[From American Journal of Science, Vol. 247, Dec., 1949, Pp. 833-855]

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American Journal of Science

DECEMBER 1949

A PRE-WISCONSIN FOREST SUCCESSION IN THE PUGET LOWLAND, WASHINGTON[1]

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Presented before the Ecological Society of America, AAAS Meeting, Vancouver, B.C., June 1949.

ABSTRACT. Pollen profiles from existing peat bogs in the Puget Lowland provide a clear picture of forest successions and climatic changes from the time of retreat of Wisconsin ice to the present. This paper applies the pollen analysis technique in a study of compacted peat layers and peaty clays that make up part of one stratigraphic unit in a complex sequence of pre-Wisconsin Pleistocene deposits that underlie the central part of the Lowland. While there are some nondepositional or erosional gaps, the forest succession as reflected in the pollen profiles indicates that the unit represents an interglacial age, including a phase of ice recession, a climatic optimum comparable with the present, and the readvance of ice of the next glacial age. These conclusions are based on samples collected from only one composite section and are therefore tentative, but the results indicate that pollen analysis will be a valuable tool in working out the pre-Wisconsin Pleistocene stratigraphy in the Puget Lowland.

INTRODUCTION

THE principal topographic elements of the central part of the Puget Lowland are north-south trending drumloidal hills and intervening troughs occupied by the branches of Puget Sound. The drumloids are veneered by the Vashon (Wisconsin) till sheet; their cores consist of flat-bedded gravels, sands, and clays, with intercalated layers of peat and lenses of till, comprising the "Admiralty sediments." Bretz (1913), following Willis (1898) in part, concluded from these and other relationships (1) that the Admiralty sediments were deposited chiefly during recession of the Admiralty glacier, (2) that the aggradational plain so formed was trenched by streams during an interglacial age, and (3) that this interglacial hill and valley topography was modified into the present trough-

[1] The first author is grateful to the John Simon Guggenheim Memorial Foundation for a fellowship during the year 1947-48, which enabled him to devote his time to research, and to the American Philosophical Society, and the General Research Council of Oregon State College for grants to defray laboratory and field expenses.

drumloid topography by the Vashon glacier during Wisconsin time.

A general restudy of the glacial geology of the Puget area now in progress (Mackin, 1941) indicates that at least two pre-Wisconsin drift sheets are separable in southern drift border areas on the basis of weathering contrasts and other conventional mapping criteria. The Admiralty sediments that underlie the Vashon till in the central part of the Lowland also include deposits of more than one pre-Wisconsin age, but the conventional methods are not applicable because such weathered mantles as may have formed during interglacials have been destroyed in process of emplacement of later till sheets; subdivision of the Admiralty sediments is essentially a stratigraphic problem with no good basis for assigning time values to the disconformities that occur within the sequence. A closely related and equally serious difficulty has been a lack of evidence as to the climatic conditions that prevailed during the deposition of Admiralty lithologic units other than till sheets, that is, to whether a given sedimentary unit was deposited in immediate proximity to glaciers, or during a period of advance or retreat, or during a warm interglacial.

Pollen profiles of sections from existing peat bogs throughout the Puget Lowland provide a clear picture of the major trends of forest succession during late glacial and recent time (Hansen, 1947a). In this postglacial sequence, the base of the peat marks the time of withdrawal of the ice, and the top of the living bog is the present, so the duration of the period of accumulation of the peat section is therefore reasonably well known. Forest succession indicated by the pollen profiles can be correlated with other kinds of data on a regional scale and furnish an excellent record of postglacial climatic trends and the many other factors, such as fire and varying physiographic conditions from place to place, that influence the normal forest development from pioneering types to climax types.

It is evident that the pollen analysis technique, applied to the compacted peats and peaty clays that occur in the Admiralty sediments, may furnish answers to some of the pre-Wisconsin glacio-stratigraphic questions outlined above, and that the mass of data bearing on postglacial forest development provides a sound basis for interpreting pre-Wisconsin forest successions in the same area. This paper illustrates the use of pollen counts in a study of a composite section of an Admiralty stratigraphic unit that apparently represents an interglacial age, including a phase of ice recession, a climatic optimum more or less comparable to the present, and the re-advance of the ice of the next glacial stage. Microscopic work and inferences as to forest types, climatic conditions and duration of the interglacial are by Hansen. Discussion of field relations, by Mackin, is confined to the sections sampled in the course of this joint study.

DESCRIPTION OF THE EVERETT GORGE SECTION

The Everett Gorge Section is exposed in the sides of a narrow "inner valley" cut within the last 25 years by waste water from an Everett reservoir (SW¼, Sec. 30, T. 29 N., R. 5 E.; see Everett quadrangle). The Gorge is essentially vertical walled, about 1,000 feet long, and with a maximum depth of about 125 feet. Sets of samples A to D (fig. 1) were taken with the aid of ropes and ladders from different parts of the walls, such that the top of a lower unit sampled downstream (as A), is traceable by eye to the base of the next higher unit (as B) sampled upstream. Because pollen grains are not well preserved in oxidized sand and gravel, only the silt and clay layers were sampled. Each sample represents a segment of a continuous channel picked into the cliff face far enough to eliminate the possibility of contamination by surface wash. Figure 1 shows the succession of beds and the order in which the samples are numbered.

All of the coarser sediments are strongly oxidized; open-textured gravels are deep red-brown in color and sands are tan and brown. Silts and clays are generally dark gray with shades of brown due to the presence of organic matter rather than to oxidization of iron. Oxidation effects are uniform throughout the thickness of the gravel layers and penetrate a few inches to a foot into overlying and underlying silty clays, these relations suggesting pre-gorge conditions when the gravels carried ground water under pressure in contrast to present conditions under which seepage is usually confined to the lower few inches of each gravel layer. The significant point is that oxidation varies directly with permeability and is clearly due to circulation of subsurface water; the alternation of oxidized sand-gravel layers and unoxidized silt-clay layers does not indicate lapses of time during deposition of the sequence.

The lower part of the section (units A and B) consists predominantly of dark gray and brown silty clays with which are interbedded sheets and lenses of well sorted gravel five to ten feet in thickness, with average larger pebble sizes to two inches. Thick layers of cross-bedded sand are notably absent. Interbedding of the gravel and the silty clays certainly does not mean changes in depth of water or other regional conditions of deposition. The silty clays are overbank deposits, formed in floodplain lakes and swamps, and represent the finer fractions of the suspended loads of through-flowing streams. The gravels are the channel deposits of the same streams, and represent the coarsest fractions of their bed loads.

The general picture suggested by the lower part of the Everett Gorge section is that of very slow aggradation by meandering streams flanked by floodplain lakes and swamps in which the silty clays and peats were laid down. The fact that this part of the section consists dominantly of overbank materials, and only in small part of channel gravels, indicates that the rate of lateral shifting of the streams was slow relative to the overall rate of upbuilding of the aggradational plain (Mackin, 1948, p. 502-3). It is important, in this connection, to note that the gravel lenses occupy channels cut in the finer-textured sediments, and that there is no way to determine the thicknesses of silty clay and peat that were scoured away by laterally shifting meanders during the period of deposition. There is, in other words, no geologic basis for assigning time values to the discomformities at the base of each channel gravel sheet, and it is therefore evident that estimates of rates of deposition of the silty clay and peat now seen in gorge walls can provide only a minimum figure for the duration of the period of time represented by the sequence.

The upper part of the section, particularly above C 53, is composed largely of coarse, cross-bedded sand with scattered small pebbles, probably representing channel deposits of streams of braided habit (fig. 1). The marked decrease in grain size from the channel gravels in the lower part of the section does not indicate a decrease in size of rock fragments supplied to the streams at their sources; it suggests, rather, that under changed conditions of rapid aggradation, the boulder and pebble fraction of the stream loads were being selectively deposited in aggradational fills farther "upstream," so that only the sand fractions reached the Everett locality (Mackin, 1948, p. 505-6). Similarly, the fact that laminated clays and silts, which predominate below, make up only a small part of the upper deposits is probably due to rapid lateral shifting of the braided channels as contrasted with relatively stable channel conditions that prevailed during accumulation of the lower part of the section.

An indirect line of evidence bears on the reason for the change in type of sedimentation during the deposition of the Everett section. Overbank silts and clays in the transitional part of the sequence (the C unit) are described as "fibrous" in the columnar section because, where they are exposed to the gentle washing action of the present stream, they carry a dark brown "hairy" coating made up of partly oxidized shreds of woody material. Similar woody fluff accumulates on screens used in sizing certain Puget tills deposited by glaciers that were, in the immediate vicinity, advancing through forests. The presence of macerated logs in and under these till sheets indicates that the fluff is, so to speak, the woody equivalent of rock flour. Its occurrence, together with numerous abraded wood slabs and rounded knots, in the silts and clays in the transitional part of the Everett section, and the absence of these materials in the lower part of the section, suggests that the change from stability or very slow aggradation by meandering streams to rapid aggradation by braided streams was due to advance of glaciers into the drainage basins of these streams.

DESCRIPTION OF THE POSSESSION POINT SECTION

It is virtually certain, on the basis of relationships in the Admiralty sediments elsewhere in the Puget Lowland, that the sequence exposed in the Everett Gorge is underlain at some depth by a till sheet marking the base of the major pre-Wisconsin depositional unit of which the Everett Gorge beds are a part, and it is evident that sampling for pollen analysis should, if possible, extend downward to the till. The lowest exposures in the Gorge are about 95 feet above sea level. Clays, silts, and gravels are encountered in pits and hill slope trenches at lower levels, but all of the lower valley sides and wave-cut cliffs in the vicinity are so heavily covered by creep material, landslide debris and/or Vashon till that no continuous section is available (absence of exposures at and just above sea level is

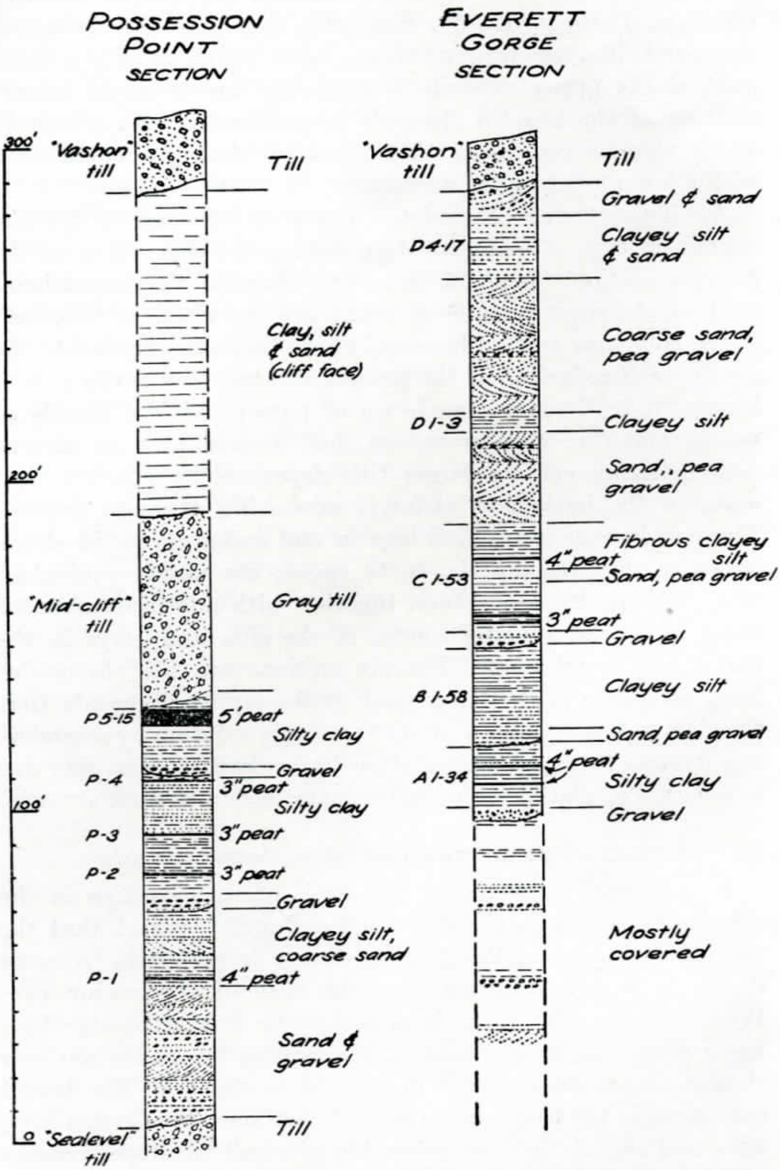

Fig. 1. Diagram of Possession Point and Everett sections showing sequence of sediments as discussed by Mackin and interbedded peats and pollen-bearing clays and silts that were analyzed for pollen.

due chiefly to a railway embankment that follows the shoreline and has checked wave erosion along the east side of Puget Sound). The nearest continuous section seen in reconnaissance is at Possession Point, a fresh-wave-cut cliff at the south end of Whidby Island, about nine miles west-southwest of the Everett locality.

The Possession Point exposures show a till at sea level, overlain by poorly sorted sand and gravel with ice shove and slump structures. These outwash materials grade upward between 50 feet and 75 feet above sea level into dark gray and brown peat-bearing silty clays with lenses of stained gravel identical in appearance with the lower part of the Everett Gorge section (fig. 1). Samples P 1 to P 4 represent thin peat layers occurring 50 to 110 feet above sea level; samples P 5 to P 15 were taken from a 5-foot bed of massive peat at 125-136 feet above sea level. The thick peat layer is overlain, with undulating, ice-scoured contact, by dense gray till (hereafter, the "Mid-cliff till") to 180-190 feet, laminated blue clay, silt and sand to about 290 feet, and Vashon till to the top of the cliff exposures at about 329 feet (fig. 1).

Similarity in lithology, and the general correspondence in elevation above sea level, indicate that the peat-bearing sediments below the "Mid-cliff till" at Possession Point probably correlate with and predate in part the lowermost (A and B) sediments in the Everett Gorge section (fig. 1). Exposures of peat-bearing silty clays with stained channel gravels at the same general elevations in sea cliffs and artificial excavations between the two localities tend to confirm the correlation and to indicate that the unit was formerly continuous throughout this portion of the Puget Lowland. The fact that individual beds of peat, clay, and gravel are lenses, nested in cut and fill arrangement, means that precise elevations above sea level has little significance concerning bed-by-bed correlation between the Everett and Possession sections.

GEOLOGIC INTERPRETATION OF THE EVERETT GORGE-POSSESSION POINT SECTION

The composite section based on this tentative correlation is divisible into three parts for purposes of discussion: (1) the "sea-level till" at Possession Point with overlying poorly sorted sand and gravel grading upward at 50-75 feet above sea level into peat-bearing silty clay with well-sorted channel gravel, indicating recession of a glacier from the central part of the Puget Lowland, (2) the peat-bearing silty clays and gravels between about 75 and 130 feet above sea level at Possession Point, and between 95 and 150 feet above sea level in the Everett Gorge, indicating floodplain sedimentation under conditions of physiographic stability, and (3) the coarse, cross-bedded sands between 150 feet and the top of the Everett Gorge section, indicating aggradation by braided streams, probably proglacial. Segments (1) and (3) consist of coarse clastic sediments that could have been deposited within a few tens or hundreds of years. The fine-textured clastic and organic sediments comprising segment (2) doubtless represent a much longer period of time, perhaps of the order of one thousand to several thousand years as a minimum. The point, mentioned earlier, that needs emphasis here is that neither the Everett nor Possession Point section is a continuous depositional sequence, and that there is no geologic basis for estimating the time values of the disconformities that occur at the base of each channel gravel sheet. Similarly, the geologic evidence proves only that the central part of the Puget Lowland was free of ice when the sediments of segment (2) were laid down; there is no basis for conclusion as to climatic conditions. It is therefore uncertain, on the basis of the geologic relations alone, whether the Everett-Possession section represents (a) a major interglacial age, or (b) a minor recession and readvance of ice during a glacial age (Willis, 1898, p. 150; Bretz, 1913, p. 174).

AGE OF THE EVERETT GORGE-POSSESSION POINT SECTION

The position of the Everett Gorge-Possession Point stratigraphic unit in the Pleistocene succession in the Puget Lowland is problematic and is not critical for present purposes, but evidence bearing on this aspect of the case needs to be outlined if only to eliminate a misunderstanding:—

If only the section in the immediate vicinity of the Everett Gorge were considered, the inclination would be to identify the advancing glacier suggested by the cross-bedded sand in the upper part of the Gorge section with the Vashon till that caps the sequence. But the flat-lying sediments at Everett and Possession Point form part of the cores of drumloidal hills that are veneered by Vashon till, not only on the top but also on the flanks, and the till sheet doubtless continues under the Puget trough that separates the two localities. As indicated in the introduction, this relationship supports Bretz' view to the effect that there was probably a considerable interval of time and more or less extensive stream valley cutting between deposition of the sediments and emplacement of the Vashon till that rests unconformably on them. The "Mid-cliff till" and overlying glacio-lacustrine sediment at Possession Point are beneath this unconformity.

Wherever the peat-bearing sediments are being eroded by waves or rivers at the present time, the beach and stream gravels include rounded boulders of compacted peat. The high degree of compaction is believed to be due, not to the thin mantle of sediments that rest on the peat layers, but to the weight of several thousand feet of ice that has covered the area subsequent to the deposition of the peat. It is therefore significant that, wherever the Vashon till sheet rests on peat-bearing phases of the sediments, it includes boulders and subrounded slabs of peat that evidently were, when incorporated in the till, quite as compact as at the present time. The "Mid-cliff till" at Possession Point, on the other hand, is locally discolored and contaminated by the same peaty materials where it rests on them, but the till contains no fragments of compacted peat. The implication is that the "Mid-cliff till" was formed during the glacial age that immediately followed the deposition of the peat-bearing sediments, and that the Vashon till, which overlies the "Mid-cliff till" unconformably, was formed during a glacial age, after the peat beds had been thoroughly compacted. It follows that if the "Mid-cliff till" ever covered the Everett locality, it was removed by erosion previous to emplacement of the Vashon till.

These relations, taken together, indicate that the Everett Gorge-Possession Point peat-bearing sediments could not have been formed during the interglacial immediately preceding the Vashon (Wisconsin) glacial age, but most date from a time earlier in the Pleistocene history of the Puget Lowland.

METHODS AND TECHNIC

Samples were taken from the exposures at 6-inch intervals from the clay and silt strata and other inorganic layers that seemed promising for pollen analysis. At least one sample was taken from the thin peat laminae, and if the peat layer was 3 or more inches thick, several samples were taken. Much of the clay-silt strata was brownish in color due to the amount of organic material present. Samples for pollen analysis were made up for foot intervals in the clay-silt layers, but in the peat and more organic-bearing strata, all samples were prepared and analyzed. Samples were taken at 6-inch intervals in the upper Possession Point peat stratum and all of them were analyzed for pollen. Samples in the D series in the upper part of the Everett section were also prepared and studied, but few pollen grains were present, and its pollen profiles are omitted. Likewise, levels 1 to 10 and 13 to 26 in the A series were found to have insufficient pollen to use for interpretation. The pollen profiles for the B and C series, however, represent largely consecutive 1-foot horizons with the exception of a few at closer intervals in the thicker peat layers. The greatest intervals between the pollen profile horizons occur in the lower Possession Point strata, where they may be as much as 30 feet. Actually the pollen profiles represent some 150 feet of sediments (fig. 1).

In the preparation of the sediments for pollen analysis, those containing a high fraction of inorganic matter were treated with commercial hydrofluoric acid to remove at least the siliceous elements. This tended to concentrate the limited number of pollen grains where necessary, and also made identification easier. Samples of the pollen-bearing silts and clays were first agitated vigorously in water, then washed and decanted several times to remove the coarser particles. About 4 cc. of the remaining residue was immersed in hydrofluoric acid to a depth of 2 inches in a paraffin-coated paper cup. The samples were left in the acid for several days, the length of time depending upon the amount of silt present, and then washed until all traces of the acid were removed. The remaining residue, now brown as a result of the concentration of the organic material, was boiled for 10 minutes in a weak potassium hydrate solution with a few drops of gentian violet stain. If all of the acid was not removed, the gentian violet turned green and did not seem to stain the pollen grains. The residue was then washed through a fine-mesh tea strainer, centrifuged, and mounted in warm glycerin jelly. The brown peat was not treated with hydrofluoric acid, but a stronger solution of potassium hydrate was used and it was necessary to boil the sample for at least 20 minutes in order to effect deflocculation. An enormous amount of pollen was present in the peat strata, probably as a result of the compaction caused by the overlying sediments. The weight of the overlying sediments, however, apparently caused many of the pollen grains to be crushed and broken, which may have been augmented by the rigorous treatment in the preparation of the samples for microscopic analysis.

One hundred or more pollen grains were identified from each level represented in the pollen diagrams. Pollen of lodgepole pine (*Pinus contorta*) and western white pine (*P. monticola*) were separated by the size-range method (Hansen, 1947a). Mountain hemlock (*Tsuga mertensiana*) pollen was readily separated from that of western hemlock (*T. heterophylla*) by the presence of air bladders on the former. Pollen of Douglas fir (*Pseudotsuga taxifolia*) is distinct from that of any other forest tree in the Pacific Northwest and offers no difficulty in its identification, even when broken. An attempt was made to separate the species of *Abies* by the size range method, but as there is considerable overlap in their size ranges, and so many of the grains were broken, only subalpine fir (*A. lasiocarpa*) was separated with a feeling of any degree of accuracy. The other fir pollen could conceivably represent grand fir (*A. grandis*), silver fir (*A. amabilis*) and noble fir (*A. procera*). They are spoken of collectively as balsam fir in the interpretation of their pollen profiles. Spruce pollen was identified as largely that of Sitka spruce (*Picea sitchensis*), although it is possible that Engelmann spruce (*P. engelmanni*) may be represented, especially during the cooler periods of the time recorded by the pollen profiles. In addition to that of conifers, pollen of alder, willow, ericads, grass, composites, cattail, and sedges were noted, while spores of ferns and mosses were present. The non-coniferous pollen, however, was scanty, and probably largely destroyed by the compaction of the sediments and the harsh preparation methods. In the upper stratum at Possession Point, leaves of sphagnum moss were noted, but in general, the vegetative structures were indistinguishable due to crushing by the overlying sediments and the rigorous treatment in preparation of the samples.

INTERPRETATION OF THE POLLEN PROFILES

According to the stratigraphic relationships (Mackin) the composite sedimentary column of the Possession Point and

Everett sections may be considered to represent three chronological units of an interglacial stage. Interpretation of the pollen profiles, however, can best be treated in five segments, the P1-4 and P5-15 of the Possession Point sediments, and the A, B, and C series of the Everett section. The Possession Point pollen-bearing segments are separated by inorganic strata and thus do not constitute a continuous record of forest succession, while the sharp breaks in the pollen profiles from the Possession Point P5-15 to the A series of the Everett section and in turn from the A to the B series of the latter, indicate that a hiatus also is present between these segments. The B and C series of the Everett sequence apparently record continuous forest succession. The relative chronological position of the recorded forest sequence in each of the sedimentary segments, as well as the continuity of the forest succession of the composite sedimentary column, may be interpreted upon the basis of the postglacial forest succession recorded in many peat sections in the Puget Lowland (Hansen, 1938, 1940, 1941, 1943, 1947a, 1947b). These pollen-bearing sediments undoubtedly record a continuous forest succession from the time of retreat of the Vashon (Late Wisconsin) ice to the present, largely in response to climatic trends and soil development.

In the lowest and oldest pollen-bearing segment, P1-4 of the Possession Point sediments, lodgepole is recorded as the predominant species in adjacent areas, with proportions ranging from 78 to 61 per cent with an average of 68 per cent (fig. 2). White pine with 4 to 25 per cent and an average of 14 per cent, and spruce with 8 to 16 per cent and an average of 13 per cent, are the next most abundant, while other species are sparsely and sporadically recorded. The predominance of lodgepole suggests an early interglacial forest sequence under unstable physiographic and edaphic conditions in the wake of retreating ice. White pine and spruce denote a cool and perhaps moist climate. The almost complete recorded absence of Douglas fir and western hemlock further supports the inference of an initial forest stage under a cool climate and on recently deglaciated, sterile, mineral soil. In ten postglacial peat sections in the Puget Lowland, lodgepole is recorded to an average of 74 per cent in the lowest level, while white pine, the next most abundant, attains an average of 17 per cent (fig. 5). Douglas fir and western hemlock average only 1 per cent. It is believed that lodgepole existed close to the ice front, and was able to invade deglaciated terrain almost immediately in the wake of the retreating ice, and thrive until physiographic and edaphic stability had been attained and sufficient time had elapsed for migration of Douglas fir and hemlock. The last two species, having a greater longevity, being of greater stature, and more tolerant of shade, gradually replaced the initial lodgepole pine forests.

The occurrence of inorganic strata between the lower pollen-bearing segment (P1-4) and the upper (P5-15) in the Possession Point section, denotes a time interval of unknown magnitude between the two forest stages represented in the pollen profiles. The pollen profiles themselves also reflect a chronological hiatus, perhaps several hundred years. The period was long enough, however, to result in a decline of lodgepole from 61 per cent in the uppermost level of the P1-4 series to only 16 per cent in the lowest horizon of the P5-15 series (fig. 2). On the other hand, the balsam fir complex and western hemlock made significant gains, increasing from a few per cent to 46 and 12 per cent respectively in the P5 horizon. Other significant changes include expansions of subalpine fir and mountain hemlock, while white pine and spruce show declines. As the 11 horizons of the P5-15 series were taken at six-inch intervals in a compacted peat stratum, apparently deposited under normal hydrarch succession, they probably represent a continuous forest sequence. The decline of lodgepole and white pine and the rise of hemlock and fir suggest amelioration of the environment, as the influence of the retreating glacier become more remote. The increase of montane and subalpine species does not fit into such a picture, however, unless their increase denotes their presence in ice-free areas at higher altitudes from which pollen drifted down to the accumulating organic sediments. The recorded absence of Douglas fir is somewhat anomalous in the light of postglacial forest succession in the Puget Lowland, in which Douglas fir superseded lodgepole fairly early and became predominant in the region long before western hemlock had begun to expand significantly (figs. 4 and 5). Also the presence of lodgepole and hemlock in abundance in the same region suggests a series of local areas of diverse environment, particularly soil conditions, as hemlock requires humus for its best development, while lodgepole will thrive under poor soil conditions. Their contemporary records may reflect the presence of floodplain areas still under disturbance or mature bog surfaces supporting local forests of lodgepole, and other more edaphically mature areas favorable for western hemlock. With respect to trends, lodgepole and white pine generally increase upward in

Fig. 2. Pollen diagrams of Possession Point section. The horizons of the P1-4 series are spaced at greater intervals to indicate greater thickness and longer time interval.

the section, hemlock expands to a maximum of 20 per cent then declines, while white fir declines to a low of 23 per cent at the top (fig. 2). In general, the abundance of western hemlock and white fir suggests the waning influence of glaciation, white pine and lodgepole pine forests suggest local areas of disturbance and mineral soil, while mountain hemlock and subalpine fir denote favorable local areas possibly at greater altitudes, but in sufficient proximity to be significantly recorded by their pollen.

According to the stratigraphic relationship (Mackin) the P5-15 segment of Possession Point series, may be in part contemporaneous with or predate the A series of the Everett section. In either case, the pollen profiles of the former may portray a local forest sequence, as suggested by lodgepole and western hemlock co-abundance. The A series may well represent the later stage of a regional Douglas fir-hemlock forest which developed under increasingly stable conditions. This is evidenced by a maximum of 27 per cent for Douglas fir at the lowest horizon and its decline to nothing in the upper level, and high predominance of hemlock with an average of over 52 per cent (fig. 3). If the high proportion of lodgepole pine in the P1-4 unit represents a regional predominance during the early stages of the recorded interglacial in the Puget Lowland, then sufficient time must have elapsed between the deposition of the P1-4 levels and the A series to permit the development of a lodgepole-Douglas fir forest and its replacement by Douglas fir-hemlock, the last phase of which is recorded in the A series. The maximum Douglas fir expansion must have occurred during the period represented by the lower, inaccessible portion of the Everett section. This theory is supported by the fact that more than 50 per cent of the pollen identified in the lower part of the A series was that of Douglas fir, but the pollen count was insufficient to warrant a reliable index to adjacent forest composition. That Douglas fir may have attained high proportions during the chronological gap in the record, is further supported by its average maximum of 62 per cent in ten postglacial sections in the Puget Lowland (fig. 5). This suggests that Douglas fir had already passed its peak of interglacial expansion and had been largely replaced by hemlock at the time represented by the A series.

The present successional relationships of Douglas fir and western hemlock in the Puget Lowland reveal that Douglas fir is a subclimax species that thrives and persists as a result of clearing or burning of the climax forest. If a forest is undisturbed by fire, disease, or cutting for five or six centuries, Douglas fir is almost entirely replaced by western hemlock and other climax dominants (Munger, 1940). In postglacial forest succession hemlock was not able to supersede Douglas fir until perhaps about 4,000 years ago, when the climate became cooler and moister after the climatic maximum between 8,000 and 4,000 years ago (fig. 5) (Hansen, 1947). The interval between deposition of the P1-4 and the A series then, may represent the time involved in the development of Douglas fir predominance and its almost complete replacement by a forest of almost pure western hemlock. In postglacial time, the expansion of Douglas fir to its maximum average of 62 per cent and its decline to a point of hemlock predominance is thought to have required perhaps 15,000 years. It is evident, though, that expansion of hemlock under normal forest succession was deferred by perhaps 6,000 years because of increasing warmth and dryness to a degree that was unfavorable for it. This warm, dry interval was also more favorable for periodic fire, which undoubtedly helped Douglas fir to persist as the predominant species. The entire forest sequence of the present study indicates that a moister climate prevailed which may have limited the extent and frequency of forest fires. This permitted forest succession to reach a climax of hemlock-balsam fir, with spruce, white pine, and lodgepole occupying favorable local sites, while Douglas fir had entirely disappeared from sites within range of pollen dispersal. The total absence of Douglas fir pollen is peculiar, as it seems unlikely that a species as aggressive and hardy as Douglas fir could not have survived on local sites, unless it was entirely destroyed in the region by disease.

A time interval of significant magnitude but probably not so great as above is also indicated between the A and B series of the Everett section, by a disconformity (fig. 1). An unrecorded interval is also indicated by the pollen profiles, chiefly by an increase of balsam fir from 1 per cent at the top of the A series to 43 per cent in the lowest horizon of the B series (fig. 3). Balsam fir maintains high proportions throughout the series, denoting that this expansion was for an appreciable period of time as well as regional. A time lapse of significant magnitude is further supported by an abrupt decline of western hemlock from 49 per cent at the top of the A series to 16 per cent at the bottom of the B series, although there are fluctuations almost as great within the B series from one level to the next. Although hemlock declines from an average of 52 per cent in the A series to about 30 per cent in the B series, it remains more abundant than lodgepole which shows a significant increase with an average of 13 per cent as compared to less than 6 per cent for the A series (fig. 3). Balsam fir averages over 31 per cent and attains a maximum of 50 per cent. Spruce, subalpine fir, and mountain hemlock all show increases in the B series, with averages of 9, 13, and 7 per cent respectively. Again the total absence of Douglas fir pollen is strange, as it seems unlikely that this species was entirely absent in the region. In general, the pollen profiles of the B series denote a slight deterioration of the climate, with greater areas favorable for lodgepole, perhaps representing mature bog surfaces. The significant expansion of the balsam fir complex suggests the expansion of noble and silver fir in montane areas, while grand fir may have prospered in the absence of Douglas fir on flood-plain areas.

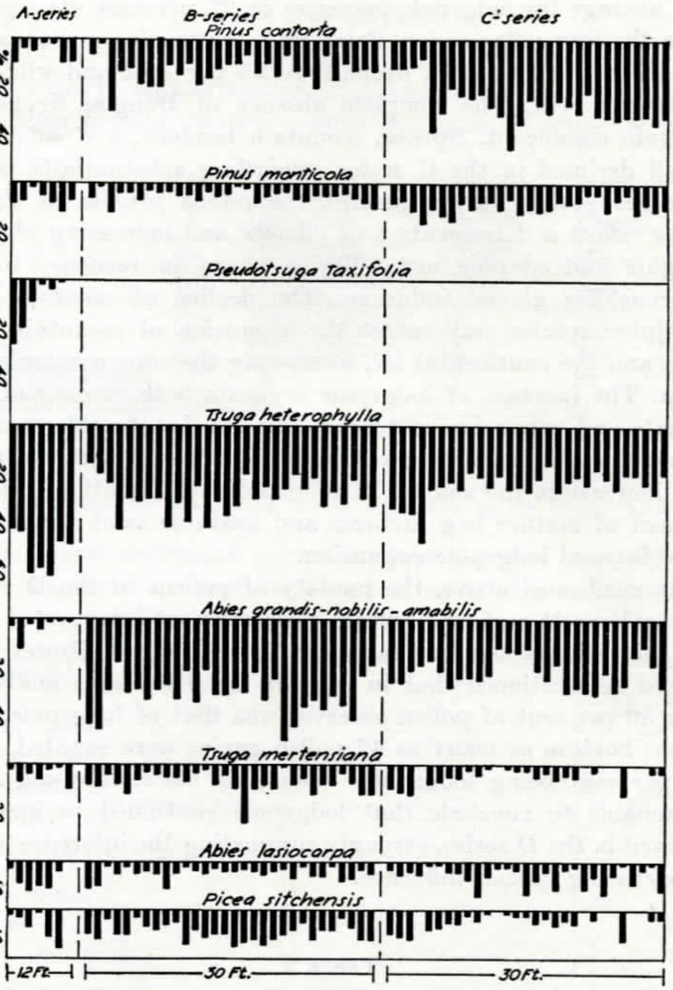

Fig. 3. Pollen diagram of the Everett section. Thickness of pollen-bearing series shown on right of pollen profiles.

The pollen profiles indicate that the B and C series of the Everett section represent a continuous forest sequence. The pollen proportions for all species are almost the same in the upper level of B and lower level of C (fig. 3). During the interim represented by series C, lodgepole gradually increased, hemlock gradually declined, while balsam fir maintained a lower average than in the B series (table 1). White pine also is stronger, with a slightly higher average than below.

The average for lodgepole increases to 27 per cent, its highest since the lower Possession Point unit, white pine increased to 9 per cent, and hemlock declined to 25 per cent and white fir to 19 per cent. The complete absence of Douglas fir pollen is again significant. Spruce, mountain hemlock, and subalpine fir all declined in the C series, recording substantially lower averages (table 1). In general, the pollen profiles of the C series reflect a deterioration of climate and increasing physiographic and edaphic instability, perhaps in response to an approaching glacial influence. The decline of montane and subalpine species may reflect the expansion of mountain glaciers and the continental ice, narrowing the zone available for them. The increase of lodgepole suggests both cooling of the climate and expansion of terrain suitable for its colonization, although a decline of hemlock may also record merely a relative increase in the amount of lodgepole. Also continued development of mature bog surfaces and unstable sand dunes may have favored lodgepole expansion.

As mentioned above, the paucity of pollens in the D series of the Everett section prevents projection of interpreted forest succession above and later than the C series. However, it should be mentioned that in each of the 9 horizons analyzed, over 50 per cent of pollen observed was that of lodgepole, and in one horizon as many as 47 pollen grains were counted, with 65 per cent being lodgepole. Upon this basis, it would seem reasonable to conclude that lodgepole continued to increase upward in the D series, strongly supporting the inference of an accelerating glacial influence.

TABLE I

Ranges and Averages of Pollen Proportions in Per Cent

SPECIES	P1-4 Range	P1-4 Ave.	P5-15 Range	P5-15 Ave.	A. series Range	A. series Ave.	B series Range	B series Ave.	C series Range	C series Ave.
Lodgepole pine ...	61–78	68.0	16–34	24.6	2–10	5.8	2–30	13.1	7–45	27.0
Western hemlock .	0–4	1.2	2–20	8.8	43–62	52.3	16–43	29.4	16–48	25.0
White pine	4–25	14.2	0–19	10.3	2–12	7.0	1–12	5.0	2–18	9.1
Balsam fir	2–4	2.5	23–50	36.1	1–12	3.1	18–50	31.4	11–31	19.2
Mountain hemlock	0–1	—	2–8	4.8	1–10	4.5	1–24	7.5	0–12	4.0
Subalpine fir	—	—	2–21	10.2	3–12	7.0	2–11	13.3	1–14	5.6
Sitka spruce	8–16	13.0	0–12	2.7	1–16	5.7	3–17	9.3	0–12	4.0
Douglas fir	0–4	1.0	0–2	0.5	0–27	9.0	—	—	—	—

CLIMATE AND CHRONOLOGY

The total period of time represented by the composite pollen profiles can be only estimated. The interval as interpreted from the pollen profiles themselves must be estimated upon the basis

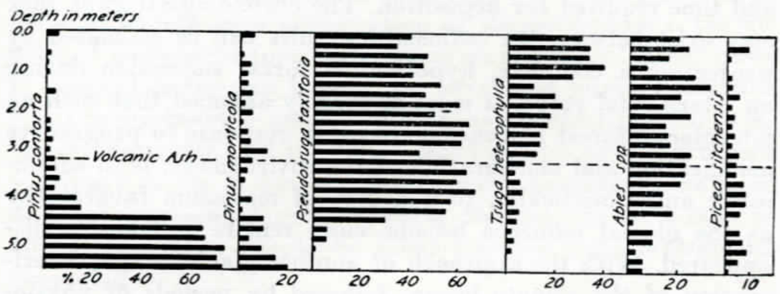

Fig. 4. Pollen diagram of postglacial peat section from bog near Granite Falls, about 15 miles northeast of the Everett section. Pollen profiles are typical for postglacial forest sequences in the Puget Lowland.

of the forest succession portrayed and the time required for it, as measured by postglacial forest succession and present-day successional relationships of the species concerned. The

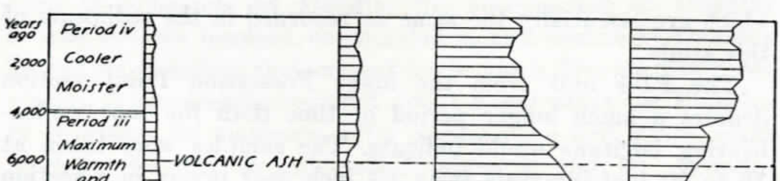

Fig. 5. Average pollen profiles of four principal forest trees from ten Puget Lowland postglacial sedimentary columns, most of them within a radius of 50 miles from the Everett section of this study.

thickness and type of organic sediments also provide a clue as to the chronology denoted by the recorded forest sequences. The depositional rate of postglacial pollen-bearing sediments may serve as a yardstick, because they are probably a continuous depositional series for a time interval which can be fairly reliably estimated. The texture, structure and thickness of the interbedded inorganic strata also denote relative rates and time required for deposition. The chronological gaps that may exist between the sedimentary units can be estimated by projecting a complete, hypothetical forest succession during an interglacial stage. It must be largely assumed that such an interglacial forest sequence occurred in response to progressive modification and amelioration of the environment, both edaphically and climatically, to a degree of maximum favorability as the glacial influence became more remote and finally disappeared. With the approach of another glacial stage, deterioration of the climate began, followed by periods of physiographic instability at progressively closer intervals as the ice sheet expanded. How long the climatic maximum persisted and the environment remained generally stabilized is conjectural because of the breaks in the record. At present, the climate of the Puget Lowland would seem to be close to a postglacial maximum as far as the climax species present are concerned, which are essentially the same as recorded in the sediments of this study.

The P1-4 unit from the lower Possession Point section denotes a much longer period of time than the four pollen-bearing horizons would indicate. The samples were taken at 10 to 20 foot intervals from 2-4 inch peat layers in a section of inorganic sediments about 70 feet thick (fig. 1). A recorded decline of lodgepole from 78 to 61 per cent is not indicative of a long time lapse in terms of postglacial forest succession. However, the interbedded inorganic members suggest a period of physiographic instability prolonged by slow ice retreat, perhaps from 2,000 to 3,000 years in duration. The climate was probably cool and moist.

The P5-15 pollen-bearing unit of Possession Point is a 5-foot peat bed of almost pure, fibrous, compacted peat, which represents a long period of deposition with at least local physiographic stability. The dense character of the peat suggests compaction to a thickness of only one-third of that of postglacial peats in the Puget Lowland. The average rate of deposition for 30 postglacial, pollen-bearing sedimentary columns in Washington and Idaho has been computed at about 2,500 years per meter. Applying this rate, an interval of 8,000 to 10,000 years may be represented by the P5-15 peat section. The decline of lodgepole from an average of 68 per cent in P1-4 to only 25 per cent in P5-15, and an increase of western hemlock from 1 to 9 per cent and balsam fir from 2.5 to 36 per cent denote some amelioration of the environment. On the basis of postglacial forest succession an interval of 2,000 years is assigned to the gap between the lower and upper Possession Point pollen-bearing units. However, as the stratigraphic relationships suggest that the P5-15 unit predates or is concurrent with part of the A series, and the pollen assemblage may not depict a regional forest sequence, the interim of 8,000 to 10,000 years can hardly be fitted into the total interglacial chronology.

If it is assumed that a regional forest of Douglas fir largely replaced lodgepole as it did in the Puget Lowland during the Postglacial, then the forest successional gap between P1-4 and the Everett A series might better provide a chronological segment of the interglacial. This method of interpretation requires an estimate of the interval involved for the replacement of lodgepole by Douglas fir, development of Douglas fir and western hemlock co-abundance, and decline of Douglas fir and its complete replacement by hemlock. During the Postglacial, it apparently required about 8,000 years for Douglas fir to attain its maximum after deglaciation and 6,000 years more for hemlock to supersede Douglas fir (fig. 5). As mentioned above, however, the warm dry, postglacial maximum probably deferred normal replacement of Douglas fir by hemlock. On these bases the interval from P1 to the top of the A series is estimated from 10,000 to 12,000 years. The pollen profiles of the A series with an average of 52 per cent for hemlock, would seem to depict the period of maximum warmth and physiographic stability for the entire interglacial stage.

A chronologic hiatus of perhaps 2,000 years may be present between the pollen profiles of the A and B Everett series, primarily denoted by an expansion of balsam fir from almost nothing to 44 per cent. The organic laminae themselves contain a high inorganic fraction, and it can be presumed that deposition was rapid, although there was little or no change in forest composition during this stage. The pollen profiles of the B series include about 30 feet of sediments, with the organic strata interbedded in clays, silts, and sands. A figure of 3,000 years is set for the interval represented by the B series. The relative trends of lodgepole and hemlock suggest the beginning of physiographic and edaphic instability. Increase in spruce, subalpine fir, and mountain hemlock suggests cooler and moister climate, which may reflect an approaching glacial influence.

The C series pollen-bearing strata are interbedded in about 30 feet of sediments, becoming progressively coarser upward. Being of equal thickness as the B series, but of texture and structure signifying more rapid deposition, the time interval is estimated at about 2,000 years. A sharp expansion of lodgepole and decline of hemlock suggest increased physiographic instability over that portrayed by the B series, and is strongly indicative of a more proximal glacial influence, while an increase in white pine connotes a cooler climate. Almost total absence of pollen in sediments above the C series may indicate destruction of forest by approaching ice, both directly and through physiographic influence. However, 100 feet of sediments, some fine, between the C series and the top of the section may represent at least 1,000 years of time.

The total time represented by the composite pollen profiles, the inorganic sediments, and the breaks between the several units may be from 16,000 to 20,000 years. Postglacial pollen-bearing sections are estimated at about 18,000 years, which record forest succession from the pioneer lodgepole pine to the present Douglas fir-hemlock forests that existed when white man first appeared. How long the present period of apparent maximum favorability for Douglas fir and hemlock will persist is difficult to say. On the basis of overall trends and long-range cycles, slight deterioration of the climate has been in progress for the last few thousand years, as evidenced by pollen profiles of peat sections from eastern North America and Europe (Hansen, 1947a).

There is no evidence in the several pollen-bearing units of this study for a period of warmth and dryness to the degree reflected in Pacific Northwest postglacial profiles. In general, they suggest a cooler and moister climate throughout the time represented than now exists. The hemlock maximum in the Everett A series probably represents a period of optimum favorability for the development of the climax forest, and the climate of this interval may have been somewhat similar to that of today, but with more moisture. The concurrence of lodgepole and western hemlock throughout, because of their different ecological requirements, suggests either a constant disturbance factor in local areas favorable for lodgepole, such as floodplains, sand dunes, or mature bog surfaces, and stabilized upland areas favorable for hemlock and balsam fir. The sustained high proportions of hemlock throughout suggest that the period represented was an interglacial stage of significant magnitude, rather than a temporary retreat of a minor stage. The stratigraphic relationships show that it was earlier than the interglacial immediately preceding the Vashon (Late Wisconsin) stage in the Puget Lowland.

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