[AMERICAN JOURNAL OF SCIENCE, VOL. 252, MAY 1954, PP. 291-308]

PALYNOLOGY OF THE TAKU GLACIER SNOW COVER, ALASKA AND ITS SIGNIFICANCE IN THE DETERMINATION OF GLACIER REGIMEN*

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ABSTRACT. Regimen determination for a glacier is based on the amounts of accumulation and ablation taking place during a budget year. The measurement of accumulation is usually made from dirt horizons exposed on the walls of crevasses. Dirt horizons are not always evident, however, and it often becomes a difficult task to determine the amount of nourishment. Because of this, the pollen and spore stratigraphy of the Taku Glacier snow cover was investigated as a possible means for locating the ablation surface of the previous budget year.

Samples in stratigraphic sequence were obtained from eight pits dug in the glacier at elevations ranging between approximately 2000 and 6000 feet. Seventy-five samples were melted and allowed to settle out in pails and the sediments taken to the laboratory for analysis. Total pollen and spore counts were made for each level sampled. Profiles were prepared from these data and comparisons made.

Coated microscope slides were exposed to the air, and spectra for airborne pollen and spores were prepared for most of the flowering period. The interpretation of the profiles is based on these spectra. Meteorologic factors affecting pollen transport are discussed.

Results show: (1) the amount of seasonal accumulation is variable and the depth to the 1951 ablation surface increases in proportion to altitude; (2) autumn snow was the only sediment remaining in the pit studied at the lowest elevation; progressively up-glacier winter, spring, and summer increments become apparent; summer snow was present only in the pit highest in elevation; (3) downward percolation of pollen and spores does not generally occur.

INTRODUCTION

The determination of the regimen of a glacier is based on the amounts of accumulation and ablation measured in terms of water equivalents during a budget year. This regime is established from the volume of accumulation taking place during an accumulation period and the volume of ablation occurring during the following ablation period (Ahlmann 1948, 1953). In order for an advancing glacier to maintain itself, it is necessary that the amount of nourishment in the area of accumulation exceed the amount lost in the area of ablation. This is a positive regime, and the flow of ice from the former area to the latter will enable the glacier to move forward at its terminus. A retreating glacier exhibits the converse of the situation described above; that is, the amount lost in the area of ablation is greater than the accretion in the area of accumulation. This is a negative regime. Any flow is insufficient to replace the loss in the area of ablation, and the glacier terminus retreats. When equilibrium between accumulation and ablation is reached, the terminus becomes stationary.

The measurement of the amount of annual accumulation has generally been made from dirt horizons exposed on the walls of crevasses. Pits have been dug in the glacier in areas where crevasses do not show up even late

* Contribution from the Juneau Ice Field Research Project which is directed by the American Geographical Society through contract with the Office of Naval Research. Snow cover refers to the 1951-1952 autumn, winter, spring, and summer increments. Although it is understood that firnification was going on at the time of the study, this terminology is followed in order to distinguish between the accumulation of the budget year and the underlying firn or ice.

in the ablation period, and the depth to the dirt layers is subsequently measured. This practice is applicable in areas where there is sufficient windblown material present to be distinguished in successive years as dirt horizons. Some areas are not so characterized and as a result the layering of dirt is not evident. Further, in an area of accumulation which is undergoing different intensities of ablation from year to year, the quantity of dust may be so variable as to be often indistinguishable. Sharp (1951a) discusses this difficulty for the Seward-Malaspina glacier system, Canada-Alaska. Under such conditions it is necessary to apply techniques which would designate this annual surface. Pollen studies were therefore made an integral part of the glaciology program of the Juneau Ice Field Research Project. It was anticipated that the pollen content of the snow cover would indicate the seasonal layers and the position of the ablation surface for the previous budget year.

The theory behind the application of palynology to the measurement of annual accumulation may be summarized as follows. The presence of different types of pollen and spores in the atmosphere in varying amounts is related to the phenology of flowering and pollination of plants of the regional vegetation. Autumn, spring, and summer snows will contain pollen grains and spores characteristic of the particular season, but winter snows should theoretically contain no plant remains. Annual ablation surfaces should contain pollen and spores of different seasons since these horizons usually represent the fusion of several seasonal nourishing layers. Pollen abundance should be highest for such surfaces, although it should vary depending on the location of the area in relation to the pollen source and the amount of ablation. Sampling of the snow from stratigraphic sections and subsequent analysis should permit an understanding of the annual accumulation when the snow pollen and spore data are related to aerial spectra for the region.

Studies presented here are introductory for this phase of glaciology as applied to a North American glacier. Original work dates back over 20 years ago to Europe, and the following is a resumé of the literature. The application of pollen analysis to glaciology was first begun in 1932 by Volkmar Vareschi in his study of ice from Grindelwald Glacier in the Swiss Alps (Vareschi, 1935a). During the next two years samples were analyzed from the Aletsch Glacier in the Alps, after which Vareschi established certain facts which enabled him to pursue his studies on a larger scale. These included: (1) There is sufficient pollen in samples of glacier ice of 2-10 dm^3 to permit a statistical study; samples are seldom lacking in pollen and more than 5000 grains per dm^3 were encountered. (2) The preserved condition of the microfossils, especially the small grains, is good, although winged conifers such as fir and spruce are often badly crushed or broken. (3) Average pollen frequency is variable for a given glacier and also variable for different glaciers; further, terminal portions contained many times more grains than the higher firn regions.

This early work was followed by several papers (Vareschi 1935b, 1937) which culminated in a comprehensive treatise dealing with the movement and structure of glaciers from the pollen stratigraphic standpoint (Vareschi,

1942). Studies presented in this latter publication were carried out on the Aletsch Glacier in Switzerland and the Gepatsch Glacier in the Tyrol. No additional work has been published on glaciers by Vareschi, although a summary of his research and its bearing on glaciology has been published by Godwin (1949). No studies other than those of Vareschi are known in the literature.

Pollen stratigraphy of the snow accumulated on Taku Glacier since the close of the 1951 ablation period was determined in conjunction with investigations of the physical characteristics of the snow cover. These latter studies were carried out by Mr. Edward R. LaChapelle of the 1952 party and constitute a record of density, ram resistance, cone hardness, grain size and type, and temperature (LaChapelle, 1954). Evaluation of the data gathered as a result of these joint studies should furnish a clearer understanding of the 1951-1952 budget year accumulation on Taku Glacier. In turn a more accurate calculation of the regimen of the glacier should be possible.

ACKNOWLEDGMENTS

Members of the 1952 party assisted with the digging of pits from which samples for study were obtained; George Argus, James Hickey, John Howe, and Fred Milan, all of the 1952 party, obtained the meteorological record and helped expose coated slides in the ice field; Arthur Gilkey, leader of the party, showed many courtesies and Edward LaChapelle assisted with the pollen downwash experiment; personnel of the U. S. Forest Service in Juneau gave invaluable aid, especially Alva W. Blackerby who exposed coated slides there; the U. S. Forest Service also made warehouse and transportation facilities available; the Tenth Air Rescue Group airlifted personnel and supplies; and John Heusser, my father, constructed the shelter assemblies used in collecting pollen and spores from the air. Laboratory work was conducted at Yale University in the Osborn Memorial Laboratories with the aid of the Theresa Seessel Fellowship.

PALYNOLOGY OF THE AIR

It was necessary to know the seasonal distribution of the various types of pollen and spores in the region of the Juneau Ice Field before an understanding of the pollen stratigraphy of the snow cover could be reached. Prior to conducting his studies on the glaciers in the Swiss Alps, Vareschi (Lüdi and Vareschi, 1936; Vareschi, 1940, 1942) obtained spectra for pollen in the atmosphere throughout the year. In the study presented here, stations were set up in Juneau and in the ice field, 16 miles above the terminus of Taku Glacier and at an elevation of 3875 feet (fig. 1). In addition the 1952 meteorologic record for the ice field was analyzed in relation to the spectrum for that locality.

METHODS

Microscope slides coated with stained glycerine gelatin mixture were exposed during the 1952 flowering period for continuous intervals at the research station in the ice field and on the roof of the Federal Building in Juneau. Stations are 25 miles apart and at a difference in altitude of ap-

proximately 3700 feet. Sufficient glycerine gelatin was applied to each clean slide so that when the mixture was spread out it provided a thin coating over an area that could be completely taken up by a 7/8-inch-square cover glass. The mixture was prepared by gently boiling 28 g of powdered gelatin, 4 g of crystallized phenol, 168 ml of glycerine, and 198 ml of distilled water for 10 minutes. A small amount of basic fuchsin dye was added to the mixture in order to provide a stain for the spores and pollen grains.

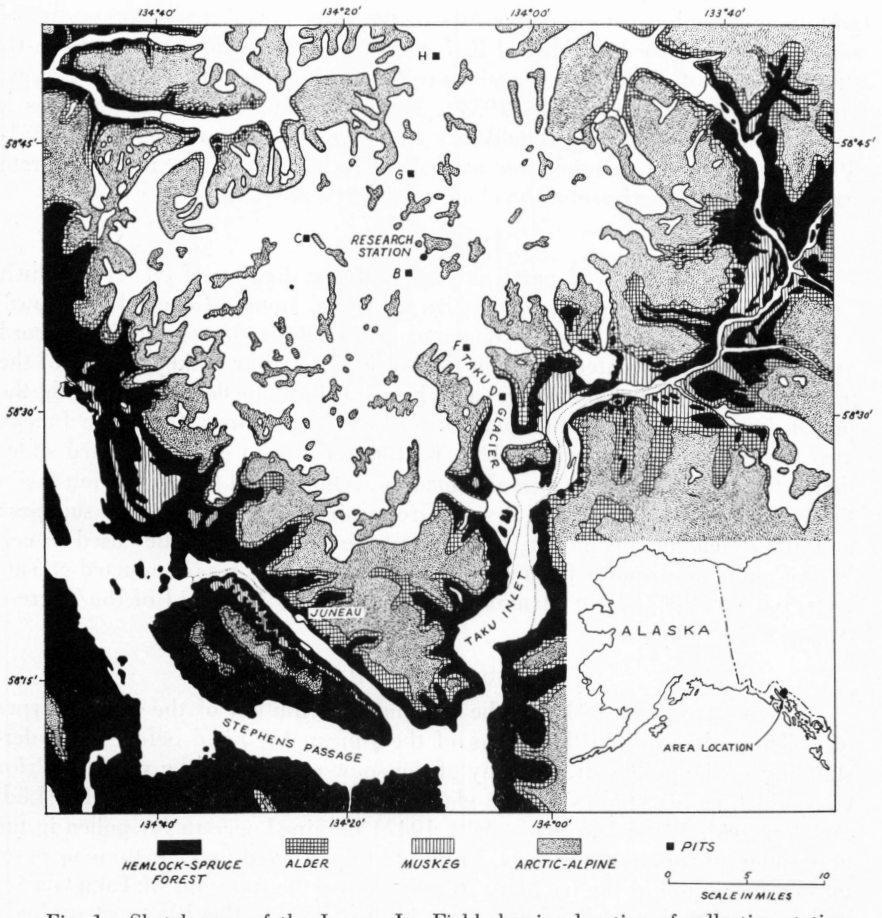

Fig. 1. Sketch map of the Juneau Ice Field showing location of collection stations, pit sites, and generalized distribution of vegetation types. Vegetation has been interpreted from vertical and trimetrogon aerial photographs on file at the American Geographical Society. Map based on that appearing in Geog. Rev., v. 40, p. 195.

Slides were horizontally exposed in shelters similar to that described by Wodehouse (1945). Shelters consisted of two circular aluminum shields, 10 inches in diameter, which were separated 4 inches apart, one above the other, by means of 1/2-inch wooden dowels. At the center of the upper side of the lower shield a grooved wooden block was fastened. The coated slides were

secured in the groove of the block by a fixed metal clip and the entire shelter assembly supported a few feet above the ground by means of an upright 1-inch wooden dowel. Both shelters used in this study were exposed to free air circulation on all sides but protected from vertically falling precipitation by the upper shield.

Exposed slides were replaced by freshly coated slides usually after exposure for a week. Large pieces of dust were removed with forceps and the slide warmed in order to melt the glycerine gelatin and also to drive off moisture which collected. A 7/8-inch-square cover glass was then carefully placed on the mixture. After cooling, slides so exposed were stored in commercial slide boxes which were placed upright in order to keep the slides horizontal. Under room temperatures the mixtures between the slide and the cover glass may run if the box is stored flat with the slides on edge.

Slides were examined in the laboratory, using a compound microscope equipped with a mechanical stage. The entire area of the cover glass was surveyed, and the number of each type spore and pollen grain was tabulated. Low magnification of 100 diameters was generally used to make the total count. A high magnification of 440 diameters was reserved for critical determinations and slides with a profusion of material. Each slide was investigated in this way and the area of the cover glass used as a basis for comparison. Fifteen slides were examined from the research station and represent a period of exposure from 24 May to 13 September. Twenty slides were studied from Juneau. These represent exposures from 15 May to 13 October.

SPECTRA

The schedule of pollination for Juneau may be essentially summarized as follows (fig. 2): (1) poplar (*Populus*) and "conifer complex" pollen (inaperturate grains) in spring, (2) spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and alder (*Alnus*) in late spring-early summer, (3) pine (*Pinus contorta*), mountain hemlock (*Tsuga mertensiana*), and grasses (Graminad) in summer, and (4) polypodiaceous ferns (Polypods) in late summer-early autumn. The spruce high during the latter interval (fig. 2) is discussed below. The sequence for the ice field is by and large similar (fig. 3): (1) spruce and western hemlock in late spring, (2) alder and birch (*Betula*) in early summer, (3) pine, mountain hemlock, and "conifer complex" pollen in summer, and (4) no late summer representatives in any significant amount. These data are incomplete as periods early and late in the year are absent. Spectra embracing an entire year would be most valuable in the interpretation of the palynology of the snow cover.

The three maxima for spruce on the Juneau slides in August, September, and October (fig. 2) are of interest since by the end of July flowering should have been completed over the altitudinal range of the tree. There are two possible explanations for this. The first is that pollen that had previously settled in the region became sufficiently reworked by wind to register the maxima. Pollen on the slides during these periods of higher counts does not appear fresh. Cells and bladders are commonly darkened and opaque. The periods indicated in figure 2 which preceded the maxima (18-25 August, 8-15

September, and 29 September-6 October) are all associated with high winds in Juneau (U. S. Department of Commerce, Weather Bureau, 1952).[1] A comparison of the sums (miles per hour) of the highest winds during these times with sums for the periods directly following the maxima shows a correlation. The sum for 18-25 August is 102 and for 25 August to 1 September, 100.

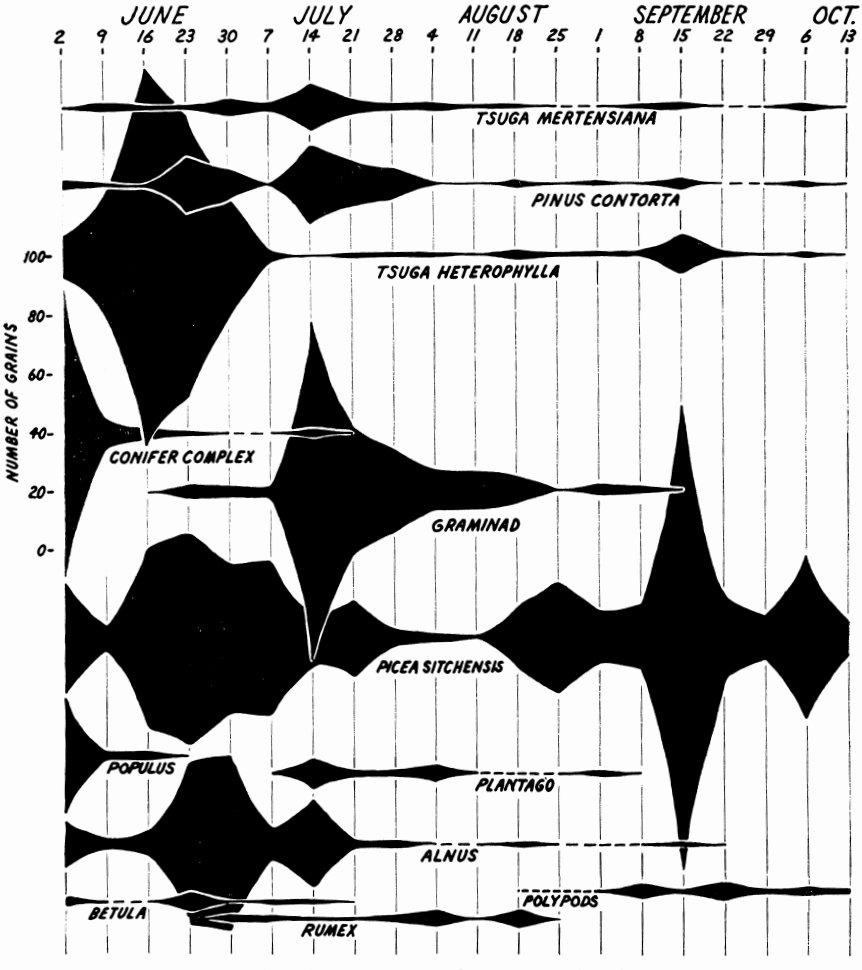

Fig. 2. Aerial spectrum for slides exposed in Juneau.

The amount falls to 79 for 1-8 September while for the period preceding the highest maximum, 8-15 September, it is 160. The amount again declines to 97 for the 15-22 September, but rises to 155 for the last maximum observed during the 29 September-6 October period. Since there is an increase of certain other species to coincide with the spruce maxima, high winds seem to be a logical explanation.

[1] Records are from the Juneau Airport, eight miles northwest of the city; no records are available for the Juneau pollen station.

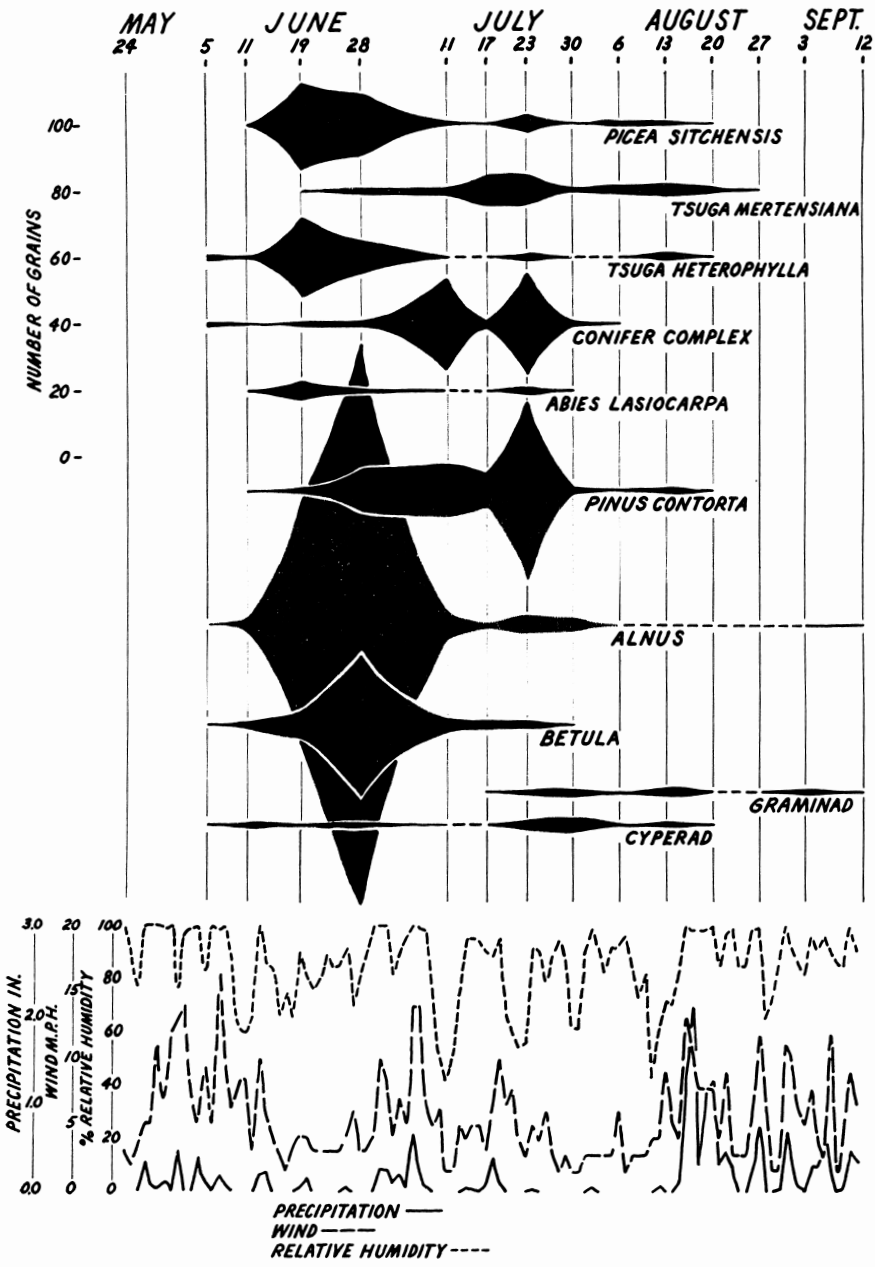

Fig. 3. Aerial spectrum for slides exposed at the research station in the ice field and record of precipitation, relative humidity, and wind for the corresponding period of exposure at the station. Prevailing wind and average relative humidity calculated from six scheduled observations per day at 0700, 1000, 1300, 1600, 1900, and 2200. Average wind from anemometer indicating total miles past station (read daily at 2200).

The second explanation is offered by Mr. Alva W. Blackerby of the Tongass National Forest in Juneau (personal communication). Millions of small moths of the spruce budworm were in the air during this storm period, and appreciable numbers were observed on the ice field. The wing of a moth was found on one slide during examination. These insects may act as a transporting agency under such conditions. High incidence of strong winds during times of maxima, however, is considered a more cogent factor, with the possibility of moths playing a role in transportation of secondary importance.

SIGNIFICANCE OF METEOROLOGIC FACTORS

An examination of the meteorologic record in figure 3 shows that precipitation, relative humidity, and wind were generally higher in late spring and late summer. Pollen was low in late spring, and it was not until 19 June that sufficient quantities were present in the air to be picked up on the slides. This pollen rise occurs following a decline in precipitation, relative humidity, and wind. The striking rise of alder on 28 June follows this interval of low wind and moisture. Alder had decreased by 11 July while wind and moisture had increased. Pollen grains were few for the period 11-17 July while relative humidity was generally high with wind and precipitation low for the same interval. Pollen increased on the slides during the subsequent exposure 17-23 July while there was less humidity and greater wind. With the increase of all three factors from about 13 August to the end of collection in September, very few grains were picked up.

Frequency of wind from a particular direction for given periods is diagrammed by polygons (fig. 4). Polygons are for individual monthly periods as well as for the accumulative record of the entire time of observation. Data for late May indicate a predominant southeasterly wind, and this continues to be the case for June. The prevailing directions for July and August are northwesterly and easterly with an increase of southeast wind in August. The polygon for the first half of September reveals a southeasterly direction for the most part. Examination of the polygon for the overall May to September period clearly shows the prevalence of wind from the east-southeast sector and from the northwest. Northerly and southerly directions have the lowest frequency of prevailing wind, and there is a low number of days with wind from the southwest. A moderate number of days is recorded with wind from the west and northeast. Wind at the research station is largely from British Columbia and the Taku River Valley to the east and southeast. Wind is also frequently from the Berners Bay drainage to the northwest. Winds seldom blow from the direction of Juneau.

This latter fact would explain certain differences between the Juneau and ice field spectra, such as in the amounts of grass, poplar, and birch pollen. It may also explain the absence of spruce pollen in the ice field during the latter half of the collection period when it was abundant in Juneau.

Since easterly and southeasterly winds are usually coincident with precipitation and storminess, while northwesterly winds are drier and fair, it is more likely that pollen reaching the ice field is derived from the northwest.

This would be from the border of the Coast Mountains along Lynn Canal. Also, since local meteorologic conditions will affect pollen settling, the pollen flora in the ice field will vary from one locality to the next and with the distance from the pollen source.

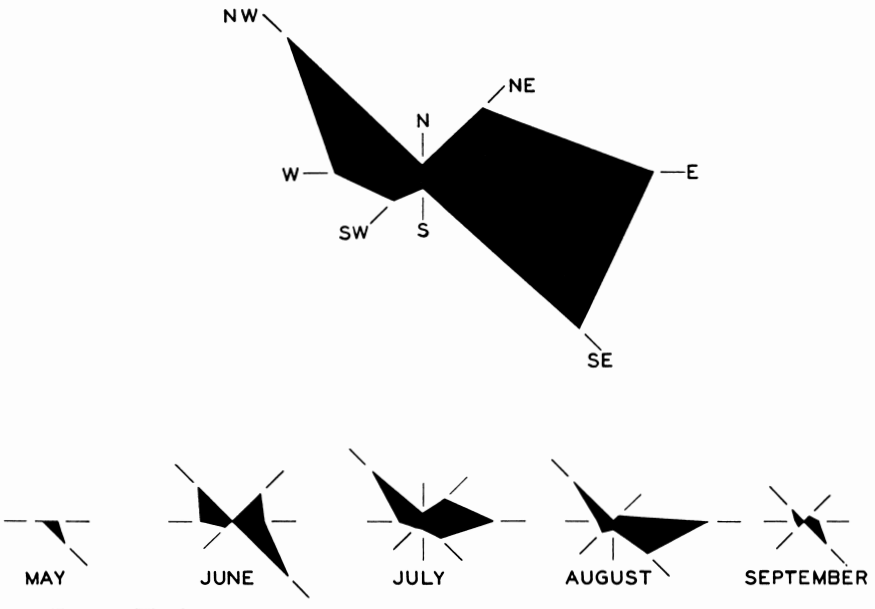

Fig. 4. Wind polygons for 111-day period of observation at the research station in the ice field. Total record is displayed above with individual monthly records as indicated. May and September polygons are partial as a result of fewer days of observation.

PALYNOLOGY OF THE SNOW COVER

Eight pits were studied on Taku Glacier. These were located between approximately 2000 feet on the lower glacier and 6000 feet near the Taku-Llewellyn Glaciers drainage divide (fig. 1). The distribution of these pits was made possible through the use of an M29c oversnow vehicle ("weasel") which greatly simplified the logistics involved in the operation. In this way 75 samples from pits ranging in depth from 9 dm to over 73 dm were gathered.

METHODS

Samples for analysis were obtained in stratigraphic sequence from the walls of pits dug through the snow cover into the underlying firn or ice. Samples were each approximately 1 cubic foot (27 dm^3) in volume and were collected in numbered steel and galvanized pails (2½ gallon size). Pails were washed as clean as possible under such conditions with clear meltwater. This wash water had been obtained by melting snow from a foot or so beneath the glacier surface, allowing the resulting water to settle out for 15-20 hours, and decanting off the sediment-free portion. A round-nosed, D-handle shovel was adequate for cutting out samples from the pit walls. In the deeper pits it was necessary to use a rope and in one instance, an improvised boatswain's chair.

Excavated samples from such deep pits were hauled to the surface with the aid of an assistant. The pails containing the samples were then heated over a Coleman "Handy Gas Plant" and the contents melted. Melting was usually carried on inside a tent where protection was offered from wind, rain, and snow. After the sample was melted, the pail was placed outside on the surface of the snow and covered by a tarpaulin in order to protect the sample from contamination by pollen falling from the air. Samples were then allowed to settle out for periods which depended upon the time available at each locality. The minimum time for settling in the pails was a period of 15 hours, and the maximum was 51 hours. Decanting followed this first settling-out period. The volume of meltwater was thereby reduced, and the residue was transferred to a liter beaker. The sediment settled in the beaker for a minimum of 14 hours and a maximum of 48 hours. The clear meltwater was again decanted. The volume of meltwater after this second decanting was sufficiently reduced so that the residue was poured into an 8-dram glass vial and corked.

Samples from the field were first treated with dilute hydrochloric acid in the laboratory. Considerable quantities of tiny metal flakes had peeled from the galvanized pails during melting of the samples and subsequent sedimentation. These particles had become mixed in almost all sediments and had to be removed. It is recommended in this regard that steel pails be used rather than galvanized ones. The former are more expensive but do not produce the metal flakes on heating. After hydrochloric acid treatment, the samples were centrifuged, washed by shaking in distilled water, and centrifuged again. Dilute potassium hydroxide solution was then added to the sediment in the centrifuge tube and the tube with its contents heated in boiling water for 10 minutes. The sample was subsequently poured hot through a wire mesh sieve in order to remove macroscopic particles. After allowing the sediment to settle for a few moments, the liquid with the smaller-size particles was decanted. Larger inorganics that had passed through the sieve remained behind in the tube. The decanted sample was then centrifuged, washed with distilled water tinted with gentian violet dye, and again centrifuged. Sediment in the centrifuge tube was transferred in a few drops of water to a clean microscope slide by means of a small pipette fitted with a rubber bulb. The slide was warmed on a hot plate at approximately 75°C. and the liquid evaporated to near dryness. Care was taken not to evaporate the material completely. A few drops of clear glycerine gelatin mixture were then added to the sediment, a 7/8-inch-square cover glass placed on the material, and the slide allowed to cool in a horizontal position.

Slides were examined under the compound microscope with the aid of a mechanical stage. High magnification of 440 diameters was used to make counts from pollen-rich samples, and low magnification of 100 diameters was used for material containing few pollen grains. When certain grains were encountered which required closer scrutiny, the 44x objective was swung into place for use with the 10x oculars. Each count was made for the entire area of the cover glass.

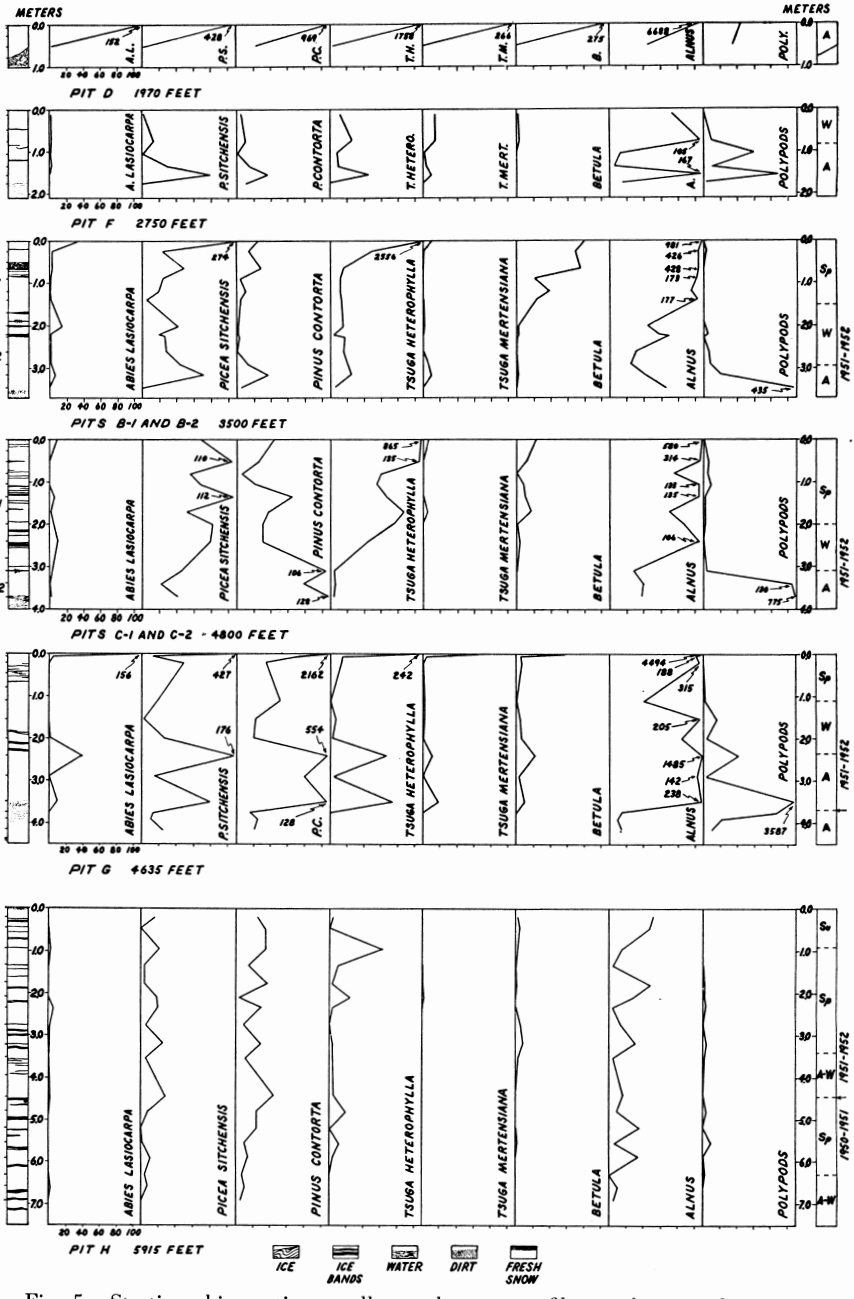

Fig. 5. Stratigraphic sections, pollen and spore profiles, and seasonal increments from pits dug in the Taku Glacier snow cover; A=autumn, W=winter, Sp=spring, and Su=summer; arrow indicates junction of 1951-1952 snow cover and underlying firn. Boundaries between seasonal increments should not be considered as fixed. Four digit and larger three digit figures are approximate and have been computed by sampling unit slide areas, obtaining an average, and multiplying this figure by total unit areas comprising the entire slide area.

SNOW COVER AND POLLEN STRATIGRAPHY

Pit D was dug 9 dm deep on 7 July and is the shallowest of all pits and lowest in elevation. Its location at 1970 feet near the tongue of Taku Glacier (7 miles from the terminus) and in the vicinity of the receding snow-ice line explains the shallow depth. No structures were encountered in the snow cover. The depth to the ice basement underlying the snow in the pit studied was quite irregular. Ice was coarse-grained and dirty. Five snow samples were taken, but three of these were lost in shipment from the ice field to the laboratory. Analyses for the remaining samples, however, are plotted in figure 5 and are interpreted to indicate autumn snow. Values at the surface are generally high, decreasing sharply at 5 dm. Fern spores show little change in number at the different levels. The number of alder grains counted (6688) from the surface sample is the highest for all samples of the entire study.

Pit F at 2750 feet and approximately 5 miles up-glacier from pit D was the next higher pit studied. Samples were collected on 9 July to a depth of 21 dm. The stratigraphic section (fig. 5) shows an ice band at 12 dm and a few stringers higher up. The interesting feature of the section is the englacial water table at 17.5 dm. Because of the difficulty involved in obtaining deeper samples and the considerable possibility of contamination, sampling was discontinued after penetrating the water layer to a depth of 3.5 dm. Unfortunately the surface sample and that from 4.5 dm were lost in shipment. Analysis of remaining samples discloses low numbers of grains for the wet snow at the base of the section studied. Above this there is a general increase in abundance, followed by a decline which in turn is followed by a general rise. The latter rise is well marked in alder, but does not show up in the ferns. This section is considered to consist of autumn and winter snow layers, spring snow having already ablated.

Pits B-1 and B-2 were excavated 5 miles up-glacier from pit F and were about 30 yards apart at an elevation of approximately 3500 feet. Pit B-1 was made on 26 June. It was the first pit dug of the series. Pit B-2 was made on 29 June. This latter pit was dug to extricate the oversnow vehicle which had been cached at the close of the 1951 season of the project and subsequently buried by snow. Pit B-2 was of considerable value since it served as a check for the amount of snow remaining above the 1951 annual ablation surface. The lower part of B-1 and the upper part of B-2 were correlated on the basis of depth and corresponding ice bands. Figure 5 shows the broken stratigraphic column to a depth of 37 dm with the portions contributed from each pit. The B-1 section contains a group of bands between the surface and a depth of 1 meter with one band a centimeter in thickness at 6.5 dm. Narrow bands wedge off at 8.5 and 17 dm. In the B-2 section a prominent 5 cm-thick band occurs at 22 dm with a centimeter-thick band at 20 dm. A dirt zone is conspicuous at the base of the column.

The conspicuous features of the profiles (fig. 5) are the abundance of fern spores in the basal dirt zone and the prominence of most species and genera in the upper levels with only a few fern spores. Analysis of the 5 cm band at 22 dm does not indicate any increase in grains by comparison to

levels immediately above or below the band. Snow in the section originated in autumn, winter, and spring. It is of interest to note that a *Pediastrum* colony was observed in the surface sample from pit B-1. Samples from 5 dm and 17 dm in the B pits were not at hand for analysis.

Pits C-1 and C-2 were excavated at 4790 feet at a distance of 7 miles to the northwest of the B pits. This locality is at the northern edge of the high plateau which drains westward, in part, to the Herbert and Mendenhall Glaciers (see fig. 1). Pit C-1 was excavated on 1 July and C-2 on 17 July. The 40 dm section in figure 5 is a composite of the two correlated columns for the individual pits. Numerous bands are distributed throughout the C-1 column with the following conspicuous: 1.5 cm at 21.5 dm, 1 cm at 24.5 dm, and 2 cm at 25 dm. No bands were observed in the C-2 pit. A dirt zone was encountered at 37 dm. Two centimeters of fresh snow fell during the excavation of pit C-1.

The presence of fern spores in abundance in the dirt zone of pit C-2 is similar to that in pit B-2. In addition, numerous pine grains are present. Alder, western hemlock, and Sitka spruce increase toward the upper levels of the profiles while pine decreases. Ferns also decline upward, although their decline is much sharper above the lower sampling levels with a few spores present thereon to the surface. Sixteen spores of club moss (Lycopods) and 22 grains of willow (*Salix*) were counted at the 37 dm level where high counts of fern spores were made. No data are available for the 2.5 dm and 28 dm levels. Autumn, winter, and spring increments are interpreted.

Pit G was located at 4635 feet, 8 miles northeast of the C pits, 7 miles north of the B pits, and 8 miles south of the Taku-Llewellyn Glaciers divide (fig. 1). Samples were collected from this pit on 12 July to a depth of 45 dm. The interface between clean and dirty sediments occurred at 35 dm (fig. 5). Dirt diminished beneath this level. A concentration of ice bands was present between the surface and a depth of 1 meter. A few bands were located just above 20 dm and a short distance below. No structures other than these were observed in the pit section studied.

Numbers of pollen grains and spores are relatively low for the two bottom samples. Fern spores increase sharply above these layers, although there is little change in the numbers of pollen. Ferns reach a maximum at 35 dm and subsequently decline while pollen shows an overall rise. Two layers with abundant pollen are evident at 24 dm and 35 dm. It should be noted that 55 spores of club moss, 13 willow grains, and 4 Compositae grains were found at the 35 dm level, whereas none of these occur at 24 dm. Above these levels profiles generally record a decline followed by a rise with maximum numbers at the surface. Fern spores were absent above 11 dm. Thirty-five caryophyllaceous grains were counted from the surface sample. These were not encountered in such a high number in all samples from the pits studied. The 4.5 and 8 dm levels were not counted. Autumn, winter, and spring layers are depicted.

The final pit H was located at 5915 feet close to the Alaska-British Columbia boundary and near the crest between Taku and Llewellyn drainage. This

is approximately 7 miles north of pit G. Pit H was the deepest pit dug and reached to a depth of 73.2 dm on 14 July. Numerous bands are distributed throughout the section with outstanding ice layers at 45 dm (2.5 cm thick) and at 50 dm (5 cm thick). Elsewhere bands are no more than a centimeter in thickness. Throughout the section no dirt level or zone was noted which could be designated as the position of the old annual ablation surface beneath new snow accumulation.

Spores and pollen grains are relatively few in this section, and no count was made higher than 63 grains for any pollen at any horizon. Alder and western hemlock show maxima in the first meter and are prominent in the second meter. Maxima for pine and spruce are at the 44.4 dm level. These pollen decline below 44.4 dm, whereas western hemlock registers a small rise, and alder is most abundant with two notable peaks. Birch and ferns are sporadic in the section and show no specific trends. Mountain hemlock is barely represented. Data for the 39.6 dm and surface levels are unfortunately missing.

The 1951-1952 snow cover above 44.4 dm is interpreted on the basis of pollen content to consist of autumn-winter, spring, and summer increments. Spring and winter layers are below 44.4 dm. It should be noted that the ram penetrometer and density studies made by Mr. LaChapelle at this site indicated the position of the old 1951 ablation surface to be at approximately 54 dm. This conclusion was drawn on the evidence of an increase in average ram resistance (snow hardness) at 52 dm and an increase in density at about 53 dm.

PROBLEM OF POLLEN AND SPORE DOWNWASH

Vareschi (1937) demonstrated that downwash does not occur from upper to lower layers. This conclusion was reached in the study of a section from the Swiss Claridenfirn. Samples from two levels a decimeter apart showed the upper sample to contain over 36,000 grains, whereas the lower contained only a single grain. The upper pollen-rich sample was obtained from a level which was interpreted to represent four years of accumulation which had been reduced to a single horizon as a result of excessive ablation. A large quantity of yellowish dirt denoted the upper level, and meltwater had caused some of the dirt to be carried downward to stain the area where the lower sample had been obtained. It would be thought that such meltwater movement would affect pollen grains and spores as well as dirt particles. Evidently such was not the case, and the fine fissures between crystals differentially separated the inorganics and the pollen. Vareschi found that the particles that had moved were only 2-3 mu whereas pollen in the upper layer was 16-140 mu.

A downwash experiment was carried out on Taku Glacier. Two funnel-type meltwater pans previously described by Leighton (1952) were secured in the roof of two niches recessed in the wall of a pit dug in the glacier at 3500 feet in elevation. Pans were situated at the 6 dm and 150 dm levels with the edge of each about half a meter from the face of the pit wall. Meltwater from the pans was directed by means of rubber tubing into covered pails placed below each pan. The experiment was conducted for a week. Results for the

lower pan are: 2 grains of spruce, 2 grains of pine, and 1 grain of western hemlock. Rapid ablation of the glacier surface during this period caused the upper pan to dislodge before any sample could be obtained.

This experiment is admittedly inconclusive, although the presence of five conifer grains would suggest that a certain amount of downwash occurred. It may be noted that these grains varied in size between approximately 60 and 90 mu, and no small-sized grains such as those of alder or birch were observed. It is possible that the grains counted represent contamination. Of interest is the analysis of the 5 cm ice band from 22 dm in pit B-2 (fig. 5). A lower number of grains is present in the band by comparison to samples analyzed from above or below. If meltwater carries pollen downward, it would be expected that grains would become concentrated in the band since the band probably represents a winter ablation surface which became thickened by spring meltwater freezing at depth. Such pollen concentration, however, was not found.

The profiles in figure 5 show examples somewhat similar to the situation described by Vareschi. Pit G at the 35 dm level contained 3587 fern spores, but 2.5 dm below only 87 spores were counted. Similarly striking are the numbers of alder and pine grains between the surface and 0.5 dm. Pine and alder at the surface are respectively 2162 and 4494 grains; at 0.5 dm these numbers decline to a corresponding 76 and 188. Surface samples may not represent a valid case since they were from snow which was not subjected to melting and percolation for so long a period as samples at depth. Samples from the surface and 0.5 dm below were collected on 12 July, approximately two weeks after alder had reached its peak (see fig. 3). This length of time should be ample for downwash to occur, although the sharp difference between numbers at the two levels suggests that little or none had taken place.

Analysis of the data given by Vareschi in this regard and those reported here would indicate that the percolation of pollen and spores in meltwater does not generally take place. Under certain conditions there may be some infiltration downward. The size of interstices between crystals is probably the most important limiting factor.

DISCUSSION

The superposition of seasonal snow and its demarcation by means of pollen and spore content form the foundation for the interpretation of the annual accumulation. Aerial spectra, however, lack winter, early spring, and late autumn aspects. The presence of certain pollen and spores throughout the accumulation then suggests that: (1) these never cease settling from the air during the year, and/or (2) there is downward movement of the microfossils in percolating meltwater.

An examination of the aerial spectrum presented by Vareschi (1942) discloses that the period of pollen settling is much more extensive than the period of pollen production (dispersal). Particular pollen such as that of pine and alder was observed to settle from the atmosphere throughout the year, although production occurred during only three to four months. This fact would imply that it is probable that pollen falls on the Juneau Ice Field

over the entire year. It is otherwise difficult to explain the large numbers of pollen in so many layers of the snow cover. It has been pointed out that downwash of grains does not generally take place. With this information in mind, the pollen and spores in figure 5 were interpreted to be representative of the layer in which they occur. There was then little or no translocation from the position where they were originally incorporated in the snow cover.

Pertinent in this regard is the pollen rise in the 1951 autumn layer in pit G (fig. 5). It would seem that a spring-summer period were depicted. The abundance of fern spores, however, intimate that this is not the situation. Ferns sporulate during late summer and autumn (fig. 2). These spores and the winter low in the overlayer establish the snow as autumnal. Further, comparisons with profiles from nearby pits help confirm this conclusion. The presence of large amounts of pollen in the autumn snow may be a result of high winds which effected the reworking of previously settled pollen. This condition was evident in the late summer and early autumn of 1952 as shown in the aerial spectrum for Juneau (fig. 2).

The quantity and type of pollen and spores settling out of the air in different parts of the ice field over the time of sampling are variable. This can be seen from surface samples taken at the pit sites (fig. 5). Pollen dispersal is dependent on wind and moisture. Also, collections were made from 26 June to 17 July during which period the quantity of different pollen types in the air changed (fig. 3).

Depths to the 1951 ablation surface in the pits studied increase with altitude. A comparison of the sections from pit D at the lowest elevation to pit H at the highest shows a progressive increase in the amount of accumulation. Pit D had only autumn snow remaining when samples were collected. Winter and spring layers had previously ablated. The next higher pit F was dug from autumn and winter snow, and no spring snow remained. Pits B-1 and B-2 which are higher in elevation contain autumn, winter, and spring snow. The low counts for the dirt zones in pits B and C indicate that only the upper portion of the zones was reached. Pit H contains the greatest amount of accumulation. This is the only pit with summer snow.

The different depths of seasonal snow reflect local meteorologic factors affecting snowfall and ablation. Precipitation which varies over the ice field and down-glacier winds and eddying currents which cause the formation of drifts and wind-scoops determine the accumulation. In addition, compaction influences the seasonal amount of snow. Pits C-1 and H have larger amounts of spring snow whereas pits B-1, B-2, and G have equal amounts of autumn, winter, and spring snow. Pits C and H have more spring accumulation as a result of less ablation and/or greater spring snowfall.

The designation of the 1951 ablation surface for pit H at 44.4 dm does not agree with the 53.5 dm depth arrived at as a result of analyzing the data on density and snow hardness (LaChapelle, 1954). The reason for this lack of accordance is not clearly understood. The maxima for spruce and pine at the 44.4 dm level are the basis for concluding that the annual surface rests at this level. Peaks for alder below this depth are interpreted as spring 1951 and are comparable to the peaks for spring 1952 in the upper part of the

profile. Assuming the 53.5 dm level to be the 1951 ablation surface, there is little in terms of pollen evidence to agree with this. A possible explanation for the 9 dm discrepancy is that degeneration occurred to almost a meter below the pollen-interpreted 1951 ablation surface. Density and snow hardness figures are lower in the layers immediately below this horizon. The 1951 ablation was more pronounced than in previous years of the project or in 1952, and it is likely that degeneration occurred to a greater depth than usual. Of significance in this discussion are the density profiles given by Sharp (1951b) for the firn of upper Seward Glacier, Canada. Density values in the vicinity of the annual dirty layer decrease conspicuously. Although these values generally increase with overall depth, they decrease when the annual dirty layers are reached. If this explanation is correct, then the change in physical characteristics which occurred at the 53.5 dm level occurred in spring sediments.

As stated previously, the studies presented here are experimental and are subject to human and technical errors. In that they are also introductory, it is anticipated that future work may resolve these errors and overcome certain shortcomings that are not yet apparent. Certain features of the technique such as the amount of pollen downwash are not fully understood. Moreover, the palynology of the air needs greater understanding before a thorough interpretation of the annual accumulation can be made. Eventual clarification of these problems will allow a more precise evaluation of the palynology of the glacier snow cover and its relation to regimen studies.

References

Ahlmann, H. Wilhelmsson, 1948, Glaciological research on the North Atlantic coasts: Royal Geog. Soc., Research Ser. 1.

————, 1953, Glacier variations and climatic fluctuations: New York, American Geographical Society.

Godwin, H., 1949, Pollen analysis of glaciers in special relation to the formation of various types of glacier bands: Jour. Glaciology, v. 1, p. 325-329.

LaChapelle, E. R., 1954, Snow studies on the Juneau Ice Field: New York, American Geographical Society.

Leighton, F. B., 1952, Investigations in the Taku Glacier firn. *In* Scientific observations of the Juneau Ice Field Research Project, Alaska, 1949 season: New York, American Geographical Society, p. 23-48.

Lüdi, W., and Vareschi, V., 1936, Die Verbreitung das Blühen und der Pollenniederschlag der Heufieberpflanzen im Hochtale von Davos: Geobot. Forschungsinst. Rübel in Zürich, Ber., 1935, Zürich.

Sharp, R. P., 1951a, Accumulation and ablation on the Seward-Malaspina glacier system, Canada-Alaska: Geol. Soc. America Bull., v. 62, p. 725-744.

————, 1951b, Features of the firn on upper Seward Glacier, St. Elias Mountains, Canada: Jour. Geology, v. 59, p. 599-621.

U. S. Dept. Commerce, Weather Bureau, 1952, Monthly climatological summary, Juneau, Alaska (airport) for May, June, July, and August; Local climatological data, Juneau, Alaska (airport) for September and October: Washington, Govt. Print. Office.

Vareschi, V., 1935a, Pollenanalysen aus Gletschereis: Geobot. Forschungsinst. Rübel in Zürich, Ber., 1934, Zürich.

————, 1935b, Blütenpollen im Gletschereis: Zeitschr. Gletscherkunde, Band 23, p. 255-276.

————, 1937, Prüfung der neuen pollenanalytischen Methode der Gletscherforschung an Hand eines Firnprofils von bekannter Entstehungszeit: Zeitschr. Gletscherkunde, Band 25, p. 17-35.

————, 1940, Pollenniederschlag in den Hochalpen: Zeitschr. die gesamte Naturwissenschaft, Heft 3/4, p. 62-74.

————, 1942, Die pollenanalytische Untersuchung der Gletscherbewegung mit besonderer Berücksichtigung der Verhältnisse am Grossen Aletschgletscher (Wallis, Schweiz) und Ergänzungen von Gepatschferner (Ötztalergruppe, Tirol): Geobot. Inst. Rübel in Zürich, Veröffent. Heft 19, Hans Huber, Bern.

Wodehouse, R. P., 1945, Hayfever plants: Waltham, Mass., Chronica Botanica Co.

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