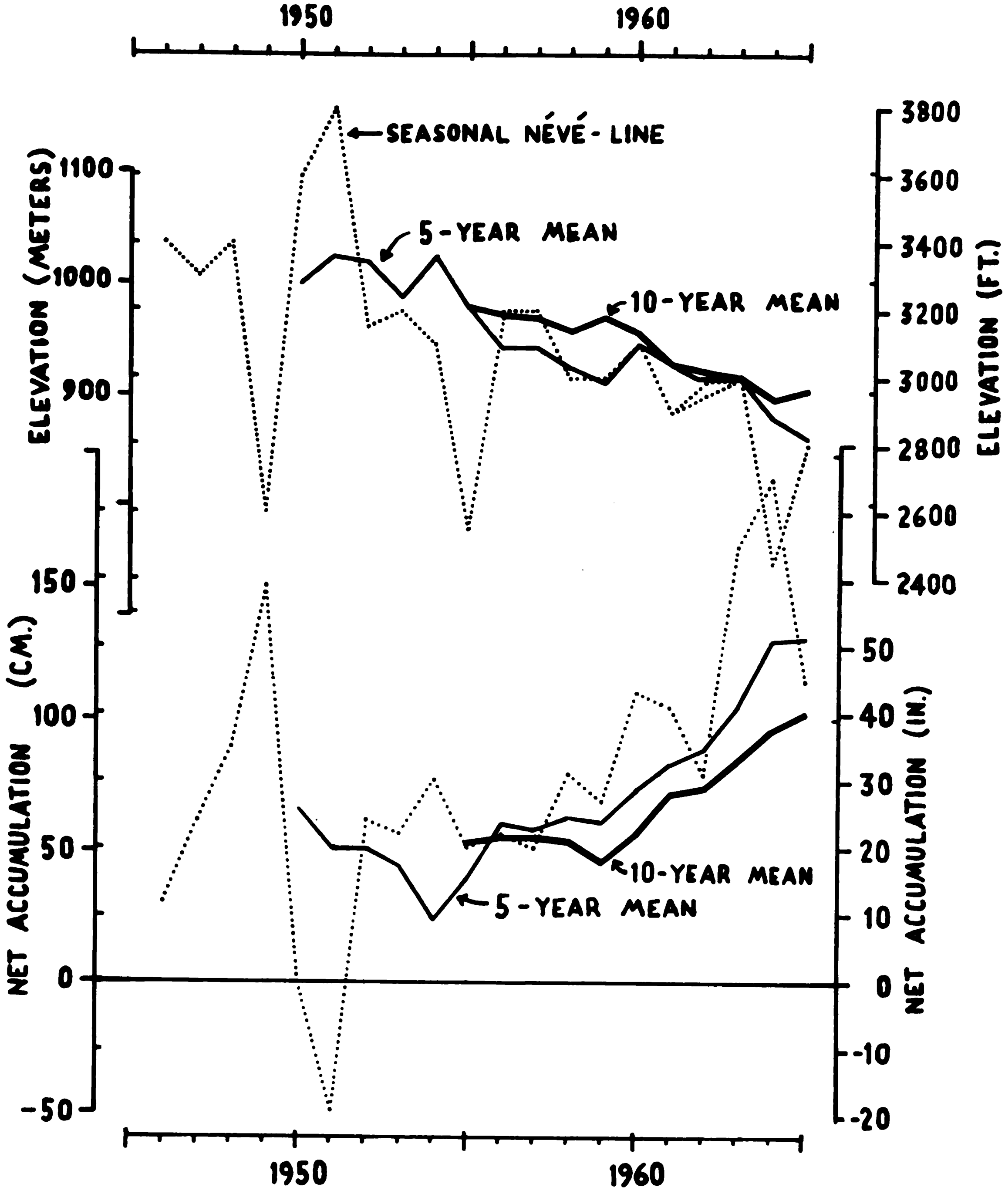


FIG. 20 COMPARATIVE NÉVÉ-LINE AND NET ACCUMULATION TRENDS ON THE TAKU GLACIER, 1946-65

APPENDIX A

Ablation Records, 1962-64

Gross Ablation, 1962
8 B Movement Stake Transect
Mean Elevation: ca. 1,814 m. (5,950 ft.)

a) Total Gross **Ablation** (cm. of firn):

Stake numbers east to west	1	2	3	4	5	6	7	Mean
Date:								
23 June 1962	Stakes emplaced							
to 9 July 1962	27.3	28.2	31.2	35.0	34.3	38.1	-	32.3
to 6 Aug. 1962	-	48.2	68.6	66.0	86.4	91.4	96.6	76.2
								108.5

b) Daily Mean Gross Ablation (cm. of firn/day):

Date:								
23 June 1962	Stakes emplaced							
to 9 July 1962	1.71	1.76	1.95	2.18	2.16	2.38	-	2.02 cm/day
to 6 Aug. 1962	-	1.72	2.45	2.36	3.08	3.26	3.45	2.72 cm/day
								2.39 cm/day

Gross Ablation 1962
9 B Movement Stake Transcect
Mean Elevation: ca. 1356 m. (4,450 feet)

a) Total Gross Ablation (cm. of firn):

Stake numbers east to west	1	2	3	4	5	6	Mean
Date:							
23 June	Stakes emplaced						
to 9 July	47.1	46.4	47.1	50.2	50.8	48.3	48.32
to 23 July	64.2	76.2	60.4	67.4	63.6	51.2	63.83
							112.15

b) Daily Mean Gross Ablation (cm. of firn/day):

Date:							
23 June	Stakes emplaced						
to 9 July	3.36	3.31	3.36	3.58	3.63	3.45	3.45 cm/day
to 23 July	3.56	4.76	3.77	4.21	3.98	2.84	3.85 cm/day

Gross Ablation, 1962
10 B Movement Stake Transect (Profile IV)
Mean Elevation: ca. 1082 m. (3,550 feet)

a) Total Gross Ablation (cm. of firn):

Stake numbers east to west	1	2	3	4	5	6	Mean
Date:							
20 June	Stakes emplaced						
to 1 July	38.1	38.1	39.4	36.2	36.8	37.5	37.7
to 6 July	15.2	20.6	19.0	20.3	21.6	21.6	19.1
to 16 July	39.4	41.3	38.1	40.6	39.4	40.6	39.9
to 10 Aug.	85.8	88.3	-	80.0	-	86.5	85.2
Total	178.5	188.3	-	177.1	-	186.2	182.5

b) Daily Mean Gross Ablation (cm. of firn/day):

Date:	1	2	3	4	5	6	Mean
20 June	Stakes emplaced						
to 1 July	3.46	3.46	3.58	3.29	3.34	3.41	3.42 cm/day
to 6 July	3.04	4.13	3.80	4.07	3.62	4.32	3.83
to 16 July	3.94	4.13	3.81	4.06	3.94	4.06	3.99
to 10 Aug.	3.43	3.53	-	3.20	-	3.45	3.41
Stake mean	3.5	3.7	-	3.48	-	3.65	3.59

Gross Ablation 1962
Site 62-15 (8 D)
Elevation: 1737 m (5700 ft.)

Date:	Gross ablation of firn (cm):	Mean daily rate:
5 Aug. to	Stakes emplaced	
7 Aug. to	3.5 cm	1.75
27 Aug.	26.0 cm (This is an approximate value. Between 7 Aug and 27 Aug, ca. 15.0 cm. of new snow accumulated at this site).	1.30
29 Aug.	5.1 cm.	2.5

Gross Ablation, 1962
Site 62-17 (8 B)
Elevation 1814 m (5,950 ft.)

Date:	Gross ablation of firn (cm):	Mean daily rate
28 July	Stakes emplaced	
to		
6 July	27.30 cm.	3.0 cm.

Gross Ablation, 1962
Site 62-19 (Taku-Llewellyn Glacier Divide)
Elevation 1890 m (6,200 ft.)

Date:	Gross Ablation of firn (cm.)	Mean daily rate
29 July	Stakes emplaced	
to		
1 Aug.	6.6 cm.	2.2 cm.
to		
2 Aug.	Ablation stake moved accidentally;	
to	stake reset	
7 Aug.	7.0 cm.	1.4 cm.
to		
28 Aug.	Accumulation of 33.0 cm. of new snow since 7 Aug.	

Gross Ablation, 1962
Site 62-20 (8 A)
Elevation: 1920 m. (6,300 ft.)

Date:	Gross Ablation of firn (cm.)	Mean daily rate
27 July	Stakes emplaced	
to		
4 Aug.	6.0	0.75
to		
7 Aug.	1.27	0.43
to		
28 Aug.	Accumulation of 20.6 cm. of new snow since 7 Aug.	

Gross Ablation, 1963
Site 8 B
Elevation 1414 m (5,950 ft.)

Date:				
27 Aug.	Stakes emplaced			
	1	2	3	4
30 Aug.	3.5	4.0	3.0	4.0
31 Aug.	2.5	1.5	1.5	2.5
14 Sept.	Accumulation of new snow			
	15.0	10.0	4.0	-
16 Sept.	4.5	2.0	2.0	-
22 Sept.	Accumulation of 94.5 cm. new snow since 16 Sept.			
23 Sept.	Stakes buried by new snow.			

Gross Ablation, 1963
Site 10 B
Elevation 1082 m (3,550 ft.)

Date:	1	2	3	4	5	6	7	8	9
12 Aug	Stakes emplaced: (0.6 cm dia, 122 cm. length).								
13 Aug 1200	3.0	3.0	4.0	3.0	2.0	4.0	2.0	2.5	2.0
13 Aug 1700	6.0	6.5	7.0	5.0	4.0	5.5	4.0	4.5	4.0
13 Aug 1530	13.0	12.5	13.0	13.0	11.0	13.5	12.0	13.5	13.0
15 Aug 1700	Stakes reset								
16 Aug 1500	4.5	4.0	4.5	4.5	4.5	4.5	3.5	4.0	4.0
17 Aug	4.5	4.5	4.0	5.0	4.0	4.5	4.5	3.5	4.0
18 Aug 1400	2.0	3.5	2.5	2.5	2.0	4.0	3.0	2.5	3.0
23 Aug 1600	16.0	16.0	16.0	20.0	16.0	12.0	13,0	12.0	15.0
26 Aug									

Date:	A	B	C
23 Aug 1600	Set stakes (2.5 x 2.5 cm., 200 cm. length)		
26 Aug	15.0	11.0	7.5
2 Sept 1700	29.0	32.0	24.0
14 Sept	83.0	63.0	52.0

Gross Ablation, 1964
10 B Movement Stake Transect (Profile IV)
Mean elevation ca. 1082 M (3,550 ft.)

a) Daily mean gross ablation (cm. of firn):

	1	2	3	4	5	6	Mean
5 July	Stakes emplaced						
6	4.06	4.83	3.81	3.81	4.32	3.81	4.11
14	4.06	4.83	-	3.81	4.32	-	4.27
15	3.30	3.81	-	3.30	3.81	-	3.56
30	3.30	3.81	3.81	-	-	3.81	3.68
31	-	6.35	7.62	-	-	7.62	7.19
1 Aug	-	6.35	7.62	3.30	3.81	7.62	5.74
2	6.35	5.08	5.08	7.62	6.35	5.08	5.92
3	3.30	5.59	5.84	8.38	5.08	6.35	5.77
4	3.81	2.54	6.10	3.30	2.54	4.32	3.76
5	3.81	2.54	6.10	3.30	3.56	4.32	3.94
6	8.89	7.62	5.08	3.30	4.32	7.62	6.15
7	2.54	3.30	5.08	2.54	4.32	3.81	3.61
8	10.16	5.08	6.35	5.08	3.30	5.08	5.84
9	4.57	3.30	3.81	3.81	2.54	3.81	3.63
10	5.08	3.30	3.05	2.54	3.30	3.30	3.43
11	5.08	3.81	3.81	5.08	3.81	4.32	4.32
12	2.54	4.32	5.85	1.27	1.78	2.54	3.05
13	3.81	3.81	3.81	3.81	3.81	2.54	3.61
14	3.81	2.54	3.81	3.30	3.81	3.30	3.43
15	1.27	1.27	1.78	1.78	1.27	1.78	1.52
16	1.27	3.30	1.78	1.78	2.54	1.78	2.08
17	3.05	1.78	3.21	1.78	2.54	1.78	2.34
18	1.27	1.78	2.54	2.54	-	2.29	2.08
19	2.03	1.78	1.52	2.54	-	2.29	2.03
20	3.05	3.05	2.54	3.81	2.54	3.30	3.05
Mean (cm/ day)	3.98	3.61	4.23	3.54	3.40	3.86	3.92

Gross Ablation, 1964
Site 8 A
Elevation: 1,290 m. (6,300 ft.)

Dates:	Gross ablation (cm. of firn):
1 Aug 1615h	Stakes emplaced
7 Aug 1400h	6.35 10.91 11.42 11.42 13.20 12.45 11.69 11.17 11.42 12.45 10.91 10.66
20 Aug	All stakes buried by new snow

(Mean daily ablation = 1.86 cm/day).

Gross Ablation, 1964
Site 9 B
Elevation: 1,356 m. (4,450 ft.)

Dates:	Gross ablation (cm. of firn):			
1 Aug 1730h	Stakes emplaced			
7 Aug 1230h	8.90	6.35	13.96	15.24

(Mean daily ablation = 1.85 cm/day)

Gross Ablation, 1964
Site 10 C
Elevation: 1,113 m. (3,650 ft.)

Dates:	Gross ablation (cm. of firn):					
1 Aug 2030h	Stakes emplaced					
7 Aug	15.24	15.24	15.24	19.04	17.78	15.24

(Mean daily ablation = 2.72 cm/day).

APPENDIX B

Hand-Auger Core data.

1962 Accumulation Records

Site: 62-1 South of Taku A
Elev: 945 M (3,100 ft.)
Date: 1 Sept. 62

Depth meters	Thickness of Ice Strata cm.	Density gm/cm3
0.30		.519
0.60		.556
1.20		.510
1.56	0.2	
1.63	0.3	
2.00	1.8	
2.50		.558
2.83	2.5	
2.98	3.1	
3.04	2.2	
3.10	30.0 straticulated	
3.20		.779
3.49	2.2	
3.51	9.0 straticulated	
3.60	40.0 bubbly ice	
3.80		.821
4.00		.810
4.50		.828
4.60 Bottom of hole		

Site: 62-2 SW Branch - Taku Junction
Elev: 975 M (3,200 ft.)
Date: 22 Aug. 62

Depth: meters	Thickness of Ice Strata: cm	Density: gm/cm^3
0.38	1.3	
0.40		0.602
0.53	1.4	
0.75	2.0	
0.85	1.2	
0.90		0.589
1.05	1.1	
1.14	1.4	
1.80		0.626
2.20		0.637
2.38	0.4	
2.39	0.2	
2.44	0.5 to 1.4	
2.49	2.3	
2.80		0.633
3.00	1.5	
3.03	0.5	
3.30	0.5	
3.35	0.3 to .5	
3.37		0.598
3.49	2.9	
3.64	1.4 to 2.1	
4.00		0.707
4.10		0.731
4.20		0.733
4.31	7.0	
4.40		0.679
4.80		0.681
5.30		0.712
5.36	1.3	
5.51	3.7	
5.56	0.3	
5.62	1.0	
5.65		0.733
5.66	1.3	
5.80	0.9	
5.85	0.5	0.750
5.92	0.6	
5.95	0.4	
5.96	0.3	
6.20		0.678
6.60	0.9	
6.68	0.8	
6.90		0.738
7.10	1.3	
7.15	0.4	
7.18	0.5	
7.19	0.4	
7.20		0.720
7.36	2.6	
7.42	1.8	
7.60	1.2	
7.64	4.0	
7.70		0.742
7.81	1.4	
7.85		0.736
7.90	0.8	
7.95	0 to 1.0	
8.00	2.5	
8.08	1.5	
8.19	10.0	
8.30		0.785
8.49	1.7	
8.60		0.883
8.70		0.856
8.80		0.867
9.00		0.899
9.20 Bottom of hole		

Site: 62-3 Icy Basin
Elev. 1,067 M (3,500 ft.)
Date: 21 July 62

Depth meters	Thickness of Ice Strata: cm	Density: gm/cm^3
0.90		0.592
1.00	1.5	
1.40		0.613
1.50	4.0	
1.90		0.635
2.00	1.3	
2.40		0.692
3.40		0.674
3.52	0.4	
3.60	1.2	
3.74	0.8	
3.76	0.8	
3.90	0.5	
4.00		0.613
4.10	2.0	
4.20	0.5	
4.40		0.819
4.60	28.0	0.821
5.30	dirty layer	(1961 A.S.)
5.30		0.845
5.60	dirty layer	
6.00	dirty layer	
	Bottom of hole	

Site: 62-4 (JIRP site 108)
Elev: 1,082 M (3,550 ft.)
Date: 20 July 62

Depth: meters	Thickness of Ice Strata: cm	Density: gm/cm^3
0.6		.569
0.65	0.6	
1.00	2.0	
1.1		.534
2.1		.561
2.20	2.7	
3.5		.613
3.60	0.3	
3.75		.624
4.00	1.5	
4.5		.679
4.60	2.5	
5.00	1.0	.683
5.05	1.3	
5.1	2.0	
5.15	1.0	
5.20	0.6	
5.30	0.8	
7.1		.777
7.20	6.1	
7.22	1.0	
7.27	1.4	
7.3		.631
7.50	1.0	
7.65	1.0	
7.7		.668
7.75	1.2	
7.90	7.0 to 10.0	
8.1	3.0	
8.2	0.8	
8.25	0.3	
8.3	11.0	
8.4	30.0 straticulated	
8.7	30.0	.727
8.75		.784
9.0	Bottom of hole	

Site: 62-5 Southwest Branch Taku Glacier
Elev: 1,113 M (3,650 ft.)
Date: 21 Aug 62

Depth meters	Thickness of Ice Strata: cm	Density: gm/cm^3
.5		0.720
1.3		0.550
1.9		0.602
2.1		0.538
2.2	.8	
2.48	.3	
2.57	.9	
2.7		0.609
3.0		0.578
3.4		0.548
3.68	1.4	
3.82	3.0	
4.11	1.6 to 1.9	
4.2		0.607
4.31	.4	
4.58	.9 to 1.6	
4.9		0.637
5.1	1.5	
5.14	.5 dipping	
5.33	.5 dipping	
5.35		0.642
5.47	.8 dipping	
5.53	1.19	
5.55		0.698
5.70		0.668
6.03	.4	
6.4		0.690
6.7		0.668
6.87	1.0 to 1.7	

Depth: meters	Thickness of Ice Strata: cm	Density: gm/cm^3
6.95	.8	
7.13	.3	
7.20	.3	
7.22	.4	
7.25		.625
7.80	ice gland	
8.40	ice gland	
8.6		.700
8.78	ice gland	
8.84	ice gland	0.733
8.86	ice gland	
8.95	ice gland	.722
9.37	1.4 dipping	
9.42	0.5 to 1.3 dip.	
9.5		.733
9.75		.722
10.0	5.0	
10.1		.692
10.11	.4	
10.22	1.8	
10.3		.700
10.45	.5	
10.47	1.9	
10.5		.733
10.8		.724
11.0	Bottom of hole	

Site: 62-6 (JIRP Site 10 C)
Elev: 1,113 M (3,650 ft.)
Date: 23 Aug. 62

Depth: meters	Thickness of Ice Strata: cm	Density: gm/cm³	Depth: meters	Thickness of Ice Strata: cm	Density: gm/cm³
.6		.681	4.8		.594
.9		.576	5.41	1.7	
1.15		.637	5.5		.592
1.65		.633	5.6		.589
1.98	0.5		5.7		.596
2.3	5.8		6.3		.628
2.4		.576	6.68	0.6	
2.5		.556	6.72	0.8	
2.7		.548	6.75		.692
2.85	0.9		6.89	0.6 to 1.3	
3.11	0.7		7.0	1.7 to 2.1	
3.2		.578	7.20	0.4	
3.37	0.4		7.23	0.7 to 1.5	
3.43	0.5		7.25	0.7	.650
3.54	0.5		7.38	0.6	
3.6		.523	7.41	0.5	
3.76	0.6		7.43	0.6	
3.89	2.5		7.45		
4.1		.580	7.6	15.0 strat.	.843
4.26	2.0		7.8		.709
4.3		.607	7.9		.650
4.66	0.3		8.2		.716
4.74	6.0		8.3	Bottom of hole	

Site: 62-7 Upper SW Branch
Elev: 1,163 M (3,800 ft.)
Date: 18 Aug. 62

Depth: meters	Thickness of Ice Strata: cm	Density: gm/cm3
.2		0.642
.4	1.8	
1.0	0.8	
1.1		0.548
1.3	3.7	
1.4	ice gland	
1.49	1.2	
1.87	0.2	
1.9	ice gland	
2.0		.558
2.4		.569
2.6		.567
3.1		.578
3.2		.583
3.6	1.9	
3.65	0.5	
3.74	0.9	
4.15	2.8	
4.29	0.8	
4.3		.594
4.41	0.4	
4.47	3.1	
5.34	0.4	
5.4		0.602
5.7		0.607
6.2		0.607
6.34	0.3 to 0.9	
6.44	.8	
6.53	.8	
6.60		0.619
6.65	0 to 0.4	
6.76	.2	
6.82	0.4 to 0.8	
6.84	0.8	
6.94	0.5	
6.97	0.3 to 1.4	
7.04	0.4	
7.51	0.3	
7.6		0.635
7.71	0.4	
7.77	0.3	
8.5	0.7	
8.6		0.650
8.79	0.8 to 1.2	
8.83	3.9	
8.9		0.707
9.02	1.3	
9.06	1.2	
9.12	0.4	
9.20	0.4	
9.25	2.1	.714
9.69	0.6	
9.72	2.4	
9.78	1.3	
9.84	0.8	
9.95		0.746
10.06	2.6	
10.30		0.716
10.40		0.744
10.61	1.8	
10.66	5.6	
10.75		0.725
10.90	Bottom of hole	

Site: 62-8
Elev: 1,250 M (4,100 ft.)
Date: 19 July 62

Depth: meters	Thickness of Ice Strata: cm	
0.6	1.5	
1.0	4.0	(No density measurements made)
1.1	0.3 to 0.8	
1.5	2.0	
3.9	1.5	
4.75	4.0	

Site: 62-10 N of TricouniPeak
Elev: 1,433 M (4,700 ft.)
Date: 17 Aug. 62

Depth: meters	Thickness of Ice Strata: cm	Density: gm/cm^3
1.30	ice gland	
1.40	0.4 to 0.6	
1.60		0.633
1.70		0.640
2.20		0.611
2.30	2.4	
2.70		0.580
2.90	0.4	
3.07	1.6	
3.20	0.9	
3.25	3.3	
3.30		0.572
3.55	1.2	
3.60		0.607
3.65	0.3	
4.10		0.619
4.50		0.615
4.86	1.1	
4.88	0.9	
4.90	3.1	
5.10	1.0	
5.23	1.6	
5.37	0.4	
5.44	0.8	
5.53		0.500
5.58	0.3	
5.80		0.602
6.80		0.611
7.00	1.3	
7.30		0.615
7.55	1.0 to 2.4	
7.71	1.4	
7.75	1.5	
7.77	1.2	
7.78	0.2	
7.80	0.4	
7.82	1.7	
7.95	5.2	
8.05	0.3 to 0.7	
8.08	3.2 to 4.0	
8.10	0.3 to 0.9	
8.20	0.9	
8.23	0 to 1.2	
8.27	1.2	
8.42	5.3	
8.53	0.4	
8.55	0.4	
8.70	9.0	
8.80	50.0 straticulated	
9.35	6.3 straticulated	
9.50	30.0 straticulated	
9.50	30.0	0.725
10.12	0.4	
10.18	3.8	
10.32	0.3	
10.50		0.650
10.60	3.3	
10.70		0.677
10.90	Bottom of hole	

Site: 62-11 (WSW of Carpet Peak)
Elev: 1,463 M (4,800 ft.)
Date: 19 July 62

Depth: meters	Thickness of Ice Strata: cm
0.35	1.2
1.20	3.0
2.0	0.3
2.5	1.0
3.0	1.0
3.5	1.0
3.7	0.5 to 1.0
4.0	4.0 to 5.0 (1961 A.S.?)
4.4	1.0
4.6	1.0
4.8	6.0

No density measurements made.

Site: 62-12 (100 meters E of Camp 9)
Elev: 1,524 M (5,000 ft.)
Date: 24 July 64

Depth: meters	Thickness of Ice Strata: cm	Density: gm/cm^3
0.35	1.3	
0.40		0.578
1.00	0.8	
1.10		0.648
1.50		0.618
2.40		0.631
2.80		0.578
3.32	1.0	
3.50		0.540
3.75	1.6	
3.90	1.1	
4.00	0.8	
4.20		0.622
4.60		0.644
4.70	0.9	
4.95	1.6	
5.30		0.618
5.45	0.3	
6.20		0.631
6.60		0.635
6.65	0.8	
6.68	0.7	
6.70	1.4	
7.20		0.640
7.85	23.0 straticulated	
7.95		0.718
8.10	3.5 bubbly ice	
8.24	0.4	
8.37	13.0	
8.55	7.0	
8.70		0.659
8.80	Bottom of hole	

Site: 63-13 1.5 km NW of Emperor Peak
Elev: 1,570 M (5,150 ft.)
Date: 17 July 62

Depth: meters	Thickness of Ice Strata: cm	Density: gm/cm^3
0.45	1.0	
0.62	1.0	
0.65	0.5	
0.69	1.0	
1.00		0.615
2.00		0.700
2.10		0.580
2.20	1.0	
3.00		0.545
3.32	1.0	
3.82	2.0	
3.85	0.5	
3.90		0.630
4.00		0.605
4.90		0.625
5.80		0.705
5.90		0.705
7.00		0.645
7.44	2.0	

Site: 62-14 (Camp 16)
Elev: 1,608 M (5,275 ft.)
Date: 16 July 62

Depth: meters	Thickness of Ice Strata cm	Density: gm/cm^3
.35	1.3	
2.00	0.3	
2.50	0.6	
4.25		0.658
5.00	21.5 bubbly ice	0.899
5.10		0.910
5.20		0.844
5.30		0.888
5.4	Bottom of hole	

Site: 62-15 (JIRP Site 8D)
Elev: 1,737 M (5,700 ft.)
Date: 5 Aug. 62

Depth: meters	Thickness of Ice Strata: cm	Density: gm/cm^3
0.40		0.731
0.55	1.7	
0.58	0.8	
0.65	1.3	
1.20	3.0	0.622
1.22	0.3	
1.35	0.2	
1.40		0.655
1.60	1.3	
1.65	0.4	
1.76	3.7	
1.86	1.0	
2.10		0.602
2.40		0.594
3.20	ice gland	
3.40		0.602
4.00		0.554
4.30	ice gland	0.587
4.50	4.4	
4.60		0.648
4.70	1.5	
4.80	1.5	
4.85	0.5	
5.40	1.4	0.576
5.75	0.4	
5.80	1.0 to 2.0	
6.50	7.2	
6.90	5.4	
7.00		0.580
7.40	2.0 to 2.4	
7.60		0.619
8.20		0.624
8.40	ice gland	
8.60		0.602
8.90	ice gland	
9.02	1.1	
9.10		0.642
9.20	0.8	
9.30	ice gland	
9.40		0.606
9.50	ice gland	
9.57	5.7	
9.65		0.624
9.78	1.4	
10.00	0.3	
10.15	0.6	
10.17	0.5	
10.22	6.5	
10.33	1.8	
10.44	1.8	
10.52	2.4	
10.70		0.635
10.76	0.8	
11.00		0.637
11.15	4.5	
11.25		0.646
11.40		0.628
11.50		0.626
11.60		0.615
11.70		0.613
12.10		0.637
12.53	1.2	
12.60		0.659
13.04	1.1	bubbly ice
13.10	4.0	clear ice
13.30	2.4 to 3.5	
13.50		0.653
13.90		0.666
14.00	6.0	
14.06	0.6	
14.10		0.650
14.18	0.3	
14.22	0.5	
14.25	0.3	
14.30		0.679
14.70	Bottom of hole	

Site: 62-16
Elev: 1,737 M (5,700 ft.)
Date: 7 Aug. 62

Depth: meters	Thickness of Ice Strata: cm	Density: gm/cm^3
.2	2.1	
.3		.548
.8	.5	
.9	2.4	
1.1		.567
1.6	0.5	
2.3		.548
2.5	3.0	
2.8		.523
2.9	.4	
3.2	.6	
3.8	8.1	
3.9		.569
4.0	ice gland	
4.2		.585
4.5		.550
4.8	ice gland	
5.0		.580
5.2	2.5	
5.5		.588
5.7	3.2 to 4.8	
5.85	1.3	
5.9		.567
6.7		.611
6.8	.4	
7.4	ice gland	
7.6		.602
7.9	7.5	
8.2	1.3	
8.25	.3	
8.5	1.0	.613
8.6	1.2	
8.7	5.2	
9.	6.7	
9.5		.637
9.7		.613
10.2	ice gland	
10.3		.637
10.7		..664
10.9	ice gland	
11.1		.655
11.3	4.3	
11.5		.794
11.7		.742
11.8	14.0	.896
12.0	Bottom of hole	

Site: 62-17 (JIRP Site 8 B)
Elev: 1,814 M (5,950 ft.)
Date: 28 July 62

Depth: meters	Thickness of Ice Strata: cm	Density: gm/cm³
0.55	0.8	
0.77	0.3	
0.80		0.756
0.95	0.6	
0.97	0.3	
1.10		0.681
1.30	5.8	
1.90		0.552
2.20	ice gland	
2.50		0.719
2.60	1.1	
2.85	2.6	
3.10		0.642
3.25	1.3	
3.80		0.640
3.90	0.3 to 13	
4.10		0.653
4.20	1.2	
4.50	1.4	
4.80		0.644
4.95	0.7	
5.10	6.3	
5.28	0.2	
5.31	0.3	
5.40	3.0	
5.88	1.5	
5.60		0.684
6.20	core is very firm	
6.20		0.684
6.50	2.4	
6.70		0.595
6.90	3.5	
7.00	0.4	
7.10		0.662
7.60	ice gland	
7.80		0.665
8.30		0.688
8.40		0.693
8.50	1.3	
8.67	0.6	
8.70	0.6	
8.80		0.657
9.00	Bottom of hole	

Site: 62-18 (SE of Camp 8, E of Mt. Everlast)
Elev: 1,844 M (6,050 ft.)
Date: 29 Aug. 62

Depth: meters	Thickness of Ice Strata cm	Density: gm/cm^3
0.32	0.2 to 1.1	
0.35		0.522
0.70		0.552
1.40		0.541
1.62	1.0	
2.80	0.4	
3.30	0.6	
3.45	0.6	
3.53	0.2	
3.60		0.576
3.80	1.7	
4.30		0.565
4.50	1.3	
5.25	0.5	
5.50	0.5	
5.60		0.585
6.00	0.6	
6.25		0.611
6.40	0.4	
6.95	1.3	
7.01	0.4	
7.06	0.3	
7.10	0.3	
7.42		0.609
7.65	3.3	
7.77	3.5	
8.50		0.609
8.69	4.1	
8.80		0.576
9.35		0.622
9.50	4.0 to 5.0	
9.70		0.635
9.87	5.6	
10.00	Bottom of hole	

Site: 62-19 (Taku-Lewellyn Glacier Divide)
Elev: 1,890 M (6,200 ft.)
Date: 29 July 62

Depth: meters	Thickness of Ice Strata: cm	Density: gm/cm3
.50		.729
.95	5.9	
2.10		.626
2.20	1.5	.633
2.70		.622
3.50		.666
3.70		.664
4.00		.622
4.35	0.9	
4.50		.637
4.80	0.6	
5.30		.613
5.50	35.0	
5.70		.722
5.80	0.6	
7.05	33.0 straticulated	
7.05		.644
7.55	9.2	
7.70		.646
7.80		.556
7.90		.552
8.00		.543
8.6		.556
9.0		.618
9.5	2.3	
9.6		.618
9.9	2.2	.637
10.0		.622
10.2		.598
10.31	5.0	
10.70	1.7	
11.15	0.6	
11.7		.615
11.8		.622
12.0		.619
12.1		.624
12.60		.635
13.00		.637
13.50		.648
13.70	3.0	
14.20	2.8	
14.30	3.2	
14.45	4.1	
14.55	2.5	
14.60		.659
14.80	1.3	
14.86	13. to 2.3	
14.95	straticulated	
15.00		.907
15.20	5.9	
16.00		.657
16.70		.657
17.10		.664
17.40		.670
17.60	Bottom of hole	

Site: 62-20 (JIRP Site 8A)
Elev: 1,920 M (6,300 ft.)
Date: 27 July 62

Depth: meters	Thickness of Ice Strata cm	Density: gm/cm^3
0.67	1.5	
0.76	1.4	
0.92	3.1	
1.00		0.614
1.15	1.2	
1.39	6.0	
1.60		0.629
2.05		0.569
2.10	ice gland	
2.30	2.5	
2.50		0.642
3.10	0.4	
3.20		0.585
3.50		0.614
3.85		0.658
4.25		0.772
4.80	ice gland	
5.15		0.607
5.35	1.3	
5.80	ice gland	
6.00		0.662
6.20	3.6	
7.40		0.693
7.60	ice gland	
8.20		0.649
9.32	0.3	
9.40		0.583
9.65	0.4	
9.70		0.578
9.72	1.0	faint
9.75	0.5	faint
9.80		0.583
9.91	1.6	
9.95	1.6	
10.00	Bottom of Hole	

Site: 62-21 (20A)
Elev: ca. 1951 M (6,400 ft.)
Date: 4 Aug. 62

Depth: meters	Thickness of Ice Strata: cm	Density: gm/cm^3
0.6	2.5	
1.0	1.8	
1.7	2.4	
2.2	0.4	
2.5		.532
4.2		.580
4.3	2.6	
4.74	0.3 to 1.0	
4.80		.554
4.90	4.7	
5.10	1.1	
5.25	1.0	
5.40	1.5	
5.80		.583
6.00	9.2	
6.20	70.0 straticulated	
7.00		.823
7.20		.817
7.31	29.0 straticulated	
7.31		0.784
7.60	30.0 very compact firn	
7.60		0.674
8.20		0.755
8.50	6.3	
8.70	8.2	
8.90		0.635
9.10		.645
9.30	11.0	
9.80		.602
10.30		.587
10.40		.587
10.80		.607
11.30		.613
11.50		.637
11.70	9.5	
12.50	0.5	
12.80	0.4	
13.00		.650
13.20	2.2	
13.50	3.1	
13.61	0.2	
13.65	1.5	
13.69	0.6	
13.90		0.698
14.20	0.3	
14.50	50.0 straticulated	
14.80		0.782
15.00		0.750
15.50		0.750
15.75	2.8	
16.10	6.0	
16.30		0.798
16.60	47.0 straticulated	
16.70		0.894
17.00	43.0	
17.60		0.894
17.80		0.664
18.12	2.5	
18.15	30.0	
18.55	34.0	
18.9	50.0	
19.2		0.812
19.4		0.864
19.6		0.685
20.2		0.707
20.32	6.0	
20.50		0.685
21.20		0.681
21.32	5.2	
22.25	1.0	
22.55		0.733
22.58	3.0	
22.68	1.3	
22.75	1.3 very compact firn	
22.80 Bottom of hole		

APPENDIX C

1963 Accumulation Records

SIPRE Site 8B - Hand Auger Core Data
29 Aug. 63
30 Aug. 63

Depth (meters)	Ice Strata Thickness (cm.)
0.39	0.9
0.40	1.2
0.85	2.0
1.30	1.1
1.63	0.2
1.66	0.5
3.70	1.1
3.85	0.9
4.06	2.6 straticulated
4.40	soft zone
4.70	firm material
5.00	1.3
5.25	soft zone
5.50	10.0
7.0	3.0
8.0	8.0
8.55	1.0
8.7	4.0
8.9	1.0
10.5	5.0
10.7	2.0
11.1	2.0
13.0	1.0
13.5	4.0
14.1	1.0
14.6	1.0
15.0	Bottom of hole

Pit 8 B
27 Aug. 63

Depth cm.	Spl. Wt. $cm.^3$	Density gm/cm^3	
05.0	500	0.502	
20.0	"	0.510	
40.0	"	0.562	
60.0	"	0.528	
80.0	"	0.514	
100.0	"	0.508	
120.0	"	0.544	
140.0	"	0.538	
160.0	"	0.556	
180.0	"	0.552	
200.0	"	0.558	
220.0	"	0.612	
240.0	"	0.580	
260.0	"	0.582	
280.0	"	0.602	
300.0	"	0.582	
320.0	"	0.500	
340.0	"	0.610	
360.0	"	0.592	
380.0	"	0.652	
400.0	"	0.596	
420.0	"	0.612	
440.0	"	0.522	schwimmschnee
460.0	"	0.542	
480.0	"	0.576	
500.0	"	0.552	
520.0	"	0.548	
540.0	"	0.584	
560.0	"	0.586	

Depth cm.	Ice Strata cm.
15.20	0.32 to 0.64
30.50	1.27
40.50	1.27
61.00	7.62 to 10.16
230.20	0.64
271.00	0.64 undulating
387.00	0.32
399.00	0 to 0.64
414.00	0.32 to 5.08
453.00	0.32 to 2.54
473.00	0.32 to 3.54
524.00	0.32 to 2.54
560.00	10.16

Bulk density 0.56213

Crevasse 8Y Stratigraphy
Elevation 1,737 M. (5,700 ft.)
3 Sept. 63

	Depth		Thickness of Ice Strata		
Feet	Inches	Meters	Inches	Centimeters	
0	0	0	Surface	3 Sept. 63	
	8	0.20	0.25	0.64	
1	8	0.50	1.50	3.81	discontinuous
4	8	1.42	1.50	3.81	"
5	6	1.67	0.50	1.27	"
5	10	1.77	0.25	0.64	
5	11	1.80	1.00	2.54	
6	4	1.93	0.25-0.50	0.64 to 1.27	
6	11	2.11	0.50	1.27	
9	8	2.94	1.00	2.54	
10	2	3.10	0.25	0.64	
11	6	3.50	0.50	1.27	
11	10	3.60	0.50	1.27	
13		3.96			
to 14		4.27	(Crevasse widens from ca. 2.0 to 5.0 ft.)		
14	8	4.47	2.0-3.0	5.08 to 7.62	continuous
15	8	4.77	0.5-1.0	1.27 to 2.54	"
16	8	5.08	3.0-4.0	7.62 to10.16	" , undul.
17	1	5.43	0 -2.0	0 to 5.08	discontinuous
18	10	5.74	2.0-6.0	5.08 to15.24	continuous
19	8	5.99	0 -1.0	1.27 to 2.54	discontinuous
23	3	7.09	0.5-1.0	1.27 to 2.54	
24	6	7.47	0 -3.0	0 to 7.62	"
25	11	7.90	0.5-2.0	1.27 to 5.08	
27	7	8.41	0.5-1.0	1.27 to 2.54	
28	11	8.81	0.5-2.0	1.27 to 5.08	
30	8	9.34	0.5-2.0	1.27 to 5.08	series of thin strata
32	11	9.93	1.0-3.0	2.54 to 7.62	
35	4	10.77	0 -1.0	0 to 2.54	discontinuous
36	7	11.15	3.0-4.0	7.62 to10.16	continuous
40	9	12.42	0.25-1.0	0.64 to 2.54	
41		12.50	1.00	2.54	zone of large crystals
42	7	12.98	0.50	1.27	
43	6	13.26	0 -1.0	0 to 2.54	discontinuous
44	6	13.56	1.0-3.0	2.54 to 7.62	continuous

End of stratigraphic record.

10B Pit A Stratigraphy
17 Aug. 63

Depth cm.	Ice Strata Thickness cm.
0	
45.7	0.32 to 0.64
96.5 to 101.6	0.64 to 1.92
114.3	0.32
129.5	0.64
177.8	0.64
220.0	0.32
246.0	0.64 to 1.27
325.0	depth hoar
356.0	0.64 to 2.54
369.0	1.27 to 2.54
376.0	Bottom of pit
580.0 to 600.0	12.7 to 15.24

Site10B Pit A Density
9 Aug. 63

Depth (cm.)	Volume ($cm.^3$)	Density gm/cm^3
0.0	500	0.468
20.0	500	0.496
40.0	500	0.538
60.0	250	0.561
80.0	250	0.524
100.0	250	0.540
120.0	250	0.568
140.0	250	0.520
160.0	250	0.516
180.0	250	0.568
200.0	250	0.548
220.0	500	0.598
240.0	500	0.586
260.0	500	0.628
280.0	500	0.628
300.0	500	0.576
320.0	500	0.602
340.0	500	0.668
360.0	500	0.676

Crevasse 10B-1 Stratigraphy
Elevation 1,082 M. (3,550 ft.)
17 Aug. 63

Depth Feet	Inches	Meters	Ice Strata Thickness, cm.
0	0	0	Surface (17 Aug. 1963)
1	6	0.46	0.32 to 0.64
3	2	0.97	5.08 straticulated
3	9	1.14	0.32
4	3	1.30	0.32
5	10	1.78	0.64
6	3	1.91	firmness increases
7	5	2.26	0.32
8	1	2.46	0.64 to 1.27
10	8	3.25	depth hoar zone, var. thickness
11	3	3.43	5.08 to 10.16 undulating with apparent depth hoar
11	8	3.56	0.64 to 2.54
12	1	3.69	1.28 to 2.54
12	4	3.76	floor of snow pit (17 Aug. 1963)
13	10	4.21	7.62 undulation, dirty zone
15	9	4.80	7.62 undulating, possible a.s.
17	7	5.36	12.70 to 15.24
22	2	6.76	2.54 continuous, undulating, contains yellowish dust.
24		7.32	30.48 upper surface undulating
24	11	7.60	30.48 undulating, discontinuous straticulated zone of var. thickness
26	3	8.00	10.16 possible a.s.
29	11	9.12	12.70 undulating
31	4	9.55	45.72 straticulated zone
32	10	10.00	2.54
36	3	11.05	thin dirt zone
39	8	12.09	2.54 to 20.32 undulating, very dirty
42	2	12.85	0 to 2.54 discontinuous
44	5	13.54	30.48
46	1		
46	1	14.05	0 to 5.08 discontinuous
48	3	14.71	5.08 undulating
50	8	15.44	7.62 very dirty zone
54		16.46	2.54 slightly undulating
55	9	16.99	2.54 slightly undulating

End of stratigraphic record.

Crevasse Stratigraphy
10B-2 ca. 50 yds. N of crevasse 10B-1
10 Sept. 63

	Depth			Thickness of Ice Strata		
	Meters	Feet	Inches	Centimeters	Inches	Remarks
	1.45	4	9	1.27	0.50	
	1.57	5	2			
to	1.93	6	4			crevasse widens
	1.75	5	9	1.27 to 5.08	0.50 to 2.00	undulating
	1.86	6	1			
	2.20	7	3			straticlated
to	2.33	7	8	0 to 1.27		undulating
	2.59	8	6			
to	3.90	12	10			straticulated zone
	3.91	12	10	0 to 7.62	0 to 3.00	discontinuous
	3.99	13	1	7.62	3.00	straticulated
	4.11	13	6	7.62	3.00	straticulated
	4.24	13	11	15.24	6.00	straticulated
	4.47	14	8	1.27 to 5.08	0.50 to 2.00	und.; a few thin discontinuous strata above and below this stratum.
	4.96	16	3	7.62 to 10.16	3.00 to 4.00	continuous
	5.06	16	7	22.86	9.00	straticulated
	5.28	17	4	3.81	1.50	
	5.41	17	9	2.54	1.00	straticulated
	5.68	18	8	30.48	12.00	straticulated
	5.93	19	9	1.27 to 7.62	0.50 to 3.00	und., continuous
	6.15	20	2	20.32	8.00	straticulated, contains dirt; undulating
	6.63	21	9	5.08 to 7.62	2.00 to 3.00	strat., und.
	6.76	22	2	12.70	5.00	strat., continuous
	7.14	23	5	5.08 to 10.16	2.00 to 4.00	continuous
	7.62	25		0 to 10.16	0 to 4.00	disc., und.
	8.48	27	10			straticulated zone.
to	9.42	30	11			Strata are thicker, closer together and more continuous toward the base
	9.62	31	7	0 to 5.08	0 to 2.00	und.
	9.75	32		0 to 10.16	0 to 4.00	und.
	9.88	32	5	7.62	3.00	contains faint dirt layer overlain by und. ice stratum up to 5.0 cm. (2.0 inches) thick
	10.39	34	1	22.86	9.00	strat.
	10.61	34	10			thin dirt layer
	10.81	35	6	2.54 to 5.08	1.00 to 2.00	
	10.86	35	8	10.16	4.00	strat.
	10.97	36		2.54	0 to 1.00	

10B-2 ca 50 yds. N of crevasse 10B-1 (con't.)
10 Sept. 63

Depth Meters	Feet	Inches	Thickness of Ice Strata Centimeters	Inches	
11.56	37	11	27.94	11.00	straticulated zone. Individual strata are undulating and up to 5.0 cm. (2.0 in) thick.
12.32	40	5			Small pod of dirt in depression in thin undulating stratum
12.68	41	7	0 to 5.08	0 to 2.00	und.
12.88	42	3	12.70	5.00	strat.
13.08	42	11	1.27	0.50	
13.11	43		0 to 5.08	0 to 2.00	
13.21	43	4	0 to 2.54	0 to 1.00	
13.26	43	6	0 to 2.54	0 to 1.00	
13.55	44	6	0.64	0.25	
13.59	44	7	55.88	22.00	Strat.
14.35	46	9	0 to 2.54	0 to 1.00	
14.51	47	7	10.16	4.00	Strat.
14.78	48	6	1.27 to 5.08	0.50 to 2.00	
15.02	49	3	78.74	31.00	Strat.
15.79	51	10	2.54	1.00	
15.85	52		2.54	1.00	
16.03	52	7	10.16	4.00	Strat.
16.86	55	4	0 to 1.27	0 to 0.50	
16.96	55	8	0 to 2.54	0 to 1.00	
16.99	55	9	Ice pod		5 x 15 cm. (2 x 6 in.)
17.02	55	10	Ice pod		8 x 30 cm. (3 x 12 in.)
17.07	56		0 to 5.08	0 to 2.00	
17.12	56	2	81.28	32.00	Strat.
17.88	58	8	5.08	2.00	
18.44	60	6	2.54 to 3.88	1.00 to 1.50	
19.30	63	4	2.54	1.00	
21.82	71	7	2.54	1.00	
23.36	76	8	5.08	2.00	
23.95	78	7	Ice pod		7.6 x 15 cm (3 x 6 in)
24.28	79	8	3.81	1.50	
25.99	85	3	0 to 6.35	0 to 2.50	
26.34	86	5	Ice pod		30.0 x 30.0 cm. (12.0 x 12.0 in.)
26.95	88	5	2.54 to 5.08	1.00 to 2.00	und.
27.38	89	10	10.16	4.00	und.
27.89	91	10	Ice pod		8.0 x 20.0 cm. (3.0 x 8.0 in.)
28.29	92	10	5.08	2.00	und.
30.48	100				Water level in crevasse

Crevasse 8X stratigraphy
2 Sept. 63

	Depth			Thickness of Ice Strata		
	Feet	Inches	Meters	Inches	Centimeters	
		6	.15	1.0	2.54	
	2	6	.76	2.5	6.35	
	4	2	1.28	1.0	2.54	
	10		3.05			Numerous intermittent strata
to	15	8	4.77			ca. 10.0 cm. (4.0 in) apart
	15	8	4.77	1.0 to 2.0	2.54 to 5.08	Undulating
	16	10	5.13	1.5	3.81	
	17	4	5.28	3.0	7.62	
	18	10	5.74	4.0	10.16	
	20		6.10	1.0	2.54	
	26		7.92	5.0	12.70	Above this level the crevasse
	28		8.53	3.0	7.62	is lined with a 30.0 cm.
	31		9.45	1.5	3.81	(12.0 in) thick zone of
	32	6	9.90	0 to 3.0	0 to 7.62	icicles.
	35		10.67	2.0	5.08	
	38	6	11.73	4.0	10.16	Above this stratum the cre-
	40	10	12.44	2.0	5.08	vasse is lined with a 15.0
	43	9	13.34	4.0	10.16	cm. (6.0 in) icicle zone.
	46	5	14.15	6.0	15.24	Zone of large crystals/
	49	8	15.14	14.0	35.56	Straticulated
	51		15.55	1.0	2.54	
	51	9	15.78	1.0 to 4.0	2.54 to 10.16	
	54	9	16.69	2.0	5.08	
	55	9	16.79	1.0	2.54	
	57	9	17.60	0 to 2.0	0 to 5.08	
	60	9	18.52	0 to 4.0	0 to 10.16	Und.
	71	4	21.74	1.0 to 3.0	2.54 to 7.62	
	72		21.95	1.0	2.54	
	76		23.16	Bottom of crevasse		

Crevasse 8Y
3 Sept. 63

Depth Meters	Depth Feet	Depth Inches	Thickness of Ice Strata Inches	Thickness of Ice Strata Centimeters	
0.20		8	$\frac{1}{4}$	0.64	
0.50	1	8	$1\frac{1}{2}$	3.81	
1.42	4	8	$1\frac{1}{2}$	3.81	Intermittent
1.67	5	6	$\frac{1}{2}$	1.27	
1.77	5	10	$\frac{1}{4}$	0.64	
1.80	5	11	1	2.54	
1.93	6	4	$\frac{1}{4}$to$\frac{1}{2}$	0.64 to 1.27	
2.11	6	11	$\frac{1}{2}$	1.27	
2.94	9	8	1	2.54	
3.10	10	2	$\frac{1}{4}$	0.64	
3.50	11	6	$\frac{1}{2}$	1.27	
3.60	11	10	$\frac{1}{2}$	1.27	
3.96	13				
to 4.27	to 14				Crevasse widens from 2 to 5 feet
4.47	14	8	2-3	5.08 to 7.62	
4.77	15	8	$\frac{1}{2}$-1	1.27 to 2.54	
5.08	16	8	3-4	7.62 to10.16	Undulating
5.43	17	1	0-2	0 to 5.08	
5.74	18	10	2-6	5.08 to15.24	
5.99	19	8	0-1	0 to 2.54	
7.09	23	3	$\frac{1}{2}$-1	1.27 to 2.54	
7.47	24	6	2-3	5.08 to 7.62	
7.90	25	11	$\frac{1}{2}$-2	1.27 to 5.08	
8.41	27	7	$\frac{1}{2}$-1	1.27 to 2.54	
8.76	28	9	0-1	0 to 2.54	
8.81	28	11	$\frac{1}{2}$-2	1.27 to 5.08	
9.34	30	8	$\frac{1}{2}$-2	1.27 to 5.08	Straticulated
10.03	32	11	1-3	0 to 2.54	
10.77	35	4	0-1	0 to 2.54	
11.15	36	7	3-4	7.62 to10.16	
12.42	40	9	$\frac{1}{4}$-1	0.64 to 2.54	
12.50	41		$\frac{1}{4}$-$\frac{1}{2}$	0.64 to 1.27	
12.70	41	8	1	2.54	Zone of large crystals
12.98	42	7	$\frac{1}{2}$	0.64	
13.26	43	6	0-1	0 to 2.54	
13.56	44	6	1-3	2.54 to 7.62	

APPENDIX D

1964 Accumulation Records

8A SIPRE hand auger hole
22 July 64

Depth	Ice Strata
1.2 M	2.0 cm
3.6 M	firm zone
6.5 M	firm zone
9.5 M	5.0 cm

Crevasse 8D-1
16 Aug. 64

Depth Feet	Depth Inches	Meters	Stratigraphy (cm.)	
2	8	.81	5.0 to 10.0	
3	10	1.16	0 to 1.0	
4		1.22	0.5 to 1.0	
7	4	2.33	1.0	
8	3	2.52	0.5 to 1.0	
10	5	3.18	4.0	
17		5.18	0.5 to 1.0	continuous
21		6.40	5.0	
21	8	6.60	0.5 to 1.0	
24	5	7.45	1.0 to 7.0	discontinuous
25		7.62	1.0 to 5.0	continuous
25	7	7.80	1.0	
27	9	8.46	0.5 to 1.0	
28' 0"		8.53	1.0 to 3.0	
28' 4"		8.63	0 to 1.0	
28' 8"		8.73	0 to 1.0	
28	10	8.78	1.0	
29	8	9.04	2.0 to 3.0	
30	3	9.22	0 to 1.0	
31		9.45	2.0 to 5.0	
31	9	9.68	0 to 5.0	very discontinuous
33	5	10.19	0 to 10.0	" "
35		10.67	5.0 to 10.0	continuous
35	9	10.90	0 to 5.0	very discontinuous
38		11.58	1.0 to 10.0	
39	1	11.92	1.0 to 10.0	
40	5	12.32	2.0 to 8.0	
41		12.50	1.0 to 2.0	
42	5	12.93	2.0 to 6.0	
43		13.11	1.0 to 4.0	
45	6	13.87	1.0 to 10.0	
50	10	15.49	1.0 to 10.0	
53		16.15	1.0 to 3.0	
53	2	16.20	0 to 1.0	
55		16.76	5.0 to 15.0	straticulated
58	8	17.88	3.0 to 10.0	
59	1	18.01	1.0	
60	8	18.49	0 to 1.0	
60	11	18.57	0 to 1.0	
61	8	18.79	0 to 1.0	
64		19.51	1.0 to 2.0	

Crevasse 8D-1 (con't.)

Depth Feet	Inches	Meters	Stratigraphy (cm.)	
67		20.42	5.0 to 13.0	continuous
69	6	21.18	2.0	
69	10	21.28	30.0	
71	7	21.82	5.0 to 10.0	
72	8	22.15	1.0 to 10.0	
74	7	22.74	3.0 to 10.0	
79	9	24.31	5.0 to 10.0	
80	6	24.53	5.0 to 10.0	continuous
80	10	24.63	5.0 to 10.0	
81	3	24.77	3.0 to 12.0	possible dirty zone
83	2	25.35	3.0 to 10.0	
84	10	25.85	1.0 to 5.0	
85	4	26.01	3.0 to 10.0	
87	9	26.75	30.0 to 40.0	possible dirty zone
90	9	27.66	6.0 to 15.0	

Pit at crevasse 8D-1
6 Aug. 64

Depth:		Vol. of core: cm^3	Density cm/cm^3
Feet	Meters		
1	.30	250	0.45
2	.61	"	0.76
3	.91	"	0.58
4	1.22	"	0.50
5	1.52	"	0.48
6	1.83	"	0.51
7	2.13	"	0.64
8	2.44	"	0.64
9	2.74	"	0.64
10	3.05	"	0.66
11	3.36	"	0.70
12	3.66	"	0.58
13	3.96	"	0.58
14	4.27	"	0.64
15	4.57	"	0.64
16	4.88	"	0.64
17	5.18	"	0.65
18	5.48	"	0.65
19	5.79	"	0.64

8D Pit 2 ca. 50 meters SW of 8D-1
16 Aug. 64

Depth Feet	Depth Inches	Depth M	Core Vol. cm^3	Density gm/cm^3	
1		0.30	250	0.58	
1	10	0.55	"	0.68	above 8.89 cm ice stratum
2	2	0.66	"	0.53	below ice stratum
3		0.91	"	0.53	
4		1.22	"	0.54	
5		1.52	"	0.58	
6		1.83	"	0.50	
7		2.13	"	0.54	
8		2.44	"	0.51	
9		2.74	"	0.55	
10		3.05	"	0.53	
11		3.36	"	0.58	

Depth Feet	Depth Inches		Depth M	Ice Thickness Inches		Ice Thickness Centimeters
1	11.5	=	.59	3.5 in	=	8.89 cm
6		=	1.83	0.5 to 2.5 in	=	1.27 to 6.35 cm
7	7.5	=	2.32	0.5 in	=	1.27 cm
10	6	=	3.20	1.0 in	=	2.54 cm

Crevasse 10 A-1 ca. 10 M downglacier
from Mvt. flag no. 3

2 Aug. 64

Depth M	Ice Strata CM	
.13	.3	
.16	1.0	
.28	1.0	
.32	2.0	
.39	2.0	
.51	5.0	upper half straticulated
.62	0.6	
.65	0.3	
.71	0.3	
.73	0.2	
.80	0.2	
.82	0.3	
.95	1.3	
1.09	1.0	
1.16	1.6	
1.43	1.3	
1.52	0.2	
1.53	0.3	
1.87	1.0 to 3.0	
1.95	0.6 to 1.2	
2.20	0.4 to 1.0	
3.77	0.8	
4.90	1.0 to 7.0	
5.20	0 to 8.0	ice gland
5.60) to 5.70)	straticulated	
5.95	1.0	

Depth M	Ice Strata CM	
6.05	0 to 0.6	
6.10	0.5 to 1.0	
6.15	0 to 1.0	
6.17	1.0 to 2.0	
6.35	0 to 1.0	
6.43	0 to 2.0	
6.95	1.0	
7.20	1.0 to 3.0	
7.37	2.0 to 4.0	
7.44	0 to 2.0	
7.54	1.0 to 4.0	undulating
7.65	0 to 5.0	undulating; trace of dirt
7.75	0 to 6.0	undulating; trace of dirt
8.60	15.0	straticulated; upper surface und.
9.10	2.0 to 6.0	
10.70	1.0	dirty layer
11.40	20.0	straticulated

Strata dipping excessively. Depths are therefore approximate

Crevasse 10 A-1 ca. 10 M downglacier
from Mvt. flag no. 3
2 Aug. 64

Depth M	Ice Strata CM	
.13	.3	
.16	1.0	
.28	1.0	
.32	2.0	
.39	2.0	
.51	5.0	upper half straticulated
.62	0.6	
.65	0.3	
.71	0.3	
.73	0.2	
.80	0.2	
.82	0.3	
.95	1.3	
1.09	1.0	
1.16	1.6	
1.43	1.3	
1.52	0.2	
1.53	0.3	
1.87	1.0 to 3.0	
1.95	0.6 to 1.2	
2.20	0.4 to 1.0	
3.77	0.8	
4.90	1.0 to 7.0	
5.20	0 to 8.0	ice gland
5.60) to 5.70)	straticulated	
5.95	1.0	

Depth M	Ice Strata CM	
6.05	0 to 0.6	
6.10	0.5 to 1.0	
6.15	0 to 1.0	
6.17	1.0 to 2.0	
6.35	0 to 1.0	
6.43	0 to 2.0	
6.95	1.0	
7.20	1.0 to 3.0	
7.37	2.0 to 4.0	
7.44	0 to 2.0	
7.54	1.0 to 4.0	undulating
7.65	0 to 5.0	undulating; trace of dirt
7.75	0 to 6.0	undulating; trace of dirt
8.60	15.0	straticulated; upper surface und.
9.10	2.0 to 6.0	
10.70	1.0	dirty layer
11.40	20.0	straticulated

Strata dipping excessively. Depths are therefore approximate

Crevasse 10 A-2
100 Meters W. of 10 A-1, on Profile IV
4 Aug. 64

Depth M	Thickness cm.		M	cm.	
.13	0.3		10.09	2.0	
.22	0.2		10.19	3.0	
.40	1.0 to 1.5		10.46	1.0 to 2.0	
.48	0.2 to 0.5		10.61	1.0 to 2.0	trace of dirt
.54	0.2				
.68	4.0 to 5.0		11.63	1.0 to 3.0	
.82	0.3		14.68	1.0 to 2.0	
.84	0.3		16.64	15.0	
.97	0.3		16.89	4.0	
.98	0.4		19.25	water level in crevasse	
1.14	0.2 to 0.4				
1.19	0.2 to 0.5				
1.73	1.0 to 2.5				
1.81	0.5 to 1.2				

5 Aug. 64

3.84	2.0	
4.06	3.0	continuous
4.21	1.0 to 2.0	discontinuous
4.45	3.0 to 5.0	continuous
4.27 to 4.57	possible a.s.	
4.96	1.0	continuous
5.16	0.5 to 1.0	"
5.46	1.0 to 2.0	"
5.79	1.0 to 5.0	undulating, possible a.s.
6.50	1.0 to 3.0	
6.55	30.0	
7.04	2.0	
7.09	2.0	
7.67	2.0 to 10.0	undulating
7.95	1.0 to 5.0	
8.10	1.0	
8.26	0 to 3.0	undulating, trace of dirt
8.61	0.5	
8.76	2.0 to 5.0	continuous

Crevasse 10 A-3
20 Meters NE of 10 A-2
6 Aug. 64

Depth M	Thickness cm	
.22	0 to 1.2	
.29	0 to 0.5	
.50	3.0	continuous
.64	0 to 0.8	
.71	4.0	"
.88	0 to 1.5	
1.00	0.2 to 1.5	"
1.48	2.0 to 3.0	
1.58	0.3 to 1.0	"
1.78	0 to 2.0	
1.91	1.0 to 3.0	
2.01	2.0	
2.13	1.0 to 1.5	
2.23	0 to 1.0	
2.38	1.0 to 2.0	
2.64	0.5	
2.77	0 to 0.5	
3.05	1.0 to 2.0	continuous
3.50	crevasse widens	
4.06	top of icicle zone	
4.27	base of icicle zone	
4.42	1963 a.s. (?)	
4.77	0.5 to 2.0	
5.03	0.5 to 2.0	
5.21	0 to 3.0	very discontinuous
5.18	0.5 to 3.0	
5.38	0.5 to 2.0	
5.48	1.0 to 2.0	undulating
5.73	0.5 to 5.0	undulating, probable a.s.

Depth M	Thickness cm	
5.99	0 to 1.0	
6.10	0.5 to 2.0	discontinuous
6.20	0 to 0. 5	"
6.30	1.0 to 3.0	continuous
6.40	1.0 to 2.0	"
6.43	1.0 to 3. 0	"
6.53	1.0	
6.74	1.0 to 3.0	undulating
7.32	3.0 to 6.0	und. (a.s.?)
7.47	0.0 to 1.0	
7.55	1.0 to 2.0	continuous
7.62	1.0 to 2.0	"
7.65	1.0 to 4.0	"
7.82	0.5 to 1.5	"
7.95	1.0 to 6.0	undulating; faint dirt (a.s.)
8.31	0 to 3.0	discontinuous
8.53	5.0 to 6.0	continuous
8.66	6.0	"
8.81	1.0 to 3.0	"
8.99	10.0	
9.17	1.0 to 2.0	discontinuous
9.27	1.0 to 4.0	"
9.39	1.0 to 3.0	continuous
9.58	1.0 to 3.0	
9.65	0.0 to 1.0	
9.78	2.0 to 5.0	continuous, undulating
10.06	3.0 to 10.0	undulating, dirt zone (a.s.)
10.21	1.0 to 3.0	
10.31	1.0 to 3.0	
11.18	2.0	continuous
11.20	5.0 to 10.0	
12.02	5.0 to 15.0	undulating

Crevasse 10 A-3
20 Meters NE of 10 A-2
6 Aug. 64

Depth M	Thickness cm	
.22	0 to 1.2	
.29	0 to 0.5	
.50	3.0	continuous
.64	0 to 0.8	
.71	4.0	"
.88	0 to 1.5	
1.00	0.2 to 1.5	"
1.48	2.0 to 3.0	
1.58	0.3 to 1.0	"
1.78	0 to 2.0	
1.91	1.0 to 3.0	
2.01	2.0	
2.13	1.0 to 1.5	
2.23	0 to 1.0	
2.38	1.0 to 2.0	
2.64	0.5	
2.77	0 to 0.5	
3.05	1.0 to 2.0	continuous
3.50	crevasse widens	
4.06	top of icicle zone	
4.27	base of icicle zone	
4.42	1963 a.s. (?)	
4.77	0.5 to 2.0	
5.03	0.5 to 2.0	
5.21	0 to 3.0	very discontinuous
5.18	0.5 to 3.0	
5.38	0.5 to 2.0	
5.48	1.0 to 2.0	undulating
5.73	0.5 to 5.0	undulating, probable a.s.

Depth M	Thickness cm	
5.99	0 to 1.0	
6.10	0.5 to 2.0	discontinuous
6.20	0 to 0. 5	"
6.30	1.0 to 3.0	continuous
6.40	1.0 to 2.0	"
6.43	1.0 to 3. 0	"
6.53	1.0	
6.74	1.0 to 3.0	undulating
7.32	3.0 to 6.0	und. (a.s.?)
7.47	0.0 to 1.0	
7.55	1.0 to 2.0	continuous
7.62	1.0 to 2.0	"
7.65	1.0 to 4.0	"
7.82	0.5 to 1.5	"
7.95	1.0 to 6.0	undulating; faint dirt (a.s.)
8.31	0 to 3.0	discontinuous
8.53	5.0 to 6.0	continuous
8.66	6.0	"
8.81	1.0 to 3.0	"
8.99	10.0	
9.17	1.0 to 2.0	discontinuous
9.27	1.0 to 4.0	"
9.39	1.0 to 3.0	continuous
9.58	1.0 to 3.0	
9.65	0.0 to 1.0	
9.78	2.0 to 5.0	continuous, undulating
10.06	3.0 to 10.0	undulating, dirt zone (a.s.)
10.21	1.0 to 3.0	
10.31	1.0 to 3.0	
11.18	2.0	continuous
11.20	5.0 to 10.0	
12.02	5.0 to 15.0	undulating

APPENDIX E

Névé-line Records, 1946-65

Taku Glacier Névé-line Elevations
1946 - 1965

	Névé-line elevation (Meters)			Névé-line elevation (Feet)		
Year:	Seasonal:	5-Year Mean:	10-Year Mean:	Seasonal:	5-Year Mean:	10-Year Mean:
1965	853	860	902	2800	2820	2960
64	747	878	885	2450	2880	2935
63	914	912	921	3000	2990	3000
62	900	912	921	2950	2990	3020
61	885	928	927	2900	3040	3040
1960	945	945	954	3100	3100	3130
59	914	912	969	3000	2990	3180
58	914	925	957	3000	3030	3140
57	967	943	969	3200	3090	3180
56	976	943	972	3200	3090	3190
1955	778	979	978	2550	3210	3210
54	945	1024		3100	3360	
53	976	989		3200	3240	
52	960	1019		3150	3340	
51	1159	1024		3800	3360	
1950	1098	1000		3600	3280	
49	794			2600		
48	1038			3400		
47	1006			3300		
46	1038			3400		