Willamette Valley

LAKE LABISH

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A POLLEN STUDY OF LAKE SEDIMENTS IN THE LOWER WILLAMETTE VALLEY OF WESTERN OREGON[1]

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The occurrence of peat deposits beyond the limits of Pleistocene glaciation in the Pacific Northwest is uncommon. Sphagnum bogs are rare except along the Pacific Ocean where the moist, equable climate is favorable for their development. In the Willamette Valley of western Oregon, the small amount of precipitation during the growing season is probably the chief reason for the absence of sphagnum bogs. The author has made a pollen study of the only extensive one known to exist in this area (Hansen 1941a). Sedge, tule, reed, and cat-tail swamps or bogs are also uncommon, but they may be occasionally found on floodplains, in abandoned stream channels, and in oxbow lakes. Many of these areas have been drained for agricultural purposes, and often practically all evidence of their previous existence has been obliterated. Floodplain associes of willow, cottonwood, alder, ash, and large-leaf maple also mark the presence of hydroseres that are rapidly nearing the climax stage of plant succession. Many of these areas are merely alluvial floodplains where the water table remains sufficiently high during the summer to permit the growth of moisture-loving species. Few of these areas, however, have an accumulation of peat or other pollen-bearing sediments suitable for the purpose of pollen analysis. It is fortunate, therefore, that several peat deposits satisfactory for pollen analysis are present in the lower Willamette Valley. Their pollen record serves as a valuable accession to the problem of post-Pleistocene forest succession and climate in the Pacific Northwest. The Willamette Valley is a rather distinct floristic province within an otherwise more or less homogeneous hemlock-cedar forest climax of this region.

ORIGIN AND CHRONOLOGY OF THE SEDIMENTS

The peat profiles for this study were obtained from two different deposits. Two profiles were obtained from the Labish Flats, located about 4 miles northeast of Salem, Oregon. Lake Labish was formerly a shallow lake before it was drained in 1912 for agricultural purposes. The lacustrine sediments cover an area about 9 miles long and one-half mile wide. The elevation is between 140 and 150 feet above sea level. The upper end of the former lake is separated from the Willamette River by a divide not over two miles wide and about 30 feet high. The width and depth of the channel and the adjacent

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topography indicate that it is an abandoned course of the Willamette River. The channel was probably occupied by a distributary of a braided stream. The lake was evidently ponded by a delta deposited by the Pudding River. Later the Willamette River receded and the present channel carried its water. The Pudding River follows the old Willamette Channel from the lower end of Lake Labish, emptying into the present Willamette River farther north and downstream. The level of Lake Labish was maintained by smaller streams debouching into it. One of them is now the Little Pudding River.[2] Peat samples of the profiles were taken at quarter-meter intervals with a Hiller peat borer. One profile was taken in section 31 of T. 6 S., R. 2 W., and the other was obtained in section 21 of the same township. The depth of the lacustrine sediments in both profiles is 7 meters. The depth has been somewhat reduced since drainage, by consolidation, oxidation, and deflation. The surface of the sediments has been lowered by at least 3 feet, and undoubtedly some of the original surface has been lost through deflation. Shorelines of the original lake exist from 15 to 25 feet above the present surface. The lowest level sampled consists of fine sand and silt which grades into clay at 6.5 meters. The clay changes to gray-brown sedimentary peat at 5 meters, which in turn grades into brown fibrous peat at 4 meters. The last type continues to the surface and becomes coarser upward in the profiles. Both profiles are essentially the same with respect to the thickness of the various types of sediments. *Hypnum* moss leaves are present throughout the fibrous peat. A layer of pumice less than an inch thick occurs at 1.75 meters in both profiles. It is not possible to state the source of the pumice because there have been several active volcanoes in the Cascades of Oregon during the post-Pleistocene (Williams 1935, 1941). A bog about 13 miles west of Bend, Oregon, has two layers of pumice, while bogs farther south in the Cascade Range rest on a thick mantle of pumice. The latter evidently came from the eruption of Mount Mazama, which resulted in the formation of the caldera holding Crater Lake.

A third profile of lacustrine sediments was sampled at Onion Flat, about 2 miles northeast of Sherwood, Oregon. This deposit lies about 30 miles north of Lake Labish, and 10 miles south of Portland, at an elevation between 130 and 140 feet above sea level. The peat and other pollen-bearing sediments have accumulated in a former channel of the Tualatin River which rises in the Coast Range to the west and empties into the Willamette River about 2 miles south of Oregon City.[3] Samples were obtained in section 21 of T. 2 S., R. 1 W. The depth of the sediments in the area of sampling is 12 meters. This bog has also been drained and the present surface is not that which existed before drainage. The bog is underlain with sand and gravel which grade into

[2] U. S. Geol. Surv. Topogr. map, Mount Angel Quadrangle, Oregon.

[3] U. S. Geol. Surv. Topogr. map, Oregon City and Tualatin Quadrangles, Oregon.

silt at 12 meters. Fine clay with considerable organic matter present occurs from 12 to 9 meters. The stratum between 9 and 5 meters consists of a gray-brown sedimentary peat, and fibrous peat is present from 5 meters to the surface. The surface sediments seem to have been more oxidized than those at Labish Flats. No definite stratum of pumice or ash is discernible with the naked eye, but volcanic glass is abundant at 0.5 and 0.75 meters. This suggests that a greater thickness of surface sediments has been removed than at Labish Flats, where the pumice layer occurs at 1.75 meters. It is probable that the pumice and glass had the same origin. In none of the profiles, therefore, is the forest succession recorded by tree pollen to the present time. Each year the surface is plowed, so that the upper several inches of peat are not suitable for pollen analysis. The uppermost sample of each profile was obtained from the highest undisturbed horizon.

Peat deposits formed in depressions lying on glaciated sites may be readily dated with their maximum ages. The Willamette Valley, however, was not glaciated during the Pleistocene. The mountain glaciers in the Cascade Range a few miles to the east apparently were of insufficient magnitude to reach the Willamette Valley. nor was the Coast Range to the west glaciated (Fenneman 1931). During the melting of the last stage of the Wisconsin glacier, the Willamette Valley was inundated by backwater from the glacier-swollen Columbia River (Bretz 1919). The water reached a height of several hundred feet above the valley floor as is evidenced by the occurrence of ice-rafted erratics (Allison 1935). This inundation suggests that any peat deposits or other types of lacustrine sediments on the Willamette Valley floor are of postglacial origin. As previously stated, Lake Labish was ponded in an abandoned channel of the Willamette River, probably a distributary of the main stream when it carried a greater volume of water than at present. The Onion Flat sediments were deposited in a former channel of the Tualatin River, although it apparently was not an oxbow left by a meandering stream. It was probably formed when the Tualatin River carried a greater volume of water than the main channel could hold, and spilled over as a distributary to further erode small tributary valleys. These channels must have been occupied by their respective streams when there was considerably more water available from their hydrographic basins than at present. This probably occurred during the early post-Pleistocene when there was heavy precipitation as well as an abundance of meltwater from wasting mountain glaciers. It is hard to say how long these channels were occupied by their respective streams. If they were abandoned soon after the recession of the continental ice sheet to the north and subsidence of glacial water in the Willamette Valley, the sediments of this study had their initiation in early post-Pleistocene. The 12-meter depth of the Onion Flat profile and the forest succession recorded in the lower half suggests that this is probably true.

Twelve meters of sediments, largely organic, are of considerable magnitude, especially in the Willamette Valley where the summers are dry and far from the optimum for the maximum rate of peat deposition. The average depth of 16 post-Pleistocene peat deposits west of the Cascades in Oregon, Washington, and British Columbia is about 31 feet, as shown by profiles in a study by Rigg and Richardson (1938). Most of these deposits lie in regions climatically favorable to rapid peat accumulation. It is realized that climate is not the only factor that controls the rate of organic sedimentation, but peat deposits in the dryer regions east of the Cascades, in Washington, average about 19 feet in depth (Hansen 1941g). The depth of the Onion Flat sediments is almost twice that of Labish Flats. The rate of peat deposition may vary in the same region, but the relative thickness and proportions of clay, sedimentary, and fibrous peat indicate that the former represents a longer period of time, and not merely a more rapid rate of sedimentation. The thickness of sedimentary peat is about 4 meters, whereas that of Lake Labish is only 1 meter. Sedimentary peat probably has the slowest rate of deposition of the several types of sediments present, and such a great difference in its thickness in the two profiles suggest a much earlier origin for the Onion Flat sediments. The thickness of fibrous peat is also much greater in the latter profile. The writer believes that the sediments of Onion Flat were initiated much earlier than those of Lake Labish, and that they date from extremely early post-Pleistocene.

In preparation of the sediments for microscopic examination, the potassium hydrate method was used. One hundred or more pollen grains of indicator species were identified from each level. The number of pollen grains of nonsignificant species was also recorded and listed in the tables. Few or no pollen grains are present in the levels of the bottom meter of the Labish profile. These horizons are not included in the tables or pollen profile diagrams. The identification of the winged conifer pollen was based upon the size range of the pollen of the several species within each genus. This method has been described by the author in several previous papers (Hansen 1941a, 1941b, 1941d). No attempt was made to separate the pollen of Sitka spruce (*Picea sitchensis*) from that of Engelmann spruce (*P. Engelmanni*). It probably consists chiefly of the former, which is abundant along the coast a few miles to the west, while Engelmann spruce is largely confined to the upper slopes of the east side of the Cascade Range. Those species recorded by their pollen as 1.5 per cent or less are listed in the tables as 1 per cent.

FORESTS IN ADJACENT AREAS

The Willamette Valley is from 25 to 30 miles wide and about 125 miles long. It lies within the Humid Transition life zone (Bailey 1936). It is also included in the hemlock-cedar climax of the Coast Forest (Weaver and

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Clements 1938), but because of the low summer rainfall the forests are few and scattered. Little or no western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*) are present. The valley is intensively cultivated and most of the virgin forests have been removed, but the coniferous forests were never as dense as those of either the Coast and Cascade Ranges (Peck 1941). The principal coniferous species is Douglas fir (*Pseudotsuga taxifolia*) which grows on slopes and better drained areas. Oregon white oak (*Quercus garryana*) is the chief broadleaf tree, and usually occurs in groves. It is difficult to say what the successional relationship is between these two species, because they are often found growing together. The chief other coniferous species present is lowland white fir (*Abies grandis*) which thrives in low areas along the streams or other moist habitats. Farther south scattered specimens of western yellow pine (*Pinus ponderosa*) occur, while in certain localized areas groves of this species exist. On the floodplains of streams and other moist sites grow associes of cottonwood (*Populus trichocarpa*), willow (*Salix lasiandra*), Oregon ash (*Fraxinus oregana*), red alder (*Alnus rubra*), largeleaf maple (*Acer macrophyllum*), and vine maple (*A. circinatum*). It can be seen that the forests of the Willamette Valley are abundant neither in extent nor in the number of species.

OAK + D. FIR

The eastern slope of the Coast Range is forested largely with Douglas fir with an occasional hemlock. The summers are apparently too dry for the latter species to thrive. Pollen analysis of a sphagnum bog in the east foothills of the Coast Range and farther to the south shows that hemlock has not been nearly so abundant as Douglas fir during that part of the postglacial period represented by the peat deposit (Hansen 1941a). On the west slope of the Coast Range the precipitation increases and western hemlock becomes more abundant at the expense of Douglas fir. Along the coast is a strip composed largely of Sitka spruce and western hemlock, and along the immediate ocean on the stabilized sand dunes and other sandy soil thrives lodgepole or shore pine (*Pinus contorta*). Pollen analyses of two bogs on the Oregon Coast show that western hemlock and Sitka spruce have been predominant during the post-Pleistocene (Hansen 1941d). On a few of the higher peaks of the Coast Range noble fir (*Abies nobilis*) occurs, while western white pine (*Pinus monticola*) and silver fir (*A. amabilis*) have been recorded at several stations in the northern part. On the western slope of the Cascade Range facing the northern part of the Willamette Valley, the forests are composed chiefly of Douglas fir, with western hemlock increasing in abundance with the altitude. Also at higher elevations thrive western white pine, silver and noble fir, lodgepole pine, western red cedar, and Englemann spruce. The last is not so common on the west as the east slope. Near timberline, mountain hemlock (*Tsuga Mertensiana*), alpine fir (*Abies lasiocarpa*), white-bark pine (*P. albicaulis*), and Alaska cedar (*Chamaecyparis nootkatensis*) flourish.

The presence of pollen in the sediments from all or most of these species justifies the mention of their occurrence in adjacent areas. Less significant species, as far as pollen analysis is concerned, that thrive on favorable sites in the Willamette Valley and adjacent slopes of the Coast and Cascade Mountain Range are *Arbutus menziesii, Castanopsis chrysophylla, Corylus californica, Myrica californica, Cornus occidentalis, Osmaronia cerasiformis, Philadelphus gordonianus, Amelanchier florida, Prunus emarginata, Ceanothus sanguineus, Crataegus douglasii, Symphoricapos albus,* and *Ribes sanguineum.*

Forest Type Maps (1936) designate the Willamette Valley as non-forested and agricultural lands, and the adjacent mountain slopes as Douglas fir types of various size classes. It is also included in the Pacific Douglas fir forest under the classification by Shantz and Zon (1924). Over most of the hemlock-cedar climax west of the Cascades, Douglas fir is a subclimax species that has been able to persist as one of the chief dominants because of periodic fires (Munger 1940). In western Oregon, however, western hemlock is almost absent and Douglas fir is not likely to be replaced by the former even if no periodic fires occur. The climate is too dry. It would be hard to say what the climax vegetation is for the Willamette Valley, but it appears that the climate and edaphic conditions are such as to form a tension area in which Douglas fir and white oak are in equilibrium at present. An increase in summer rainfall probably would permit an increase in Douglas fir as subclimax to western hemlock, while a decrease in the annual precipitation would perhaps cause a trend toward an oak-grassland sere.

The Willamette Valley is designated as having a humid microthermal climate, with a summer deficiency of precipitation (Thornthwaite 1931). The average mean annual rainfall for five stations in the valley, within a radius of 25 miles to both bogs, is 43.5 inches. About 10 per cent of this occurs during May to August, inclusive (Weather Bur., U.S.D.A., 1936). The elevation of these stations ranges from 400 to 57 feet above sea level. At Glenora, in the northern part of the Coast Range, and less than 50 miles from Onion Flat, the mean annual precipitation is 130 inches. At Government Camp on Mt. Hood, at an elevation of 3800 feet and about 60 miles from either peat deposit, the annual mean precipitation is about 85 inches. Thus the Willamette Valley is bordered by areas with very moist climate, which has undoubtedly influenced the pollen record of the forest trees in the peat profiles. The general direction of the wind during the period of anthesis is westerly, which suggests that the forests of the Coast Range are more strongly represented than those of the Cascades. This is also somewhat corroborated in the pollen profiles themselves.

FOREST SUCCESSION

There is no reason to assume that the Willamette Valley, the Coast Range, and unglaciated parts of the Cascades were not forested during the Pleistocene when areas to the north were covered with ice. Forests grow to the edge of mountain glaciers at present, and even upon certain glaciers in Alaska (Washburn 1935). The climate of the Pleistocene during continental glaciation, however, may have been more severe, but it was probably sufficiently mild in western Oregon to support forests. The forests that existed within range of pollen dispersal to the site of Onion Flat during the time represented by the lower 6 meters of sediments were composed almost entirely of lodgepole pine, Sitka spruce, and lowland white fir (fig. 1). Lodgepole pine

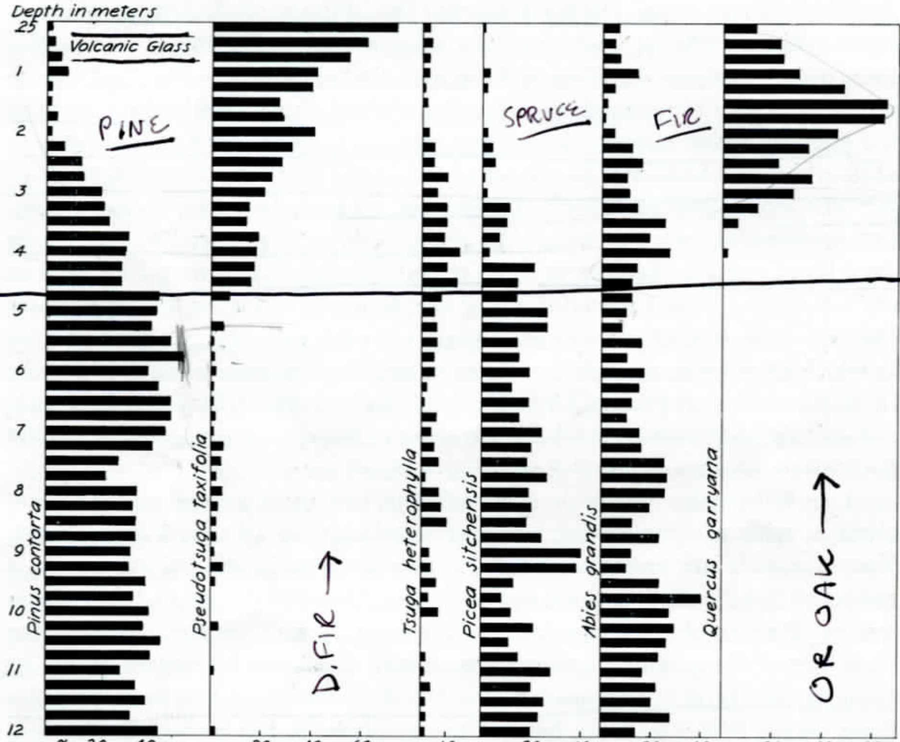

Fig. 1. Pollen Profiles. Onion Flat

proportions fluctuate from 24 to 50 per cent with an average of about 40 per cent. Sitka spruce fluctuates from 8 to 40 per cent and lowland fir varies from 10 to 40 per cent. While the pollen percentages of lodgepole pine run higher than those of spruce and fir, it does not necessarily mean that it was predominant, since lodgepole sheds a greater quantity of pollen than Sitka spruce, and probably more than lowland white fir. It is interesting to note that lodgepole pine and Sitka spruce are entirely absent from the Willamette Valley and the east slope of the Coast Range at present. These two species may be over-represented by their pollen because of its transportation by water. The Tualatin River rises in the Coast Range so that its drainage area is in proximity to the spruce and lodgepole forests of the Pacific Coast. During high water in the spring the Tualatin River may have spilled over into its former channel occupied by the accumulating Onion Flat sediments. Pollen from the coast forests reached the streams and were carried into the lake and incorporated with the sediments. The relatively low proportions of western hemlock pollen in these horizons, however, do not substantiate this theory, or perhaps hemlock was not as abundant during early post-Pleistocene as it is today on the coast. It was apparently predominant during most of the post-Pleistocene on the Oregon Coast (Hansen 1941d).

Lodgepole pine continues its predominance upward in the Onion Flat profile to the 3.75 meter level. It is also recorded by its pollen as the principal species with fir and spruce in the lower 2.5 meters of the Lake Labish profiles (figs. 2, 3). As previously stated, the greater depth of the Onion Flat profile

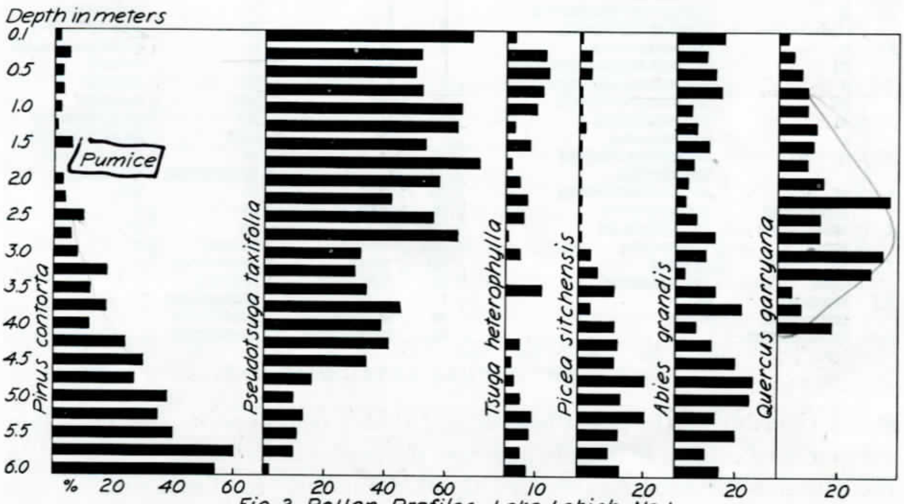

Fig. 2. Pollen Profiles. Lake Labish. No. I.

indicates a longer period of time for its sedimentation than that of Lake Labish. It seems possible that the upper 7 meters of the former are contemporaneous with the entire Lake Labish profiles. They also are 7 meters deep, but, as stated above, the lower meter is practically devoid of pollen. The pollen spectra of the principal species recorded correlate remarkably well in the upper 6 meters of all three profiles, which substantiates the theory of their synchronism. The predominance of lodgepole pine for such a long period of time as portrayed in the Onion Flat profile is significant. In several other bogs analyzed for their fossil pollen that lie beyond the glaciated region, lodgepole pine is not recorded as the predominant species in adjacent areas (Hansen 1939c, 1941a, 1941c, 1941d, 1941f). This suggests that the adjacent forests had reached a climax when the lowest pollen-bearing sediments were deposited or had remained more or less stabilized during the glacial period, or at least during the latter part. The forests apparently had not been destroyed during glaciation nor had conditions favorable for an invasion by lodgepole developed. This was true even along the Oregon Coast where lodgepole pine thrives at present (Hansen 1941d). In a bog farther south in the Willamette Valley, in the east foothills of the Coast Range, Douglas fir is recorded as having been predominant during the entire period represented by the profile (Hansen 1941a). Either the sediments do not record all of the postglacial, or lodgepole was not abundant in this region

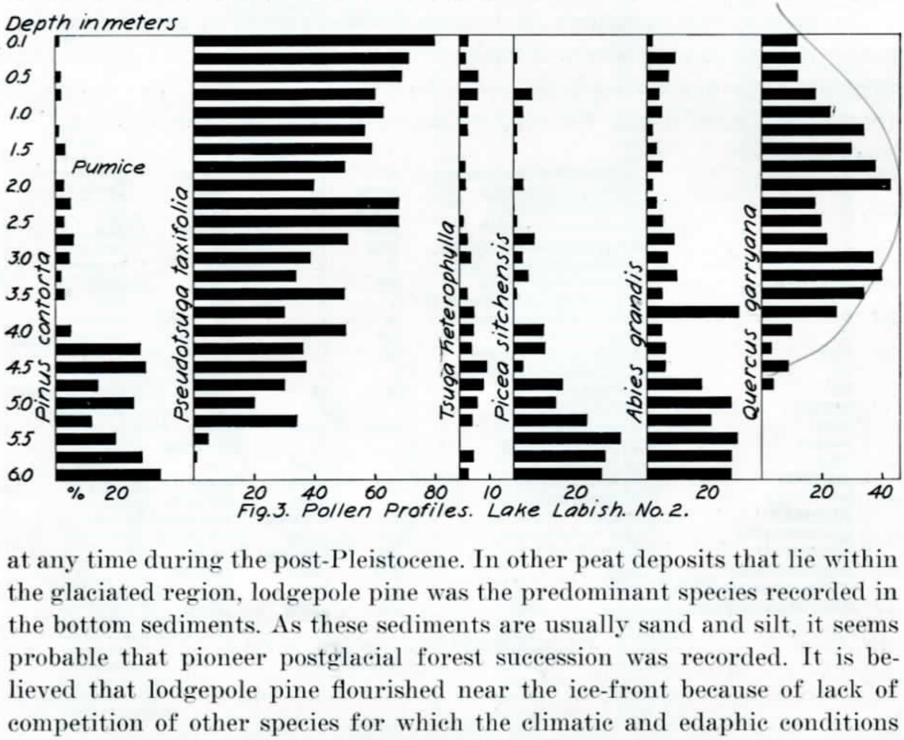

Fig. 3. Pollen Profiles. Lake Labish. No. 2.

at any time during the post-Pleistocene. In other peat deposits that lie within the glaciated region, lodgepole pine was the predominant species recorded in the bottom sediments. As these sediments are usually sand and silt, it seems probable that pioneer postglacial forest succession was recorded. It is believed that lodgepole pine flourished near the ice-front because of lack of competition of other species for which the climatic and edaphic conditions were unfavorable. As the environment became moderated and somewhat stabilized, other species invaded and replaced lodgepole because of its greater intolerance for shade and shorter life span. This was evidently true both east and west of the Cascade Range in Washington (Hansen 1938, 1939a, 1939b, 1940a, 1940b, 1941b, 1941e). The comparative absence of Douglas fir and western hemlock in the lower horizons of all profiles suggests that the edaphic and climatic conditions were unfavorable for these species. The high proportions of Sitka spruce and lowland white fir, both moisture-loving species, suggests that the climate was very wet. Heavy precipitation and melting of the glaciers in the Cascades may have resulted in erosion in the hills and inundation in the valley, with constantly changing edaphic and topographic conditions. Lodgepole pine was able to survive in abundance because of its ability to live under an adverse climate and unstable edaphic conditions, and its early seed-bearing age. The latter characteristic permits it to migrate more readily and re-establish itself under changing edaphic and topographic conditions than the other species. This is evidenced by its invasion of pumice-covered areas in the Cascades of southern Oregon, burns, sphagnum bogs, and sand dunes along the Pacific Coast. The pollen percentages of lodgepole pine generally decline upward in all profiles from their maxima in the lower levels and become negligible in the upper horizons (figs. 1, 2, 3). Sitka spruce and lowland white fir are most abundantly recorded in the lower levels of the Labish profiles as well as in the other. In one of the former they both show higher proportions at several levels than lodgepole pine (fig. 3). Spruce is the first to show a decline and it is recorded by negligible percentages in the upper 3 meters of all profiles. Lowland white fir maintains higher proportions in the higher horizons, indicating that conditions remained more favorable nearer to the present time for this species than for spruce. Lowland white fir is common in the Willamette Valley today, and is recorded to 16 per cent in the top level of one of the Labish profiles (fig. 2).

Douglas fir is recorded by its pollen in low proportions in the lower 7 meters of the Onion Flat profile with a maximum of 5 per cent at 3 levels (fig. 1). It likewise is represented by slight percentages in the lower horizons of the Lake Labish profiles (figs. 2, 3). This is consistent with its trend in the Puget Sound region (Hansen 1938, 1940a, 1941b). It increases sharply from 4.75 meters in the Onion Flat profile and from 5 and 5.5 meters in the others, to attain 74, 69, and 80 per cent respectively in the uppermost level. In its general increment upward toward the top, Douglas fir shows a number of fluctuations of considerable magnitude. The greatest of these variations occurs conversely with those in the pollen spectra of Oregon white oak and will be discussed later. Bogs located within the hemlock-cedar climax of the Coast Forest in the Puget Lowland of western Washington show Douglas fir as rapidly replacing the pioneer forests of lodgepole and western white pine (Hansen 1938, 1940a, 1941b). It was in turn replaced more gradually by western hemlock to some extent, but was able to persist in equal abundance with the latter, owing to periodic fires that interrupted forest succession toward the hemlock-cedar climax. It did not, however, attain so high proportions as in the profiles of this study. In eastern Washington, Douglas fir has played a minor part in postglacial succession because of the dry climate (Hansen 1939b, 1940b, 1941f). On the Pacific Coast of Oregon and on the west side of the Olympic Peninsula it also has been unimportant in the forest complex during the post-Pleistocene (Hansen 1941c, 1941d). Douglas fir has been predominant on the east slope of the Coast Range in west central Oregon during most of the postglacial period (Hansen 1941a).

The pollen of white oak does not make its appearance in the lower levels of the profiles. In the Onion Flat profile it is first recorded at 4 meters by 1 per cent, and in the others at 4.57 and 4.75 meters with 10 and 4 per cent respectively (figs. 1, 2, 3). The fact that this species is not recorded by its pollen in the lower levels in the Onion Flat profile is further evidence that this profile represents a much longer period of time. Oak soon increases sharply after its initial appearance, being recorded as 35 per cent at 2.75 meters in the Onion Flat profile, and 35 and 40 per cent at 3 and 3.25 meters respectively in the Lake Labish sediments. In the latter, Douglas fir shows abrupt declines at these same levels. Oak then precipitately declines to 22 per cent in the Onion Flat profile at 2.5 meters, and to 14 and 18 per cent at 2.5 and 2.25 meters respectively in the other two. It again increases to 65 per cent in the former at 1.5 meters, and to 37 and 43 per cent at 2.25 and 2 meters respectively in the Lake Labish sediments. These are the highest proportions attained in the white oak spectra. That these maxima are all approximately synchronous is denoted by the occurrence of the pumice layer immediately above in the Labish profiles and slightly higher in the other (figs. 1, 2, 3). The general trend of Douglas fir increment is again interrupted at the oak maxima, showing a decline to less than the oak proportions in the Onion Flat and one of the Labish profiles. It should be noted that this increase and decrease of oak and Douglas fir respectively are not merely relative. There is an actual decrease in the frequency of Douglas fir pollen at these horizons. White oak declines from these maxima, and is recorded by 13, 3, and 12 per cent in the uppermost horizons. In a bog near Tacoma, Washington, located on the Tacoma "prairies," oak is recorded by its pollen to as high as 14 per cent in the middle horizons of a 10.5 meter peat profile (Hansen 1938). This area is characterized by scattered groves of white oak on the gravelly soil of the outwash plain from the Vashon glacier of the Puget Sound region. The oak maximum in this bog may be synchronous with those of this study. It seems possible that white oak is under-represented, because of the vast areas on either side of the Willamette Valley forested with Douglas fir, while oak is and probably always has been confined to the valley. Also from the writer's observations it seems probable that oak does not produce as much pollen as Douglas fir.

Western white pine is recorded by its pollen to higher proportions in the lower levels of all profiles and declines to only a trace near the top (tables). This trend is consistent with that of most peat profiles west of the Cascade Range. Western hemlock is the most abundantly recorded of the other conifers. In the Onion Flat profile it attains its greatest abundance in the middle horizons, as it does in one of the others. In the third, it shows its

TABLE 1

Percentages of Fossil Pollen. Onion Flat Profile

Depth in meters	*Pinus contorta*	*P. monticola*	*P. ponderosa*	*Pseudotsuga taxifolia*	*Tsuga heterophylla*	*T. mertensiana*	*Picea sitchensis*	*Abies grandis*	*A. nobilis*	*A. lasiocarpa*	*Thuja plicata*	*Quercus garryana*	*Pinus* spp.*	*Abies* spp.*	*Alnus**	*Salix**	Cyperaceae*	*Typha**	*Nymphozanthus**
0.25	2	...	...	74	3	...	1	7	...	...	...	13	...	...	5	156	4	3	...
0.5	3	1	2	62	4	...	...	5	...	...	...	23	1	1	3	198	...	...	...
0.75	5	2	4	55	3	...	...	7	...	...	...	24	1	1	4	94	...	...	...
1.0	8	1	...	42	3	...	3	15	...	...	...	30	...	...	2	208	...	...	...
1.25	2	2	...	40	1	...	2	5	...	...	...	48	2	...	...	35	...	...	...
1.5	2	1	...	27	2	...	...	2	...	...	1	65	1	...	5	27	7	1	...
1.75	4	2	...	29	...	...	...	1	...	...	...	64	1	...	...	15	...	1	...
2.0	2	1	1	41	3	...	2	5	...	...	...	45	1	...	2	12	3	...	...
2.25	7	5	...	32	5	...	4	12	...	...	1	34	3	...	1	10	...	1	...
2.5	14	3	7	28	5	...	5	16	...	...	...	22	3	...	1	3	...	...	...
2.75	15	4	...	24	10	1	1	10	...	...	...	35	...	...	3	10	...	...	...
3.0	22	2	...	21	6	...	2	11	...	...	8	28	3	1	1	4	6	...	...
3.25	23	11	...	15	10	2	11	14	...	...	...	14	2	...	...	4	1	...	1
3.5	25	...	4	14	13	...	10	25	3	...	...	6	7	...	...	2	2	1	1
3.75	33	2	8	19	9	1	7	19	...	...	2	...	4	...	4	2	3	23	26
4.0	32	2	2	18	15	...	3	27	...	...	...	1	3	3	3	4	5	60	32
4.25	30	2	...	17	10	...	21	14	...	2	4	...	9	3	12	5	...	3	4
4.5	30	10	...	16	14	4	14	12	...	...	...	...	4	2	1	2	...	3	...
4.75	45	8	2	7	8	1	14	12	1	2	...	...	8	1	...	9	3	2	...
5.0	44	7	...	...	5	3	26	10	2	3	...	...	3	...	1	12	3	3	2
5.25	42	10	...	5	6	3	26	8	...	...	...	...	7	3	1	...	5	4	...
5.5	50	5	1	1	6	2	14	16	1	4	...	...	9	...	...	1	8	4	...
5.75	55	10	1	1	5	...	15	10	...	3	...	...	11	1	...	6	...	2	...
6.0	41	10	...	2	5	4	19	17	...	2	...	...	14	3	...	4	1	2	...
6.25	45	20	2	1	2	1	12	15	1	1	...	...	15	1	...	5	1	5	...
6.5	50	7	3	1	1	4	19	12	1	2	...	...	7	2	...	3	...	7	...
6.75	50	10	2	2	6	5	15	10	...	...	...	...	12	2	3	1	5	4	...
7.0	48	3	...	1	4	3	24	15	1	1	...	...	7	1	...	5	7	8	...
7.25	43	...	1	5	5	5	20	16	3	2	...	...	9	4	...	9	11	5	...
7.5	29	5	4	4	7	8	18	25	...	...	...	...	11	3	...	3	...	4	...
7.75	24	8	4	2	1	7	26	26	1	1	...	...	5	2	...	2	8	...	...
8.0	36	6	2	4	7	2	19	25	...	...	...	...	6	3	...	...	2	...	...
8.25	35	13	...	3	8	1	20	19	1	...	...	...	7	1	...	1	2	...	...
8.5	36	12	2	2	10	6	18	12	...	2	...	...	2	1	...	7	5	1	...
8.75	36	6	2	2	...	2	24	23	...	5	...	...	6	1	...	4	...	...	...
9.0	34	6	...	1	3	4	40	12	...	...	...	...	17	5	...	3	1	1	3
9.25	33	4	...	5	4	4	38	10	1	1	...	...	12	2	...	1	2	1	...
9.5	40	10	2	2	6	4	13	23	...	...	...	...	6	3	...	7	2	4	...
9.75	35	8	...	...	3	2	8	40	4	...	...	...	7	1	...	2	...	...	...
10.0	41	13	...	...	7	...	12	27	...	...	...	...	9	6	...	1	1	...	...
10.25	39	6	...	3	...	2	21	29	...	...	...	...	14	2	...	5	...	...	...
10.5	46	11	2	...	...	3	11	26	1	...	...	...	1	4	1	...	1	1	...
10.75	42	12	4	...	2	1	15	23	1	...	...	...	11	3	...	4	2	...	...
11.0	30	16	5	1	1	1	28	17	1	...	...	...	7	1	...	2	...	...	...
11.25	36	8	6	...	4	4	20	22	...	...	...	...	5	2	...	1	...	...	...
11.5	40	10	...	...	2	2	25	20	...	1	...	...	7	2	1	...	5	...	...
11.75	34	13	...	...	2	...	23	28	...	...	...	...	5	1	2	...	4	...	...
12.0	45	14	...	2	2	2	20	14	1	...	...	...	12	3	...	...	1	2	...

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

highest frequencies in the lower two-thirds. Its maximum is 15 per cent in any of the profiles (tables). The climate has probably been too dry for this species in the Willamette Valley. In the Puget Lowland it partially replaced Douglas fir, to become equally abundant during the latter half of the post-glacial. Mountain hemlock is appreciably recorded in the lower two-thirds of the Onion Flat profile, and to only a trace in a few levels of the others (tables 1, 2, 3). Neither western nor mountain hemlock shows a trend that correlates with the spectra of the other species. Pollen of the latter probably drifted down from higher altitudes in the Cascades, or less probably from the northern part of the Coast Range. Western yellow pine is recorded sporadically in the lower horizons and more consistently in the higher levels. This trend differs from that in the bog farther south in the Willamette Valley, where it is more abundantly recorded in the lower levels (Hansen

TABLE 2

Percentages of Fossil Pollen. Labish Profile No. 1

Depth in meters	*Pinus contorta*	*P. monticola*	*P. ponderosa*	*Pseudotsuga taxifolia*	*Tsuga heterophylla*	*T. mertensiana*	*Picea sitchensis*	*Abies grandis*	*A. nobilis*	*Thuja plicata*	*Quercus garryana*	*Pinus* spp.*	*Abies* spp.*	*Alnus**	*Salix**	Cyperaceae*	*Typha**	*Nymphozanthus**
0.10	2	......	5	69	3	......	1	16	1	......	3	1	3	3	......	1	......	......
0.25	5	......	9	52	13	......	4	10	1	1	5	2	2	2	15	......	......	......
0.5	3	......	8	50	14	......	4	13	......	......	8	......	1	6	43	6	1	......
0.75	3	......	7	52	12	......	1	15	......	......	10	3	3	1	32	6	......	......
1.0	2	......	7	65	10	......	1	5	......	......	10	......	......	1	15	1	1	1
1.25	1	2	8	64	3	......	2	7	......	......	13	1	2	8	117	3	......	......
1.5	6	......	8	53	8	1	1	11	......	......	12	......	......	1	12	......	2	2
1.75	1	......	9	71	2	......	1	6	......	......	10	2	1	5	......	7	1	......
2.0	3	1	13	58	5	......	1	4	......	......	15	......	......	......	10	1	6	1
2.25	4	......	5	42	7	......	1	3	......	1	37	1	1	1	3	1	3	1
2.5	10	......	6	56	6	......	1	7	......	......	14	2	......	......	15	2	2	......
2.75	6	1	......	64	1	......	1	13	......	......	14	1	2	3	10	3	7	......
3.0	8	4	......	32	5	......	4	10	2	......	35	1	1	7	3	9	3	2
3.25	18	......	12	30	......	......	6	3	......	......	31	5	1	......	8	1	......	1
3.5	12	8	2	34	12	......	12	13	2	......	5	3	1	1	39	7	......	......
3.75	18	......	......	46	......	......	4	22	2	......	8	2	3	6	23	3	......	2
4.0	12	......	12	39	......	......	12	7	......	......	18	4	2	......	25	5	1	1
4.25	24	5	......	41	5	......	13	12	......	......	......	6	1	5	19	2	......	3
4.5	30	2	......	34	2	......	12	20	......	......	......	7	7	......	21	......	......	......
4.75	27	3	......	16	3	......	22	26	3	......	......	3	6	1	15	1	......	2
5.0	38	1	......	10	7	......	14	25	3	2	......	5	5	......	12	3	......	......
5.25	35	7	......	13	9	......	22	13	1	......	......	7	4	4	7	3	......	......
5.5	40	4	......	11	8	......	13	20	2	2	......	12	3	......	5	......	......	1
5.75	60	5	......	10	5	......	10	10	......	......	......	15	1	2	3	1	......	......
6.0	54	6	......	2	7	......	14	15	1	......	......	17	3	3	......	......	......	......

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

1941a). Its trend in this study is more logical, however, because it is the most xerophytic of the conifers, and should have increased during later post-glacial time, if a drier climate prevailed. Other species recorded by their pollen are willow, sedge, yellow pond lily, cat-tail, alder, hazel, ash, and maple (tables 1, 2, 3). The first four record the progress of hydrarch succession. The scarcity of alder pollen is unusual because it is generally abundant in most peat profiles in the Pacific Northwest. In some cases alder seems to be correlated with Douglas fir, which suggests that it invades low, damp areas that have been denuded by fire (Hansen 1941a).

CLIMATIC CONSIDERATIONS

In this study the pollen spectra of Sitka spruce, lowland white fir, Douglas fir, and white oak are the best indicators of climatic trends. Spruce is an

TABLE 3

Percentages of Fossil Pollen. Labish Profile No. 2

Depth in meters	*Pinus contorta*	*P. monticola*	*P. ponderosa*	*Pseudotsuga taxifolia*	*Tsuga heterophylla*	*T. mertensiana*	*Picea sitchensis*	*Abies grandis*	*A. nobilis*	*Quercus garryana*	*Pinus* spp.*	*Abies* spp.*	*Alnus**	*Salix**	Cyperaceae*	*Typha**	*Nymphozanthus**
0.10	1	...	2	80	3	...	...	2	...	12	1	...	2	3	...	3	...
0.25	...	...	4	71	2	...	1	9	...	13	...	2	3	1	...	4	...
0.50	2	...	4	69	6	...	...	7	...	12	2	1	...	2	...	...	...
0.75	2	...	4	60	6	...	6	4	...	18	1	...	1	1	...	...	...
1.0	...	...	3	63	3	...	3	5	...	23	...	1	...	9	...	...	2
1.25	1	...	2	57	3	...	1	2	...	34	...	...	7	7	...	2	1
1.5	3	...	4	59	...	...	1	3	...	30	1	...	4	12	...	...	...
1.75	...	...	5	50	2	...	...	5	...	38	...	...	2	15	2	...	1
2.0	3	...	6	40	2	...	3	2	1	43	2	1	...	21	5	...	15
2.25	5	...	5	68	...	...	...	3	1	18	1	...	1	14	4	5	1
2.5	3	...	2	68	1	...	1	5	...	20	...	...	...	18	...	2	5
2.75	6	1	1	51	3	...	7	9	...	22	3	1	1	32	...	1	1
3.0	5	2	3	39	4	...	3	7	...	37	...	...	1	27	8	7	3
3.25	2	5	...	34	1	...	5	10	3	40	1	1	...	48	9	3	2
3.5	3	...	2	50	3	...	1	5	2	34	1	3	3	53	1	4	1
3.75	...	...	10	30	5	...	...	30	...	25	2	...	2	17	4	1	...
4.0	5	4	1	50	5	...	10	5	10	10	1	2	7	9	2	1	...
4.25	28	13	...	36	4	...	10	6	...	3	5	...	...	12	7	...	...
4.5	30	6	...	37	9	...	3	6	...	9	8	1	5	42	4	1	...
4.75	14	8	...	30	8	...	16	18	2	4	9	2	...	112	...	2	...
5.0	26	6	...	20	6	...	14	28	...	...	11	3	1	59	5	...	...
5.25	12	...	...	34	4	2	24	20	4	...	5	1	...	216	3	...	...
5.5	20	10	...	5	...	...	35	30	...	...	7	3	2	...	1	...	1
5.75	29	7	...	1	5	...	30	28	...	...	9	3	3	...	...	...	...
6.0	35	5	...	...	3	...	29	28	...	...	5	2	...	...	...	...	...

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

indicator of extremely moist conditions, whereas white oak thrives under the driest climate. Lowland white fir is next to spruce in its moisture requirements, and Douglas fir will survive under drier conditions than either spruce or lowland white fir, but not so xeric as oak. Lodgepole pine is a poor climatic indicator because of its wide climatic and geographic range. The predominance of its pollen in the lower levels of the Pacific Northwest peat profiles marks its invasion of primary areas before the edaphic and physiographic conditions had been stabilized and sufficiently moderated to permit the entrance of other species more tolerant of shade and with a longer life span to replace it. Western hemlock thrives under a moist climate, but it is too sparsely represented in the peat profiles of this study to serve as a climatic indicator. Its low pollen frequency, however, in itself denotes that too dry conditions prevailed for its existence in the Willamette Valley, at least during the latter two-thirds of the post-Pleistocene. Western white pine is indicative of a cool and subhumid climate, and mountain hemlock marks at least a cool climate. Yellow pine is almost as xerophytic as white oak.

In the Puget Lowland of western Washington, postglacial forest succession has probably been more a result of competition than due to climatic change. This also seems to have been true of the Oregon Coast and the west side of the Olympic Peninsula (Hansen 1941c, 1941d). In drier regions where the annual precipitation or summer rainfall is at a critical minimum, slight changes may influence forest succession over a period of time. The greater response of tree growth in dry areas is shown by comparative studies of radial increment in trees living in wet and dry climates (Douglass 1936). In dry climates, slight variations in the annual precipitation are readily reflected by the width of the annual rings, whereas in moister climates the ring width may vary only slightly from year to year, in spite of appreciable differences in the annual rainfall. It is believed that the small amount of summer rainfall in the Willamette Valley is responsible for recording more definite postglacial climatic trends than elsewhere west of the Cascade Range. High percentages of Sitka spruce and lowland white fir pollen in the lower half of the Onion Flat profile mark a wet climate during the first third of the post-Pleistocene. A continuation of proportions of appreciable but lesser magnitude upward in this profile, as well as in the contemporaneous horizons of the lower Lake Labish profiles, marks a persistence of the wet climate for some time longer. The scarcity or absence of spruce pollen in the upper horizons of all profiles and the absence of this species east of the Coast Range at present, substantiates this interpretation. The predominance of lodgepole pine as denoted in the lower strata marks the presence of unstable soil and physiographic conditions, possibly caused by increased surface water from melting glaciers in the Cascades and greater precipitation in the valley. This probably resulted in considerable erosion, deposition, inundation, emergence, and other changing environmental conditions under which trees requiring 25 years or more to reach seed-bearing age could not persist. The invasion and rapid increase in Douglas fir signify a drier climate and more stabilized edaphic and physiographic conditions as the postglacial period progressed. Instead of the entrance and development of western hemlock to attain equal abundance with Douglas fir, as occurred in the Puget Lowland, white oak invaded the valley and rapidly increased in its extent to supersede Douglas fir at some levels in its pollen proportions. This significant increase at the expense of Douglas fir marks further desiccation of the climate. The maximum of this trend was apparently reached just prior to the eruption of one of the Cascade volcanoes and the deposition of pumice in the accumulating sediments. This period of maximum dryness, as portrayed by the influx of oak, is not corroborated by a simultaneous invasion of grasses and composites, such as occurred on the Tacoma "prairies" just south of Puget Sound (Hansen 1938). A decline in the pollen percentages of oak and a resumption of Douglas fir predominace to the uppermost horizon may mark a cooler and moister climate in more recent time.

A general decrease in moisture during the middle third of the post-Pleistocene is suggested by most of the pollen spectra of Pacific Northwest peat profiles, with the exception of those in proximity to Puget Sound. Some peat deposits, however, record more definitely a dry, warm period, succeeded by a slight increase in moisture in more recent time. In a bog near Spokane, Washington, located in a western yellow pine climax, a sharp increase in the proportions of grass, chenopod, and composite pollen about one-third the way upward in the profile signifies the occurrence of a hot, dry climate (Hansen 1939b). These species were later replaced by forests consisting largely of yellow pine, suggesting a return of a moister and cooler climate, which persisted to the present time. Lake sediments in the Upper Sonoran life zone of east central Washington record relative trends of forest and grassland succession that depict a gradual drying and warming to a maximum, followed by some cooling and greater precipitation (Hansen 1941e). Pollen analyses of four profiles of lake sediments from Lower Klamath Lake of southern Oregon and northern California also denote the development of a xeric period, followed with an increase in moisture (Hansen 1941g). The evidence offered by the pollen profiles is further corroborated by the occurrence of artifacts underlying from 6 to 8 feet of fibrous peat (Cressman 1940). The wide distribution of the artifacts over hundreds of square miles of the exposed fossil lake bed marks the drying up of the lake and the occupancy of the lake bed by early man between 7500 and 4000 years ago (Antevs 1940). The salinity of certain lakes in the Great Basin is also supporting evidence for the occurrence of a xeric period during the postglacial. The present salinity of these lakes is such as to have required not over 4000 years for its development (Antevs 1938). The lakes had their origin in the Pleistocene, dried up during the post-Pleistocene, and their precipitated salts were removed by deflation or buried. The present lakes were reformed in their freshened basins about 4000 years ago (Antevs 1940). The drying and reforming of these lakes seem to be closely correlated with the disappearance and rebirth of most of the western mountain glaciers. Evidence shows that the existing glaciers in the Sierras are not remnants of the Pleistocene glaciers, but those that came into existence only a few thousand years ago (Matthes 1939). Their recession and readvance apparently have been more or less synchronous with the drying and rebirth of the lakes of the Great Basin. Pollen profiles from eastern North America also designate a drying and warming to a maximum, followed by a somewhat cooler and moister climate (Smith 1940).

SUMMARY

Three profiles of lake sediments in the Lower Willamette Valley of western Oregon record an interesting and significant trend of post-Pleistocene forest succession by the forest tree pollen recorded therein. The depth and pollen spectra of the Onion Flat profile suggest that sedimentation was initiated in early post-Pleistocene, and that it records adjacent forest succession from the Pleistocene almost to the present. An unknown thickness of the upper sediments has been removed in all profiles, due to drainage and cultivation. The Onion Flat profile probably represents a longer period of time for its deposition than the Lake Labish profiles.

The earliest recorded forests of the Willamette Valley and adjacent slopes of the Coast and Cascade Ranges consisted largely of lodgepole pine, Sitka spruce, and lowland white fir. This is extremely significant, because the first two species are seemingly absent from the Willamette Valley at present. These initial postglacial forests were slowly replaced by Douglas fir, which in turn was replaced to some extent by white oak. Douglas fir shows a general increase upward in the profiles with white oak, which supersedes the former in the upper levels of the profiles. Oak declines to the top after it attained its maximum, and Douglas fir resumed its predominance to the uppermost level.

Climatically this trend of forest succession denotes a long period of moist conditions with considerable instability of the edaphic and physiographic conditions. The latter conditions are suggested by the persistence of lodgepole pine as indicated by the presence of its pollen in abundance in the lower two-thirds of the Onion Flat profile. As the influence of recent glaciation waned, the climate became warmer and drier, as is evidenced by the invasion of Douglas fir, followed by that of white oak. The xeric period reached its maximum during the period of oak predominance. The climate

became moister and cooler during the latter part of the postglacial. The small amount of western hemlock pollen in the profiles indicates that the initial edaphic and physiographic conditions were too rigorous for its existence, and later the climate became too dry for its development to any great extent. The evidence for this climatic trend is more definite in this study than that offered by other pollen profiles west of the Cascades. Evidence for a similar dry period is present in peat profiles east of the Cascades in Washington and Oregon. These climatic interpretations are also supported by anthropological and geological studies in the Great Basin.

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