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# A POLLEN STUDY OF A SUBALPINE BOG IN THE BLUE MOUNTAINS OF NORTHEASTERN OREGON

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# A POLLEN STUDY OF A SUBALPINE BOG IN THE BLUE MOUNTAINS OF NORTHEASTERN OREGON [1]

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## Introduction

This is one of a series of studies on post-Pleistocene vegetation history and general climatic trends in the Pacific Northwest. The forest succession is interpreted from pollen profiles of peat bogs and lake sediments. Bogs are common in some parts of this region, whereas in others they are few and widely scattered. Peat profiles from many of the vegetation and climatic provinces of this vast region have been analyzed, and it is hoped that one or more profiles may be obtained from each plant association. In some cases it has been possible to obtain only a single peat profile from an extensive association. The pollen profiles of one bog may not portray adequately the vegetation history of an entire association, but the correlation of profiles from several should tend to substantiate or refute the evidence offered by a single bog. Pollen profiles of most bogs thus far studied show a fair degree of correlation, with the exception of those located in areas where a pumice mantle has been the major control of forest succession. The vegetation history has been interpreted from the pollen profiles of bogs located in the following associations: The hemlock-cedar of the Puget Lowland and southwestern British Columbia, the spruce-hemlock of the Olympic Peninsula and Oregon coast, the larch-pine of central, north central, and northeastern Washington, the hemlock-cedar-lowland white fir of northern Idaho, the pine-Douglas fir on the eastern slope of the Oregon Cascades, and the pine-hemlock about Crater Lake, Oregon. Bogs located in the Willamette Valley of western Oregon and the sagebrush areas of eastern Washington and the northern Great Basin of southern Oregon have also been analyzed. The bog of this study is of especial interest because of its high elevation. To the author's knowledge it has the greatest altitude of any bog analyzed.

In alpine and subalpine lakes of the Pacific Northwest, hydrarch succession has rarely progressed to a stage of sufficient organic sedimentation to warrant pollen analyses. It seems probable that the short growing season, the severe winters, and the low water temperature are the chief reasons for the comparative absence of peat. Another consideration is the youthfulness of the lakes, due, perhaps, to the persistence of mountain glaciers for a longer period of time than the continental ice sheet at lower elevations. The absence of peat-forming plants may be another factor in the slow rate of peat accumulation.

## Location and Characteristics of the Bog

The site of the peat deposit is Mud Lake, one of the Anthony Lakes that lie near the crest of the Blue Mountains in northeastern Oregon. It is about 25 miles northwest of Baker, in section 7 of T. 7 S., R. 37 E. on the Sumpter Quadrangle. The altitude is about 7000 feet. The lake has been ponded in a glacial valley less than two miles from the headwaters of Anthony Fork River, the upper tributaries of which rise in a series of cirques at the bases of three peaks that attain an altitude of more than 8000 feet. The lake is only a few acres in extent and very shal-

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low. The author was unable to determine whether it was formed in a kettle or dammed by a terminal moraine. A considerable portion of the lake is occupied by a submerged hydrosere. Near the shore a floating stage consists chiefly of pondweed (*Potamogeton* sp.). A zone of sedge (*Carex* spp.) from 50 to 100 feet wide surrounds much of the lake.

Peat samples were obtained at two places near the shore in the sedge zone at 2-decimeter intervals, with a Swedish-type peat borer. The depth of one profile is four meters, while that of the other is three meters. The organic sediments are underlain with volcanic ash which was impenetrable to a depth greater than six inches. Additional peat strata may underlie the ash, but the depth of the profile at this altitude suggests that it represents most, or all, of post-Pleistocene time. The source of the ash is unknown. The occurrence of a single layer of ash is common in post-Pleistocene bogs in Washington, both east and west of the Cascade Range (Hansen, '38, '39a, '39b, '40a, '41a, '41e, '41f; Rigg and Richardson, '38). Pumice strata are present in peat profiles in the Willamette Valley and Cascades of Oregon (Hansen, '42b, '42c, '42d). The ash in Washington bogs probably came from Glacier Peak in the northern part of the State (Hansen, '41f). Other possible sources are Mt. St. Helens, Mt. Adams, and Mt. Baker. The pumice strata in peat profiles of the Willamette Valley evidently came from the eruption of Mount Mazama, about 5000 years ago, which formed the caldera holding Crater Lake in southern Oregon (Williams, '41). In a montane bog near Bend, Oregon, there are two strata of pumice, separated by 2.5 meters of organic sediments (Hansen, '42c). The upper layer undoubtedly had its source in the eruption of Mount Mazama, but the source of the lower stratum is unknown. Peat deposits nearer to Crater Lake are underlain by several feet of Mount Mazama pumice (Hansen, '42d). In other parts of northeastern Oregon, a layer of volcanic ash [2] is exposed several feet below the surface of recent wash in gullies. It is not possible at present to say if this ash is synchronous with that underlying the peat deposit of this study. It is possible that the latter was transported into the lake by streams that cut into older ash deposits. This theory is somewhat supported by the abundance of pollen within the ash stratum itself. Volcanic glass is present in diminishing quantity upward in the profiles, indicating continued transportation of the ash. Brown sedimentary peat overlies the ash stratum and grades upward into fibrous peat near the surface.

## Methods

In preparation of the sediments for microscopic analysis, the potassium hydrate method was used. One hundred and fifty to 200 pollen grains were identified from each level. The identification of the winged conifer pollen was based upon the size-range method (Hansen, '41a, '41b, '41d). In this study pollen listed as that of whitebark pine (*Pinus albicaulis*) may include some of the western white pine (*P. monticola*) and limber pine (*P. flexilis*), because the size-range in these species lies within that of whitebark pine. Western white pine is present in the Canadian life zone of the Blue Mountains, but limber pine occurs only in the Wallowa Mountains of northeastern Oregon and probably is not represented here (Munns, '38). It may, of course, have existed abundantly in the past. Pollen listed as that of alpine fir (*Abies lasiocarpa*), may include a trace of lowland white fir (*A. grandis*). Species that are recorded to 1.5 per cent or less are listed in the tables as 1 per cent.

The interpretation of vegetation history from pollen profiles involves a number of errors, both obvious and intangible. Interpretation of climatic trends is also subject to sources of error involved in the

[2] Personal communication from J. E. Allen, Geologist, State Department of Geology and Mineral Industries, Portland, Oregon.

relative climatic indicator evaluation of the several species concerned. One of the sources of error in interpreting forest succession from pollen profiles is the factor of relative abundance. It is assumed that an increase in the pollen proportions of one species and a decrease in those of another denote a correlative change in their actual abundance. It is possible, however, that one species or group of species may increase in abundance while another remains static, or vice versa, although the latter shows a decrease in pollen proportions. In this study the presence of pollen from species of several life zones tends to amplify the importance of relative abundance.

## Forests in Adjacent Areas

The site of the peat profiles lies within and near the upper limits of the Hudsonian life zone (Bailey, 1936). A few miles to the south of Mud Lake, the Hudsonian grades into the Arctic-alpine zone. The highest peak in the latter zone is Rock Creek Butte with an elevation of 9097 feet. The Canadian zone surrounds the Hudsonian at lower altitudes, and in turn the Canadian gives way to the timbered Arid Transition. The bog is located in the Petran subalpine forest association according to the classification of forest climaxes by Clements (Weaver and Clements, '38). The typical dominants of this association in the Blue Mountains are alpine fir, whitebark pine, and Engelmann spruce (*Picea engelmanni*). Whitebark pine occurs abundantly near timberline. Lodgepole pine (*Pinus contorta*) is the most abundant species in both the Canadian and Hudsonian zones, occurring as a subclimax due to fire (Clements, '10). A cursory survey suggests that about 50 per cent of the forests in the vicinity of the bog consists of lodgepole pine, 25 per cent of alpine fir, and 25 per cent of Engelmann spruce. These species are present in mixed stands. Species common in the Hudsonian zone of the Cascades such as Alaska cedar (*Chamaecyparis nootkatensis*), mountain hemlock (*Tsuga mertensiana*), and alpine larch (*Larix lyallii*) are absent or rare in the Blue Mountains. A few pollen grains of mountain hemlock are present in the peat profiles, and this species was observed in this part of the Blue Mountains by Sudworth ('08). In the Canadian zone, lodgepole pine probably composes a greater proportion of the forest than in the Hudsonian zone. Engelmann spruce is also common in the upper part of the Canadian zone. Other species of greater or lesser abundance in this zone are Douglas fir (*Pseudotsuga taxifolia*), western larch (*Larix occidentalis*), western white pine, and lowland white fir. Western hemlock (*Tsuga heterophylla*) is of rare occurrence in the Blue Mountains and was not noted by Sudworth ('08), although Munns ('38) shows a single station for this species. It has existed within range of pollen dispersal to the site of the bog, however, because it is sparsely and sporadically recorded by its pollen in both of the profiles (tables I and II). Two other species, common in the Canadian zone of western Oregon and Washington but seemingly absent from the Blue Mountains, are noble fir (*Abies nobilis*) and silver fir (*A. amabilis*).

The timbered Arid Transition area is narrow and the principal species is western yellow pine (*Pinus ponderosa*). Yellow pine forests are far more extensive at lower elevations to the west than to the east, where they form only a narrow zone between the Canadian and timberless Arid Transition. In the upper part of this province, a few specimens of white fir (*Abies concolor*) are to be found. Douglas fir, western larch, and lowland white fir are also present on favorable sites. The principal broadleaf species in this zone is black cottonwood (*Populus trichocarpa*), which thrives along water courses. In the Canadian zone, aspen (*Populus tremuloides*), mountain alder (*Alnus tenuifolia*), and mountain maple (*Acer douglasii*) grow in restricted areas.

### Climate

The bog is located within a climatic province designated as semi-arid, microthermal, and with a deficiency of precipitation at all seasons (Thornthwaite, '31). The forests of the Canadian and Hudsonian zones, however, prove that there is sufficient precipitation for tree growth. The mean annual precipitation at Columbia Mine, 10 miles to the southeast, is about 35 inches; at Greenhorn, 18 miles to the southwest, it is also about 35 inches; and at Ibex Mine, 10 miles to the south, it is 29 inches (Climatic Summary, U. S. D. A., '36). At all three stations, between 20 and 23 per cent of the annual precipitation occurs from May to September inclusive. Their elevation is about 6000 feet, and the precipitation is probably similar to that in areas adjacent to the bog. At Baker, with an elevation of 3500 feet, the mean annual precipitation is almost 12 inches, with 35 per cent occurring from May to September. The mean annual precipitation at Seattle, Washington, in the midst of the hemlock-cedar climax is about 33 inches, with only a small percentage occurring from May to September. It seems probable that the more rigorous climate due to greater altitude is responsible for the relative absence of western hemlock and Douglas fir in the Anthony Lakes region.

### Vegetation History

The forests within range of pollen dispersal to Mud Lake when the lowest pollen-bearing sediments were deposited, consisted chiefly of whitebark, lodgepole, and western yellow pine. The first two are recorded to 42 per cent in the deeper profile and to 38 and 40 per cent respectively in the other. Lodgepole and whitebark pine are recorded in equal abundance, but the first produces more pollen than other Pacific Northwest conifers, and is undoubtedly over-represented in most peat profiles. Whitebark pine may actually have been more abundant than lodgepole in the Hudsonian zone. Lodgepole declines from the bottom in both profiles to its lowest proportions at 2.8 and 2 meters with 24 and 20 per cent respectively (figures 1, 2). Whitebark pine also declines but remains more abundant than lodgepole to a point about half-way up the profiles, where it is superseded by lodgepole pine. The latter remains predominant to the sur-

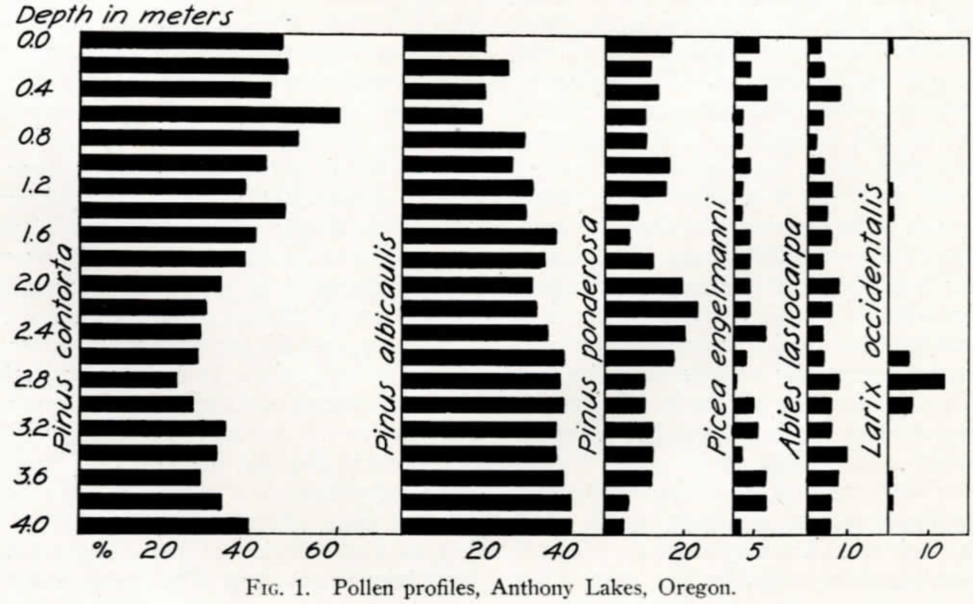


Fig. 1. Pollen profiles, Anthony Lakes, Oregon.

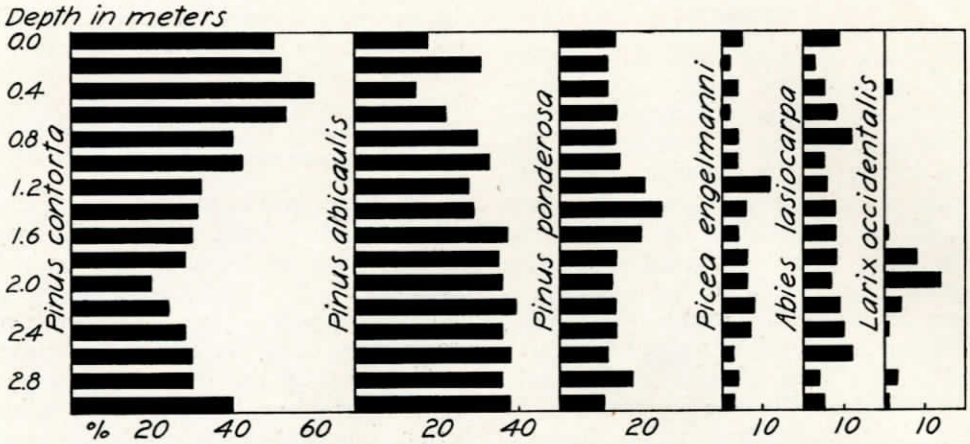


FIG. 2. Pollen profiles, Anthony Lakes, Oregon.

face and whitebark pine continues its general decrease to the surface.

The pollen profiles of western larch are significant. It is sparsely represented in the lower horizons and then shows a sharp increase to 14 per cent at 2.8 meters in the deeper profile and to the same proportion at 2 meters in the other (figures 1, 2). These levels are evidently approximately synchronous. Larch then declines to only a trace and is sparsely and sporadically recorded to the surface in both profiles. Lodgepole reaches its lowest proportions at the levels of larch maximum, and then shows an almost constant increase to the surface. The influx of larch suggests the occurrence of several fires in close succession. This species has very thick bark, and is able to survive severe fires that first destroy the parent trees of other species, and then the seedlings (Sudworth, '08, Larsen, '29). Larch then flourishes in the absence of competition with other tree species. If the area is undisturbed by fire, however, other species will gradually replace larch because of its intolerance of shade. Lodgepole may also benefit from fire, but in a different way. Many of its cones do not open when mature, but cling to the tree for many years, retaining viable seed. The heat from fire may cause the cones to open, shedding considerable seed. The absence of competition likewise permits this pine to thrive until others regain a foothold and gradually replace it (Harlow and Harrar, '41). The decrease of lodgepole to the level of larch maximum suggests that it also suffered from the hypothetical fires. Its rapid increase from this level to the surface, however, indicates that the environment was favorable from that time to the present (figures 1, 2). An initial predominance of larch recorded in the peat profile near Bend, Oregon, also denotes repeated fire prior to sedimentation (Hansen, '42c). Larch does not shed nearly so much pollen as the pines, and it is thus under-represented.

The pollen profiles of yellow pine reveal that the abundance of this species remained static to the time of larch maximum. It fluctuates between 5 and 12 per cent in the deeper profile, and from 11 to 18 per cent in the other. Yellow pine then sharply increases to attain its maximum proportions of 23 per cent at 2.2 meters in the deeper, and 25 per cent at 1.4 meters in the other profile. It declines through the next several levels and remains rather constant to the surface. Apparently the hypothetical fires did not affect the abundance of yellow pine, as it may have existed at lower altitudes and was not subject to fire. Drying of the climate may have been involved in yellow pine attaining its maximum. The horizons of yellow pine maximum in the two profiles are probably synchronous.

Other conifers recorded by their pollen in appreciable proportions are Engelmann spruce and alpine fir. They are represented as having been constant throughout both profiles and show no successional trends. Engelmann spruce fluctuates between 1 and 12 per cent, while alpine fir varies from 2 to 12 per cent in the two profiles. Fire evidently prevented these species from reaching their greatest development. Douglas fir, western and mountain hemlock, and white fir are also represented in low proportions (tables I and II). Pollen of broadleaf species present includes chiefly alder and maple, with the latter most abundant. Composites, grasses, and chenopods are sparsely but consistently represented. The pollen of chenopods may have come from dryer and alkaline areas at much lower elevations.

In most post-Pleistocene peat profiles located within the glaciated region of the Pacific Northwest, lodgepole is recorded as having been the chief pioneer invader (Hansen, '38, '39a, '39b, '40a, '41a, '41e). Peat profiles in the lower Willamette Valley of Oregon also show lodgepole pine as the pioneer postglacial invader, though it is entirely absent in this area at present (Hansen, '42b). The Willamette Valley was not glaciated but it was inundated by glacial backwater from the Columbia River (Allison, '35). The unstable physiographic and edaphic conditions during the early post-Pleistocene were probably responsible for the initial predominance of lodgepole here and in many other parts of the Pacific Northwest. The advantage obtained by lodgepole pine due to radical changes in the edaphic conditions is well exemplified by a pollen study of a 7-meter pollen-bearing profile on the east slope of the Cascade Range, near Bend, Oregon (Hansen, '42c). Two strata of pumice occur in the profile; one at 4.5 and the other at 2 meters. The pumice mantle deposited by the earlier volcanic eruption interrupted a strong trend toward a yellow pine climax, which is the normal climatic climax of this region. Lodgepole is recorded as having made a sharp increase to assume predominance immediately after the eruption. As the pumiceous soil was somewhat modified, yellow pine partially regained its former abundance, only to be interrupted again by the second volcanic eruption. Lodgepole maintained predomi-

TABLE I. *Percentages of fossil pollen. Anthony Lakes.*

| Depth in meters | 4.0 | 3.8 | 3.6 | 3.4 | 3.2 | 3.0 | 2.8 | 2.6 | 2.4 | 2.2 | 2.0 | 1.8 | 1.6 | 1.4 | 1.2 | 1.0 | 0.8 | 0.6 | 0.4 | 0.2 | 0.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Pinus contorta* | 42 | 35 | 30 | 34 | 36 | 28 | 24 | 29 | 30 | 31 | 35 | 41 | 44 | 51 | 41 | 46 | 54 | 64 | 47 | 51 | 50 |
| *P. albicaulis* | 42 | 42 | 40 | 38 | 38 | 40 | 39 | 40 | 36 | 33 | 32 | 35 | 38 | 30 | 32 | 27 | 30 | 19 | 20 | 26 | 20 |
| *P. ponderosa* | 5 | 6 | 12 | 12 | 12 | 10 | 10 | 17 | 20 | 23 | 19 | 12 | 6 | 8 | 15 | 16 | 10 | 10 | 13 | 11 | 16 |
| *Pseudotsuga taxifolia* | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | | | | 1 | 1 | | 1 | | 1 | 1 | 1 |
| *Tsuga heterophylla* | 1 | | | | | 1 | | | 1 | 1 | | 1 | 1 | | | | | 1 | 1 | | 1 |
| *T. mertensiana* | 1 | 1 | | 1 | | 2 | 1 | | | | 1 | 1 | 1 | | 1 | 1 | | | 1 | 1 | 1 |
| *Picea engelmanni* | 2 | 8 | 8 | 2 | 6 | 5 | 1 | 3 | 8 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 2 | 2 | 8 | 4 | 6 |
| *Abies lasiocarpa* | 6 | 6 | 8 | 10 | 6 | 6 | 8 | 4 | 4 | 6 | 8 | 4 | 6 | 5 | 6 | 4 | 2 | 4 | 8 | 4 | 3 |
| *A. concolor* | | | | 1 | | 1 | 2 | 1 | | 1 | 1 | 2 | | 2 | 1 | 2 | 1 | | 1 | 2 | 1 |
| *Larix occidentalis* | | 1 | 1 | | | 6 | 14 | 5 | | | | | | 1 | 1 | | | | | | 1 |
| *Pinus* spp.* | 12 | 17 | 17 | 15 | 21 | 12 | 15 | 22 | 21 | 23 | 22 | 17 | 10 | 20 | 17 | 19 | 20 | 18 | 17 | 19 | 15 |
| *Abies* spp.* | 1 | | | 2 | | 1 | | | | 1 | 1 | | | | | | | | | | 1 |
| Gramineae* | | 1 | 2 | 1 | | 1 | 2 | 1 | | | | | 1 | 2 | | 1 | | | | | 2 |
| Compositae* | 1 | | 3 | 2 | | 3 | 2 | 4 | | 2 | 2 | 2 | | | 4 | | | | 1 | | 1 |
| Chenopodiaceae* | 1 | 1 | 1 | | 1 | 1 | 1 | | 2 | 2 | 1 | | 2 | 2 | | 1 | | 1 | | | |
| Alnus* | 3 | | 2 | 3 | | 1 | | 3 | | | | | | 1 | 1 | 1 | 1 | 1 | | | 1 |
| Acer* | 6 | 8 | 6 | 4 | 3 | 7 | 2 | 4 | | 6 | 3 | 3 | 4 | 4 | 2 | 5 | 2 | 2 | 5 | 1 | 6 |
| Salix* | | | | | 5 | | 1 | | | | 1 | 1 | | 1 | | | | | | 1 | |
| Cyperaceae* | 2 | 2 | 3 | 5 | 1 | 5 | | 1 | 2 | 1 | 2 | 2 | 6 | 1 | 7 | 4 | 2 | 1 | 4 | 1 | 65 |
| Nymphozanthus* | | | 1 | 1 | 2 | 3 | 2 | 4 | 1 | | | 1 | 1 | 1 | 1 | | | | | 1 | 1 |

* Number of pollen grains, not computed in the percentages.

TABLE II. *Percentages of fossil pollen. Anthony Lakes.*

| Depth in meters | 3.0 | 2.8 | 2.6 | 2.4 | 2.2 | 2.0 | 1.8 | 1.6 | 1.4 | 1.2 | 1.0 | 0.8 | 0.6 | 0.4 | 0.2 | 0.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Pinus contorta* | 40 | 30 | 30 | 28 | 24 | 20 | 28 | 30 | 31 | 32 | 42 | 40 | 53 | 60 | 52 | 50 |
| *P. albicaulis* | 38 | 36 | 38 | 36 | 39 | 36 | 35 | 37 | 29 | 28 | 33 | 30 | 22 | 15 | 31 | 18 |
| *P. ponderosa* | 11 | 18 | 12 | 14 | 14 | 13 | 14 | 20 | 25 | 21 | 15 | 14 | 14 | 12 | 12 | 14 |
| *Pseudotsuga taxifolia* | 1 | 3 | 3 | 3 | | 1 | 1 | | | 1 | 1 | | 1 | 1 | | 1 |
| *Tsuga heterophylla* | | | | | 1 | 1 | | | | | | | | | | 1 |
| *T. mertensiana* | 1 | | 1 | 1 | 1 | 1 | | | | | | | | | | |
| *Picea engelmanni* | 3 | 4 | 3 | 7 | 8 | 6 | 6 | 4 | 6 | 12 | 4 | 4 | 2 | 4 | 2 | 5 |
| *Abies lasiocarpa* | 5 | 4 | 12 | 10 | 9 | 7 | 8 | 8 | 8 | 6 | 5 | 12 | 8 | 5 | 3 | 9 |
| *A. concolor* | | 2 | 1 | | | 1 | | | 1 | | | | | 1 | | 2 |
| *Larix occidentalis* | 1 | 3 | | 1 | 4 | 14 | 8 | 1 | | | | | | 2 | | |
| *Pinus* spp.* | 12 | 15 | 11 | 11 | 12 | 17 | 15 | 16 | 22 | 21 | 15 | 18 | 19 | 15 | 23 | 17 |
| *Abies* spp.* | | | 2 | | 1 | 1 | 3 | | | 1 | | | | | | |
| Gramineae* | | 1 | | | | | | | | | 1 | | | | | |
| Compositae* | | 1 | 1 | | 1 | 1 | 1 | 1 | 3 | 1 | | | 1 | | 1 | 1 |
| Chenopodiaceae* | | 1 | | 1 | 1 | | 1 | | | 3 | 1 | 2 | 2 | | | 2 |
| Alnus* | | | 3 | 1 | 1 | 1 | 3 | | | | | | | | | |
| Acer* | | 6 | 6 | 9 | 4 | 7 | 5 | 1 | 4 | 1 | 5 | | 2 | 8 | 2 | 1 |
| Salix* | | | | 1 | | 2 | | 3 | | 1 | | 3 | | 1 | | 1 |
| Cyperaceae* | | | 1 | 2 | 2 | | 3 | 2 | 3 | 3 | 2 | 2 | 3 | 3 | 12 | 42 |
| Nymphozanthus* | | | | 1 | 3 | 3 | 1 | | 1 | | | | | | | |

* Number of pollen grains, not computed in the percentages.

nance to the present. The vast lodgepole pine forests on the pumice mantle of central Oregon have existed as an edaphic climax since the first recorded post-Pleistocene volcanic eruption. In unglaciated regions where the forests and soil were not materially disturbed during the later part of the Pleistocene, or the early part of the postglacial period, pollen profiles show that lodgepole was not predominant when the earliest sediments were deposited (Hansen, '41b, '41c, '41d). Usually the dominants of the present formations are most abundantly recorded throughout the profiles.

## CLIMATIC CONSIDERATIONS

The chief climatic indicators are whitebark and yellow pine. The first exists at and near timberline in the Hudsonian zone and the latter thrives in the timbered Arid Transition. These two provinces are separated by the Canadian zone, but no species characteristic of this zone are recorded in significant quantity. Undoubtedly the pollen listed as that of whitebark pine includes some of western white pine. The latter is a good indicator of the Canadian zone in the Pacific Northwest, and it may have been more abundant in the Anthony Lakes region during the past. Engelmann spruce also grows largely in the Canadian zone, but its pollen proportions are too low and its profiles too constant in this study to mark any climatic trends. The most common tree by far in the Canadian zone is lodgepole, and it is of little value as a climatic index. Western larch grows in the upper part of the Transition and the lower part of the Canadian, but this species is rarely predominant, except as a result of repeated fire. The pollen profiles of alpine fir are too constant and its proportions too low to warrant a climatic interpretation. The pollen of Douglas fir, white fir, and western and mountain hemlock is too scanty in both profiles to offer any evidence for climatic trends.

Western yellow pine is perhaps the best climatic indicator. It is one of the most xerophytic of Pacific Northwest conifers, and because of its existence adjacent to the low elevation timberline, its response to climatic changes should be reflected in the pollen profiles. It would seem that whitebark pine is also a good climatic indicator, because it exists adjacent to the high elevation timberline. It is especially significant in this case since the bog is located near the upper limits of the Hudsonian zone, immediately below timberline. The high proportions of lodgepole pine, however, tend to minimize the climatic indicator value of whitebark pine in these profiles. The rapid gain in yellow pine from the horizon of larch maximum in both profiles, signifies a warming and drying of the climate as the influence of recent glaciation waned. The larch maximum suggests that fire retarded the trend of yellow pine increase. As the effects of the hypothetical fires were modified, yellow pine belatedly responded positively to the warming climate. The general decline in whitebark pine from the bottom to the level of yellow pine maximum is corroborating evidence for this climatic trend. The decline of yellow pine from its peak to proportions that are generally maintained to the surface, marks a cooling and humidifying of the climate to a degree which has persisted to the present. A continued decline in whitebark pine from the time of yellow pine maximum almost to the present, however, does not substantiate this interpreted trend. The rapid gain of lodgepole from the time of larch maximum to nearly the present denotes a sustained favorable environment for this species in the Canadian and Hudsonian zones. The recorded decline of whitebark pine during the same period may then be merely relative. It probably remained more or less constant in the upper part of the Hudsonian zone.

Yellow pine pollen preserved in the sediments must have come from forests at much lower elevation. This means that the factor of relative abundance may be of critical importance. Does the increase in yellow pine pollen proportions denote an upward movement of the timbered Arid Transition due to a warming and drying of the climate, an increase in yellow pine within its own province because of non-climatic changes in the environment, an increase in relative abundance, or merely an alteration of those factors controlling the transportation and preservation of the pollen in the accumulating sediment? Notwithstanding these possibilities, the occurrence of a post-Pleistocene xerothermic period as portrayed by the yellow pine profiles of this study is substantiated by pollen profiles of other peat deposits in the Pacific Northwest, both east and west of the Cascade Range. In some profiles the recorded succession of grasses, composites, and chenopods marks the period of desiccation, while in others the trend of forest succession depicts a gradual warming and drying to a maximum, succeeded by cooling and humidifying to a degree that has been maintained to the present (Hansen, '39b, '40b, '41b, '41e, '42a). In the Willamette Valley of western Oregon a partial replacement of Douglas fir by white oak (*Quercus garryana*) in the upper one-third of three peat profiles supports the interpreted occurrence of a xeric period (Hansen, '42a). Anthropological and geological studies in southcentral Oregon also tend to corroborate the evidence offered by the pollen profiles (Cressman, '40; Antevs, '40).

## Summary

A pollen study of a subalpine bog in the Blue Mountains of northeastern Oregon suggests that changes in relative abundance of the several species of forest trees may have been an important factor in determining their pollen profiles. The tree pollen of three life zones is preserved in the peat profiles. The Hudsonian zone, in which the pollen-bearing sediments are located, is the best represented, with lodgepole and whitebark pine predominant. The Canadian zone is poorly represented by a typical species, but lodgepole pine has probably been abundant in this zone also, because of fire. The timbered Arid Transition is represented by western yellow pine.

Whitebark pine shows a general decrease from the bottom to the surface. This indicated trend may be merely relative because of an increase in actual abundance of lodgepole pine in the Hudsonian and Canadian zones. Lodgepole pine manifests its predominance in the upper half of the profiles. Although lodgepole

probably owes its abundance to fire, its initial decline and the concurrently sharp increase of western larch to its maximum in the lower third of the profiles, marks the occurrence of repeated fire, too severe even for lodgepole. Generally constant proportions of yellow pine during this period indicates that the fires did not occur in the Arid Transition. Its increase from the level of larch maximum and lodgepole pine minimum denotes warming and drying of the climate. A decline of yellow pine immediately following its peak denotes an increase of moisture to a degree which has persisted to the present, or merely a change in relative abundance. Engelmann spruce and alpine fir are recorded in low proportions, reflecting the influence of fire in preventing their normal development in this region.

## Literature Cited


**Allison, I. S.** 1935. Glacial erratics in Willamette Valley. Geol. Soc. Amer., Bull. **46**: 615–632.

**Antevs, Ernst.** 1940. Age of artifacts below peat beds in Lower Klamath Lake, California. Carnegie Instn. Wash. Yearbook, **39**: 307–309.

**Bailey, Vernon.** 1936. The mammals and life zones of Oregon. North Amer. Fauna, **55**: 1–416. U. S. Dept. Agric. Washington, D. C.

**Clements, F. E.** 1910. The life history of lodgepole burn forests. U. S. Forest Service Bull. **79**.

Climatic Summary of the United States. 1936. Eastern Oregon. U. S. Dept. Agric. Washington, D. C.

**Cressman, L. S.** 1940. Studies on early man in south central Oregon. Carnegie Instn. Wash. Yearbook, **39**: 300–306.

**Hansen, H. P.** 1938. Postglacial forest succession and climate in the Puget Sound region. Ecology, **19**: 528–543.

——. 1939a. Pollen analysis of a bog in northern Idaho. Amer. Jour. Bot., **26**: 225–228.

——. 1939b. Pollen analysis of a bog near Spokane, Washington. Bull. Torrey Bot. Club, **66**: 215–220.

——. 1940a. Paleoecology of two peat bogs in southwestern British Columbia. Amer. Jour. Bot., **27**: 144–149.

——. 1940b. Paleoecology of a montane peat deposit at Bonaparte Lake, Washington. Northwest Science, **14**: 60–69.

——. 1941a. Further pollen studies of post-Pleistocene bogs in the Puget Lowland of Washington. Bull. Torrey Bot. Club, **68**: 133–148.

——. 1941b. Paleoecology of a peat deposit in west central Oregon. Amer. Jour. Bot., **28**: 206–212.

——. 1941c. Paleoecology of a bog in the spruce-hemlock climax of the Olympic Peninsula. Amer. Midl. Nat., **25**: 290–298.

——. 1941d. Paleoecology of two peat deposits on the Oregon Coast. Oregon State Monographs; Studies in Botany, **3**: 1–31.

——. 1941e. A pollen study of post-Pleistocene lake sediments in the Upper Sonoran life zone of Washington. Amer. Jour. Sci., **239**: 503–522.

——. 1941f. Paleoecology of a montane peat deposit near Lake Wenatchee, Washington. Northwest Science, **15**: 53–65.

——. 1942a. A pollen study of peat profiles from Lower Klamath Lake of Oregon and California. (In press, Carnegie Inst. Wash.)

——. 1942b. A pollen study of lake sediments in the Lower Willamette Valley of western Oregon. Bull. Torrey Bot. Club, **69**: 262–280.

——. 1942c. The influence of volcanic eruptions upon the post-Pleistocene forest succession in central Oregon. Amer. Jour. Bot., **29**: 214–219.

——. 1942d. Post-Mount Mazama forest succession on the east slope of the central Cascades of Oregon. Amer. Midl. Nat., **27**: 523–534.

**Harlow, W. H., and E. S. Harrar.** 1941. Textbook of Dendrology. New York.

**Munns, E. N.** 1938. Distribution of important forest trees of the United States. Misc. Publ., **287**. U. S. Dept. Agric., Washington, D. C.

**Larsen, J. A.** 1929. Fires and forest succession in the Bitterroot Mountains in northern Idaho. Ecology, **10**: 67–76.

**Rigg, G. B., and T. C. Richardson.** 1938. Profiles of some Sphagnum bogs on the Pacific Coast of North America. Ecology, **19**: 408–434.

**Sudworth, G. B.** 1908. Forest trees of the Pacific Slope. U. S. Dept. Agric., Washington, D. C.

**Thornthwaite, C. W.** 1931. The climates of North America according to a new classification. Geog. Rev., **21**: 633–655.

**Weaver, J. E., and F. E. Clements.** 1938. Plant ecology. New York.

**Williams, Howel.** 1941. Crater Lake: the story of its origin. Univ. California Press, Berkeley, Cal.