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A further Study of Interglacial Peat from Washington

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(WITH TWO FIGURES)

The Puget Lowland in Northwestern Washington has been subjected to at least two Pleistocene glaciations; the first of which is known as the Admiralty, followed by the Puyallup interglacial period, and the second as the Vashon (Bretz 1913). During the retreat of the Admiralty glacier, considerable ponding of water occurred, as is evidenced by the presence of silts, varved clays, and other types of lacustrine deposits. Peat lenses of varying magnitude are often present at different stratigraphic positions in the sequence of glaciolacustrine deposits. This paper is concerned with the pollen analysis of an interglacial peat stratum in Seattle, Washington (Hansen), and the position of the peat in the stratigraphic sequence in the Puget Lowland (Mackin). In a previous paper, Hansen (1938a) interpreted the forest succession during a brief interval of interglacial time from pollen analysis of a peat stratum located ten miles east of Auburn, Washington. That deposit is probably younger than that of this study, as will be discussed later. The post-Vashon forest succession and climate in the Puget Sound region, as interpreted from pollen analysis of bogs of post-Vashon origin, has also been worked out (Hansen 1938b). These interpretations may serve as criteria in the interpretations of the pollen spectra of this paper.

The peat of this study is located in Beacon Hill, in the south central part of Seattle. Extensive regrading for streets several years ago involved the removal of the Vashon till-mantle, exposing the interglacial sediments which form the core of the hill. The peat lenses crop out in a landslide scarp 210 to 220 feet above sea level, approximately 150 yards south of the Twelfth Avenue viaduct. The total thickness of the peat-bearing bed is about 64 inches. The lowest and thickest lens is about three feet thick; the lower half consisting of gray, silty, limnic peat, and grading upward into fibrous peat, which contains fragments of reed and sedge. This is followed upward by a series of thinner lenses of limnic peat, which contain some silt, and are interbedded by layers of silt and sand.

GEOLOGIC RELATIONS

General Statement

The Pleistocene stratigraphic sequence in the Puget Lowland, as recognized by Bretz (1913), includes from the base upwards: (1) Admiralty till, (2) Admiralty sediments, (3) Vashon till (Wisconsin age), and (4) post-Vashon glaciofluvial and glaciolacustrine deposits. In the

Seattle area the Admiralty sediments, generally flat-bedded, form the cores of a series of drumloidal hills, elongated in a north-south direction. The hills are enwrapped by a sheet of Vashon till, averaging 20 feet in thickness, but varying from 0 to 100 feet or more. Vashon retreatal sediments are highly variable in thickness and distribution; in general, they may be distinguished from the Admiralty sediments only by their stratigraphic relations to the Vashon till sheet. Bretz believes that the Admiralty sediments originally formed a proglacial aggradational plain in the central part of the Puget Lowland, with the surface of the approximate level of the present hill-tops; that this plain was trenched by north-south stream valleys during the Puyallup interglacial period, and that the valleys and divides were later modified into the present trough-drumloid topography by southward-moving Vashon ice.

Relations of Peat to Overlying Deposits

The relations of the Beacon Hill peats to the enclosing sediments are illustrated by the accompanying figure (Fig. 1). Although the Vashon till is not present in the immediate section, the peat is regarded as pre-Vashon because the overlying blue clays, silts, and gravels can be traced southward along the west flank of the Hill to a point where they are overlain uncom-

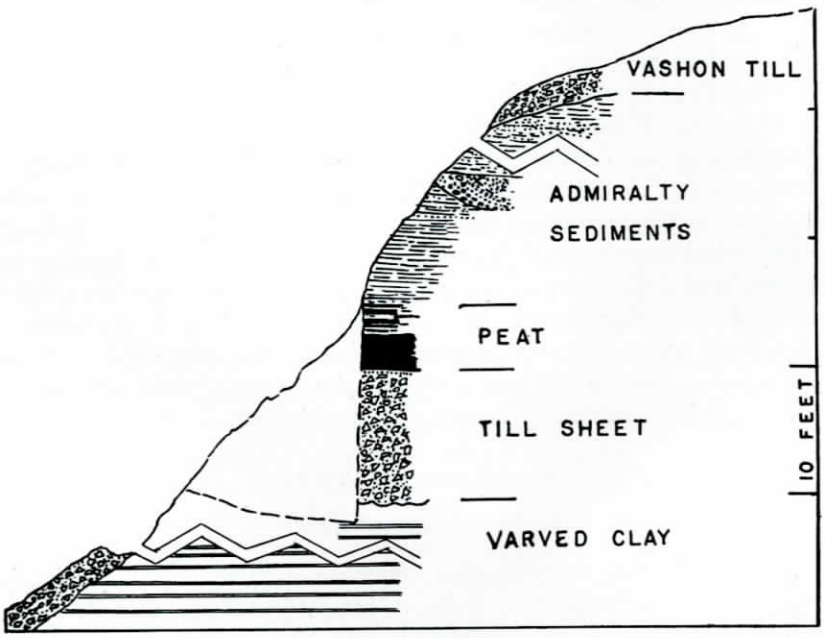

Fig. 1. Diagram showing relations of the Beacon Hill peat. Dashed line indicates outline of pit, excavated largely in rubble.

formably by Vashon till. Numerous cuts in the flanks and crests of adjacent hills show similar relationships. Bretz (1913) states that peat deposits were exhumed in the removal of Denny Hill, one and one-half miles to the northwest, where the relations of the peat layers to overlying Vashon till indicated that they were an integral part of the Admiralty sediments.

Relations of the Peat to Underlying Deposits

Landslide scarps in the lower flanks of the hill, below the level of the peat, show a 110 foot sequence of varved clays, recording approximately 500 years of sedimentation in a glacial lake. These clays are markedly different from the laminated to massive blue clays, with interbedded sand and gravel, which enclose the overlying peat beds. Individual varves are very thick at the base of the exposure, the annual units averaging 15 inches. The units thin progressively upward, averaging 1½ inches in the middle and upper parts of the sequence, but the top varves increase in thickness to a 2½ inch average. The uppermost several layers are 3 foot silt beds. Resting directly upon the silt is a 10 foot till sheet, containing striated pebbles in a gray silt matrix similar to the varve materials. The contact between the varve sequence and the till is sharp, with a 2 to 4 inch zone showing shearing and crumpling. The basal peat lens rests upon the till sheet, with a 6 inch layer of coarse sand at the contact.

The till sheet is not normally exposed at the present surface. The contact of varve, silt, till, and peat were seen in a 14 foot section, in a pit opened at a single place along the hill flank in the vicinity of the peat outcrops where topographic relations and the relative absence of landslides were favorable for excavation. Since critical evidence is not now at hand, two alternative explanations of the relations of the peat to the underlying strata will be outlined briefly.

The first hypothesis holds that the complete Beacon Hill sequence is Admiralty in age, and is in harmony with the regional conclusions of Bretz, although he did not specifically recognize the existence of the varved clays in the Admiralty sediments. According to this view an initial retreat of Admiralty ice permitted the formation of a glacial lake in which varved sediments accumulated for approximately 500 years. Lacustrine sedimentation was brought to a close by readvance of the Admiralty glacier to the latitude of Seattle. Final retreat of the ice was followed by formation of peat, and the deposition of the thick sequence of blue clays, sands, and gravels, the typical Admiralty sediments of Bretz. This hypothesis is supported by the variation in varve thickness described above, since gradation from basal thick layers, to middle thin, to upper thick, suggests retreat followed by readvance.

A minor variation of the foregoing hypothesis attributes the cessation of varve sedimentation to the draining of the lake, the relatively great thickness of the upper varves to the turbidity of the shrinking waters, and the till to a stranded berg. This view finds some support in the thinness of the sheared zone at the base of the till and in the fact that the peat deposits are somewhat thicker over the till than in other parts of the bank, where excavations through the peat failed to discover till at a corresponding level. According to this view the peat accumulated in a kettle pond on the drained lake floor, approximately five hundred years after the Admiralty glacier had withdrawn from the Seattle area.

These hypotheses serve to explain all essential features of the Beacon Hill sequence, but one of the deduced consequences fails of confirmation. The varved clays must have been deposited in a relatively extensive water body, and, if they were formed as suggested above, should be present as a persistent lower member of the Admiralty deposits in adjacent areas. Excellent exposures in sea cliffs north and south of Seattle, however, show no varves, the typical Admiralty blue clays and sands extending from sea level to the hilltop mantle of Vashon till. It is recognized that lateral gradation or deformation might explain these circumstances, but in the absence of evidence favoring either possibility, a second hypothesis seems worthy of consideration.

This alternative hypothesis makes the Beacon Hill varves a part of a sequence of considerable lateral extent, formed in a proglacial lake during a pre-Admiralty glacial stage. The varved sequence then may have been maturely dissected by streams during a pre-Admiralty interglacial period, and the residual hills further eroded and blanketed by Admiralty till and the thick cover of Admiralty sediments. The composite sequence would then have been subjected to erosion by streams during the Puyallup interglacial stage, and finally covered with Vashon drift. This relatively complex history of repeated erosion and burial would explain the lack of continuous exposures of varved clays, particularly in view of the fact that all students of glaciation of the Puget Sound area are agreed that the base of the Admiralty till is generally below present tide level.

The final solution of these problems will require much detailed stratigraphic study, supplemented by pollen analysis, of the Pleistocene sequence in the Puget Lowland. For the purpose of the present paper it should be noted, that in spite of some uncertainties, the geological relations indicate that the peat stratum was deposited during an early stage in the Admiralty deglaciation of the Seattle area.

METHODS

Eleven peat samples were obtained at approximately six-inch intervals, although this varied somewhat depending upon the thickness of the inter-

bedded silt and sand which separated the upper peat lenses. A foot or more of the face of the exposure was removed in order to secure unweathered and unoxidized material. For study, the peat was pulverized in a mortar, boiled in a weak solution of potassium hydrate, washed, centrifuged, stained with gentian violet, and mounted in glycerin jelly. A total of 113 to 262 pollen grains were counted from each level. The number of pollen grains at each level is approximately indicative of their relative abundance (table 1).

TABLE 1

Percentages of Pollens at different depths

DEPTH IN INCHES	0	6	12	18	24	30	36	42	48	54	62
Pinus contorta	47	60	54	48	30	55	40	42	49	54	39
P. monticola	7	15	25	23	46	34	20	38	39	34	30
Picea sitchensis	0.5	3	1	1	3	7	33	5	5	6	22
Abies grandis	3	1	..	5	1	..	1	..	..	..	..
A. lasiocarpa	..	..	..	..	1	..	..	2	..	..	..
Tsuga	2	..	1	..	1	..	1	1	2	..	2
Gramineae	30	8	6	5	10	..	4	2	3	5	3
Compositae	3	0.5	0.5	1	2	1	..	3	1	..	1
Alnus	4	1.5	1	2.5	..	..	..	2	1	..	1
Acer	0.5	0.5	1	7	2	..	..	1	..	..	1
Betula	1	9	8	4	2	..	..	3	..	..	..
Salix	2	1.5	..	1.5	1	..	..	..	..	..	..
Chenopodiaceae	..	..	2	1.5	1	2	1	..	..	1	..
Cyperaceae*	..	6	2	31	19	23	50	37	4	22	24
Typha*	..	..	..	12	..	..	..	..	..	..	..
Sparganium*	..	..	..	1	..	..	..	..	..	..	..
Fern*	..	9	..	..	1	..	..	1	6	..	..
Unknown*	53	13	20	21	11	15	14	7	3	10	1
Total number	262	218	172	185	122	152	174	175	113	122	155

* Number, and not computed in the percentages.

It is realized that at best, pollen analysis and its interpretation is subject to many sources of error, which have been adequately discussed by various workers (Erdtmann 1931, Fuller 1935, Sears 1930). In the analysis of interglacial peat, however, the source of error attributed to age is greatly magnified. Obviously the degree of preservation of the pollens in the peat is one of the important factors in recording the correct representation of adjacent flora during the time the peat was being deposited. The older the peat the greater the chance for destruction of the less durable pollens, and distortion of the vegetative record. Thus it should be borne in mind that the pollen analysis of the peat of this study, and the interpretation of said analysis are discussed with full cognizance of its shortcomings.

As previously shown, the stratigraphic relationships of the peat stratum to the underlying till indicate that its deposition began soon after the retreat of the Admiralty ice from the Seattle area. That forests may exist in close proximity to a glacier is shown by the study of post-Middle Wisconsin forest succession in the driftless area of Wisconsin (Hansen 1939c), and the existence of intraglacial forests in eastern Wisconsin (Wilson 1932). The driftless area was apparently forested during the later stages of the Wisconsin glacial epoch, while forests also existed in eastern Wisconsin during the period of deglaciation between the retreat of the Middle and the advance of the Later Wisconsin ice sheets. Forests actually exist upon certain stagnated Alaska glaciers at present (Washburn 1935), while Cooper (1939), in extensive studies of plant succession in recently deglaciated valleys in Alaska, has shown that forests of spruce and hemlock follow closely in the wake of the receding ice. Climatic and edaphic conditions here may be somewhat similar to those which existed near the ice-front in the Puget Lowland during the Pleistocene. The absence of pollen in the underlying blue clays, silts, and varved clays may indicate the absence of forests until the beginning of the peat deposition.

The stage of forest succession reached at the time of deposition of the uppermost peat may also serve as a chronological criterion by comparison with post-Vashon forest succession. It should be mentioned, however, that forest succession is probably controlled largely by climate, and forest succession, as interpreted from pollen analysis, is one of the few evidences at hand by which one may reach conclusions with respect to interglacial and postglacial climatic fluctuation. As shown by the pollen record, the forests which existed at the beginning of the peat deposition, whether pioneer or later, consisted chiefly of two species which also were dominant in pioneer post-Vashon succession in the Pacific Northwest. As postglacial time in the Puget Sound region progressed, the pioneer species, lodgepole and white pines, were gradually replaced with Douglas fir and hemlock, with the former coming in first and more abundantly (Hansen 1938b). This occurred at a point approximately one-fourth from the bottom in each of two bogs. The time required for the deposition of the lower quarter of peat was perhaps almost one-half of postglacial time, because of the greater compression in the lower levels, and the presence of sedimentary peat, which requires more time for its deposition than a similar thickness of fibrous peat. If this assumption is correct, the replacement of the pioneer species by Douglas fir and hemlock did not occur until almost 15,000 years of post-Vashon time had elapsed. The absence of Douglas fir and the presence of only a trace of hemlock pollen in the peat concerned here indicate that either the climate had not moderated sufficiently for the advent of these species, or the time was too short to have allowed normal

SIGNIFICANCE AND CORRELATION OF THE POLLEN SPECTRA

The forests which existed in the Puget Lowland during the initiation of the peat accumulation, consisted chiefly of lodgepole pine (*Pinus contorta*) and western white pine (*P. monticola*), with an abundance of grass (fig. 2). The frequencies of these are 47, 7, and 30 per cent respectively in the lowest level. This forest, with other species in lesser abundance (table 1), may or may not have been the pioneer forests of the interglacial period. It would be hard to estimate the amount of time which had elapsed between the retreat of the Admiralty ice and the invasion by forests. The second hypothesis concerning the stratigraphic relations, however, indicates that at least 500 years had passed before the beginning of the peat deposition. The initial post-Vashon forests to invade the Puget Lowland, areas near Spokane, Washington, and in Northern Idaho, likewise consisted of lodgepole and white pines (Hansen 1938b, 1939a, 1939b). Each of these areas supports a different forest climax at present, although the initial post-Vashon forest succession was apparently similar. The presence of an abundance of grass in the early postglacial forest succession in Northern Idaho may indicate earlier tundra-like conditions, which had existed previous to forest invasion. Upon the basis of postglacial forest succession, it seems probable that the Seattle area was invaded by forests soon after the retreat of the Admiralty glacier. The percentage of grass pollens decreases from the lowest level to the top with slight fluctuations, and seems to offer no further significance.

Lodgepole pine increases to 60 per cent at 6 inches, and then decreases to 30 per cent at 24 inches. White pine shows a gradual increase from the lowest level, to 46 per cent at 24 inches to supersede lodgepole pine. This probably indicates normal forest succession, because lodgepole is less tolerant of shade than white pine, and is gradually replaced by the latter (Larsen 1930). Lodgepole pine again increases sharply at the next horizon, and then decreases at the 36 inch level. White pine decreases at both levels to record 20 per cent at 36 inches. Sitka spruce (*Picea sitchensis*) shows a sharp and significant increase to 33 per cent at the same level, which is its highest frequency throughout its spectrum. The present range of Sitka spruce indicates its preference for a very humid climate, as it reaches its maximum development in the fog belt area along the North Pacific Coast. Spruce records a sharp decrease to 5 per cent at the next higher level, and remains uniform to the uppermost level, where it again increases to 22 per cent. Lodgepole and white pines again show an increase from the 36 inch level; the first recording 54 per cent at 54 inches, and the latter 39 per cent at 48 inches. Both species decrease in frequency to the top level, with lodgepole recording 39 per cent and white pine 30 per cent. The presence of sedge pollens in all levels sampled

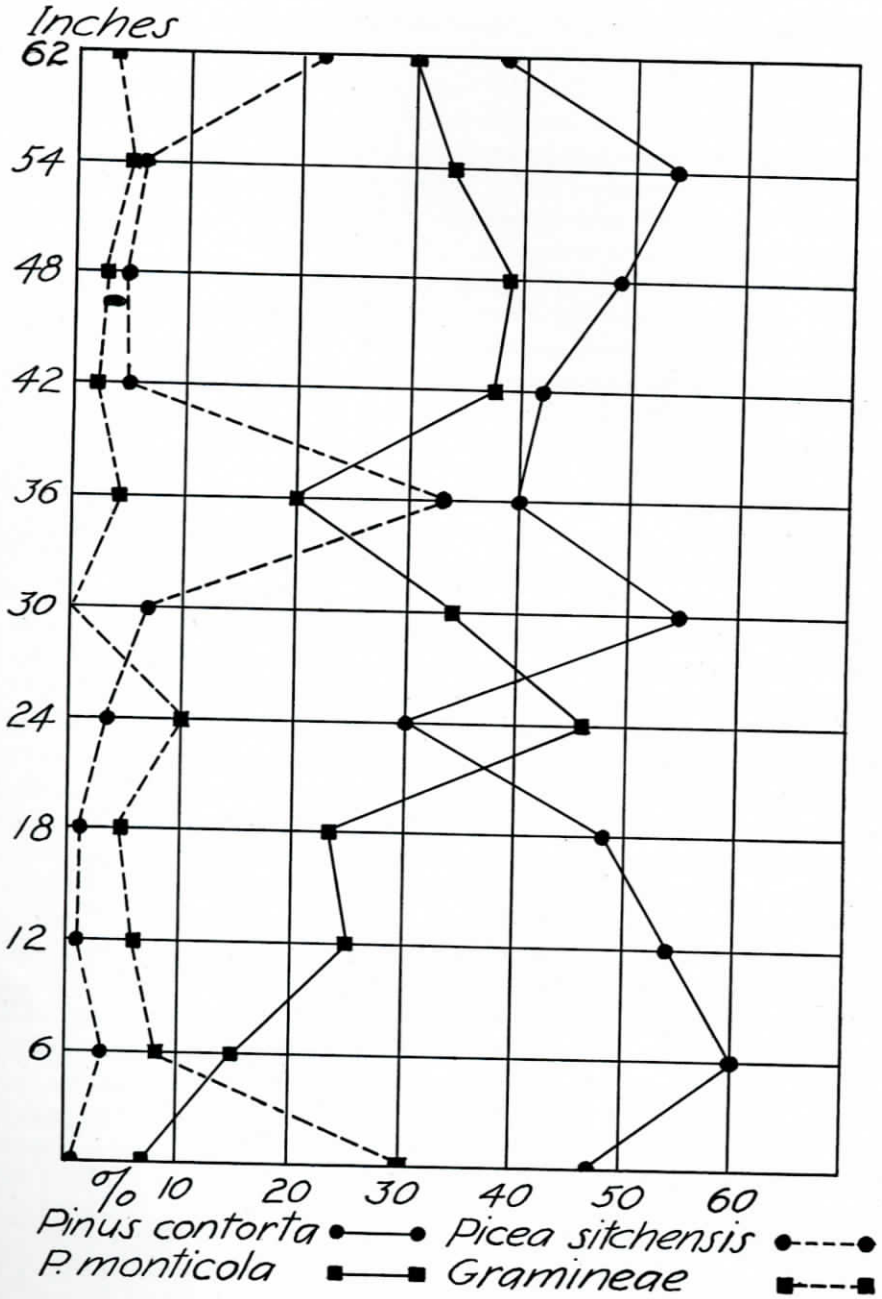

Fig. 2. Pollen diagram.

(table 1), and the absence of sphagnum moss leaves, with the exception of one at the 42 inch horizon, indicate that the bog existed in the sedge stage except when inundated. The greatest number of sedge pollen grains is recorded at 36 inches, the same level at which spruce reaches its maximum. Pollens of other species are present throughout, but not in sufficient numbers to be of importance in the indicated forest succession (table 1). Apparently lodgepole and white pines were dominant during the interval recorded by the peat deposit.

Hemlock, which shows a trace in most of the horizons, may be either western (*Tsuga heterophylla*) or mountain hemlock (*T. mertensiana*). Douglas fir (*Pseudotsuga mucronata*) which played an important part in the postglacial forest succession in the Puget Sound region, seems to be entirely lacking. The dearth of the pollens of these species may be of chronological significance as will be discussed later.

CHRONOLOGICAL CONSIDERATIONS

The period of time represented by the peat bearing strata is probably short, and represents a relatively small portion of the entire interglacial period. The fact that the peat is strongly compressed would indicate, however, that the time required for its deposition is longer than that for the same thickness of postglacial peat. Lesquereux (1885) estimates that peat in the lower levels of a deposit may be compressed to less than one-eighth of its original volume, but this would depend upon the thickness and composition of the peat. Estimates have been made for the time required for the accumulation of one foot of peat, with considerable differences of opinion by the various investigators (Sears 1933). These estimates range from 2 to 1665 years for peats in various parts of Europe and North America, accumulated under varying conditions. Sears estimates that about 300 years are required for the accumulation of a foot of peat in Ohio. The average depth of nineteen post-Vashon bogs in the Pacific Northwest, shown in a study of their profiles by Rigg (1938), is about 30 feet. This includes the lake mud and sedimentary (limnic) peat, which is taken into consideration here because it contains an abundance of pollen, records pioneer forest succession, and consequently may be used as a time factor. Upon the basis of the above figure, a foot of post-Vashon peat in this region required about 1000 years for its time of accumulation, because it is estimated by geologists that approximately 25,000 to 35,000 years have elapsed since the recession of the Vashon glacier. Considering the amount of compaction caused by its own weight, and that of the overlying sediments, as well as its great age, the peat of this study possibly required about 8000 years for its deposition. The total thickness of the peat itself is about 4 feet, and 2000 years per foot for its rate of accumulation does not seem an unreasonable figure.

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forest succession to have reached that stage. In an interglacial peat stratum underlying the Auburn Delta, ten miles east of Auburn, Washington, both Douglas fir and hemlock pollen was present, as was also that of white fir (*Abies grandis*), white pine, lodgepole pine, and Sitka spruce. White fir and white pine were the dominant species throughout the section, which seems to represent a very brief interval in the upper level of the interglacial stratigraphic sequence (Hansen 1938a).

In a much thicker section of interglacial peats, clays, and silts near Everett, Washington, as high as 40 per cent of hemlock and 15 per cent of Douglas fir pollen was noted in a peat sample about half way up in the section. There is evidence that this section represents a considerable portion of interglacial time, and the presence of an abundance of hemlock and Douglas fir pollen indicates that the forest succession had reached a stage where these species played an important part. It also indicates that the climate was favorable for the existence of these species in the Puget Lowland during the latter half of interglacial time. Thus, the stratigraphic evidence for the peat being of early interglacial origin is further corroborated by pollen analysis, while the forest succession and the thickness of the peat stratum indicate that it represents a period of not over 8000 years duration.

CLIMATIC CONSIDERATIONS

In terms of climatic interpretation the presence of an abundance of grass, and lodgepole and white pine pollens in the lowest level, marks the existence of a cool and medium dry period during the earliest stage of peat deposition. This appears to have been similar to the early post-Vashon climate in the Puget Sound region, as interpreted from pollen analysis of post-Vashon bogs (Hansen 1938b). The sharp increase of spruce to 33 per cent at the 36 inch horizon apparently marks an increase in humidity and warmth. Its sharp decrease in the succeeding level indicates a recurrence of the earlier cool and medium dry climate, perhaps caused by a minor oscillation or readvance of the Admiralty glacier. A final period of greater humidity and warmth is perhaps reflected by an increase in spruce, and conversely, by a decrease in lodgepole and white pines. The dearth of Douglas fir and hemlock pollens throughout the section indicates that the climate had not moderated sufficiently at the time of termination of the peat deposition to be favorable for the invasion of these species.

SUMMARY

The geological and stratigraphical relationships of an interglacial peat deposit in Seattle, Washington, indicate that the peat was deposited during the early part of the Puyallup interglacial stage.

Pollen analysis of the peat tends to corroborate the geological evidence, because the initial forests of interglacial time consisted of species similar to those in the same area as well as in other regions in the Pacific Northwest during early post-Vashon time.

The thickness of the peat stratum and the stage of forest succession recorded in the uppermost level, indicate that the interval of time represented by the peat was only a small portion of the interglacial stage, and hypothetically did not extend over more than 8000 years.

In terms of climate, the forest succession suggests four poorly defined alternating periods of coolness and dryness, and warmth and humidity, beginning with the former.

It is fully realized that the age of the peat tends to increase the sources of error which are inherent in pollen statistics, and all conclusions drawn on the basis of pollen analysis may be taken for what they are worth.

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