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Oregon Cascades.

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POSTGLACIAL FOREST SUCCESSION AND CLIMATE IN THE OREGON CASCADES.[1]

HENRY P. HANSEN.

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INTRODUCTION.

ONE of the most striking features of the central Oregon Cascades is the evidence of recent volcanic activity on an extensive scale. The vast expanses of pumice, the lava flows, obsidian cliffs, pillow lavas, and blocks of volcanic ejecta, as yet only slightly weathered and eroded, almost cause one to expect to see smoke pouring from a nearby crater in its final stages of eruption. Some of the volcanic activity responsible for these widely scattered ejecta occurred since the maximum of the last Wisconsin glaciation, and some even during the past few centuries (Williams, 1942, 1944). The record of this volcanic activity and Pleistocene glaciation has provided two important time markers for postglacial history of vegetation and climate in the Oregon Cascades, and in fact, for the entire Pacific Northwest. The pollen-bearing sediments and their inferred record of postglacial forest succession offer a means

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of dating relatively a few of the postglacial volcanic eruptions in the area. These local chronological data correlated with those from other areas have enabled the establishment of a relative and general chronology for climate, vegetation, and early man in the Pacific Northwest. Further study and correlation of the available evidence will probably strengthen this tentative chronology and permit the division of postglacial time into a greater number of units.

The most widespread and most obvious evidence for postglacial volcanic activity is that of the eruption of Mount Mazama, which formed the caldera holding Crater Lake in southern Oregon. This great eruption spread a mantle of pumice six inches or more deep over an area of about 5,000 square miles to the north and east of Crater Lake (Fig. 1).

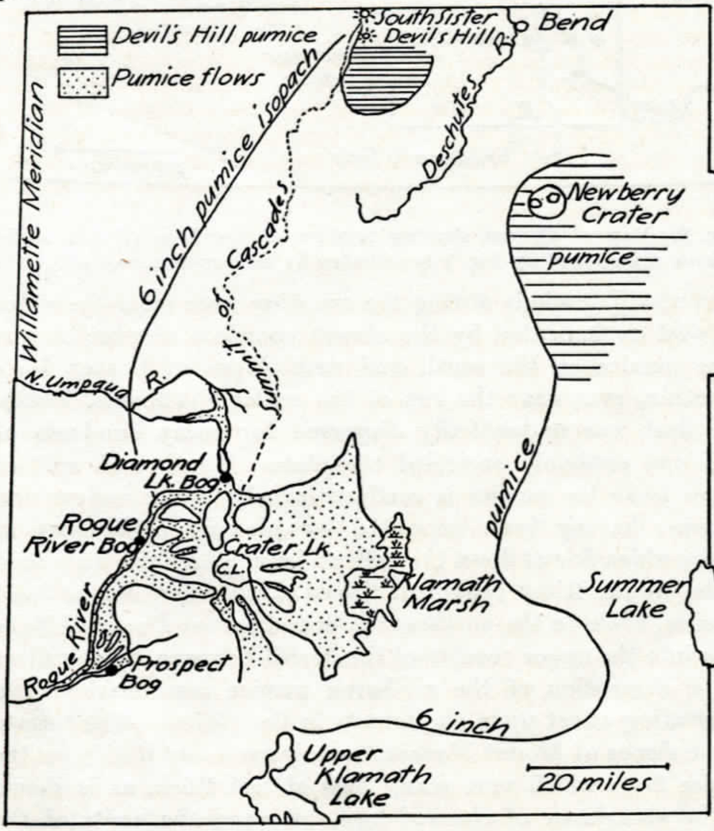

Fig. 1. Map showing the distribution of Mount Mazama pumice. (after Williams).

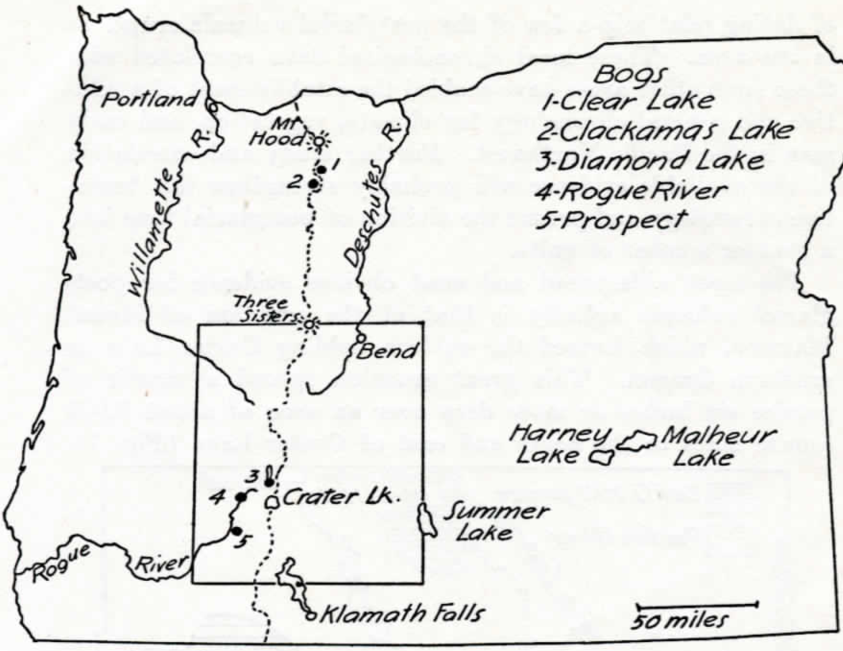

Fig. 2. Map of Oregon showing location of five bogs of this study. The area represented by Fig. 1 is indicated by the superimposed rectangle.

The prevailing winds during the eruption were from the south and west as indicated by the almost complete absence of air-borne pumice on the south and west slopes of Crater Lake Mountain, even near the rim of the crater (Williams, 1942). Fine dust was undoubtedly dispersed for many hundreds of miles and probably encircled the globe. South and west of Crater Lake the pumice is confined largely to the valleys and canyons, having been deposited by glowing avalanches of pumice which flowed down the valleys for considerable distances. In the Rogue River canyon it flowed down valley for at least 15 miles, while to the northeast it flowed across Diamond Lake basin into the upper reaches of the North Umpqua River valley.

The deposition of the air-borne pumice must have had a devastating effect upon the forests in the region. The forests on the slopes of Mount Mazama were burned and buried by the pumice flows which were many tens of feet thick, as is shown by the abundance of charred logs. Beyond the limits of the pumice flows the pumice fall probably killed the trees, especially in the region of greatest depth, first by burying entirely the seedlings and saplings, and then by the accumulative deleterious effects of the radically altered edaphic conditions. Aside from destroying the forests at the time of the eruption, the sterile pumice comprised largely of glass, has had a marked control upon the forest succession ever since. This vast pumice-covered area is today forested with species that have been able to persist only because of the absence of competition by species of the normal climatic climax.

There has been considerable postglacial volcanic activity in the Three Sisters region of the central Oregon Cascades also (Williams, 1944). Some of the mountains which were centers of this volcanic activity rose during the Pleistocene and have continued to be active in the Postglacial. Others are of postglacial origin and have erupted within the past several centuries. Most of these postglacial eruptions have been of the effusive type, resulting in lava flows of various kinds. A few volcanoes, including Tumalo Mountain and Devil's Hill, ejected pumice. Pumice from one or both of these sources either underlies or occurs as an interbedded layer in two organic sedimentary columns reported herein. Its stratigraphic position in relation to that of Mount Mazama indicates that these eruptions occurred after the climactic eruption of Mount Mazama. Another major postglacial eruption was that of Newberry Crater, located east of the main Cascade Range about 25 miles south-southeast of Bend (Williams, 1935). The dispersal of pumice from this volcano, like that of Mount Mazama, was also largely to the north and east. The stratigraphic position of Newberry pumice above that of Mount Mazama in postglacial sediments in the Summer Lake basin of south central Oregon indicates the relative times of these two eruptions (Allison, 1945). Newberry Crater pumice has not been noted in any peat sections so far.

Pleistocene mountain glaciation has left its record in the Oregon Cascades, although little work has been done on this problem. Thayer (1939) found three glacial stages which he named the Mill City, Detroit, and Tunnel Creek stages, and tentatively correlated with the Sherwin, Tahoe, and Tioga stages of the Sierra Nevada respectively (Blackwelder, 1931).

LOCATION AND CHARACTERISTICS OF THE BOGS.

This study is concerned primarily with the pollen analysis of sedimentary columns from five bogs located in the Oregon Cascades. The interpreted forest succession, climate, and chronology, however, will be correlated with those from five other peat sections in the same region, that have been described in previous papers (Hansen, 1942, 1942a). These ten bogs are located in five different areas with respect to the occurrence and distribution of pumice. Two of the bogs of this study are located on the margins of Clear and Clackamas lakes respectively, in the northern Oregon Cascades, beyond the limits of discernible pumice from Mount Mazama. Clackamas Lake, the more southerly of the two, lies about 165 miles north of Crater Lake and about 70 miles north of the six-inch pumice zone in the vicinity of Bend (Fig. 2). Clear Lake is located about six miles north of Clackamas Lake. The thickness of the Clear Lake section is 2.4 meters and that of Clackamas Lake is 2.0 meters, although only 1.7 meters are pollen-bearing. Neither a layer of pumice nor scattered fragments of volcanic glass were noted in the sections. The elevation of Clear Lake is about 3,500 feet, while Clackamas Lake lies at an altitude of about 3,300 feet. The former is bordered by a sedge bog and the latter by a sphagnum bog with several typical bog plants present. Both bogs lie within areas covered by mountain glaciers and may be considered to have had a postglacial origin. They are located in the Canadian life zone (Bailey, 1936).

The two other bogs of this study lie on Mount Mazama pumice in tributary valleys of the Upper Rogue River southwest of Crater Lake (Fig. 1), where the pumice is largely confined to the valley floors. One is located on the floodplain of Lost Creek, a short tributary that empties into the Rogue River about ten miles west of Crater Lake. It will hereafter be referred to as the Rogue River section. The bog lies at an elevation of about 4,000 feet and is covered with sedges and sedge-like plants. The thickness of the sediments in the area of sampling is 4.0 meters. The pollen-bearing section is underlain with coarse pumice which grades upward into a fine, sandy pumice, and then into fibrous peat. The other bog in this area is located near Prospect, about 17 miles southwest of Crater Lake on the flood-plain of Red Blanket Creek which empties into the Middle Fork of the Rogue River. The peat deposit lies at an elevation of about 2,500 feet. The bog surface is covered with alder and willow due to lowering of the water table by artificial drainage. The thickness of the sediments in the area of sampling is 3.2 meters, and examinations of the peat reveals that the bog has existed in the sedge stage throughout most of its existence. Both of the Rogue River bogs lie in the dryer part of the Humid Transition life zone.

A fifth section was obtained from a broad delta area at the south end of Diamond Lake where a short stream empties into the lake. The site of these sediments is located about 14 miles north of Crater Lake at an elevation of about 5,000 feet. The peat is only 0.5 meter thick and rests upon coarse pebble pumice, and the section contains a high fraction of fine pumice throughout. It is situated in the Canadian life zone.

Two of the other five bogs located in the Oregon Cascades and discussed in previous papers also rest directly upon Mount Mazama pumice. One of these is located in Munson Valley a few miles south and below the rim of Crater Lake, while the other is at Big Marsh about 30 miles due north of Crater Lake (Fig. 1). Two others are located on glacial drift or its chronological equivalent. One of these located near the Willamette Highway just west of the Cascade Drive and 50 miles north of Crater Lake is 2.75 meters deep with a layer of Mount Mazama pumice at 2.5 meters. The second has been formed at Tumalo Lake in a glaciated valley about 13 miles west of Bend. It is about seven meters deep and contains two interbedded strata of pumice. The lower layer at 4.5 meters is from Mount Mazama and the upper layer at 2.0 meters may be from Devil's Hill in the Three Sisters region, which was postglacially active (Williams, 1944). In a previous paper the author (Hansen, 1942) assigned the upper layer of pumice to Mount Mazama and the lower stratum to an unknown volcano. This was done because the upper layer is overlain by about the same thickness of peat as occurs in bogs that rest directly upon Mount Mazama pumice. A later comparison with Mount Mazama pumice revealed that it came from Mount Mazama (Allison, 1945). In yet another bog on the margin of Mud Lake, about 70 miles north of Crater Lake and west of Bend, the peat is underlain with a coarse pumice probably from a post-Mount Mazama eruption of Devil's Hill about five miles north of the site of the sediments (Hansen, 1942a).

With respect to age the bogs fall into three categories. Those at Clackamas, Clear, and Tumalo lakes and on Willamette Pass are possibly the oldest because they rest on glacial drift or its chronological equivalent. Those lying on Mount Mazama pumice are younger because the eruption of this prehistoric mountain occurred after the maximum of the last Pleistocene glaciation (Williams, 1942). The Mud Lake bog is probably the youngest, as the pumice which underlies this section is of local origin and may be from the same source as the stratum at 2.0 meters in the Tumalo Lake profile. In the latter this layer is 2.5 meters above the Mount Mazama pumice stratum and must necessarily be considerably younger.

PRESENT CLIMATE AND VEGETATION.

The vegetation and climate of the Oregon Cascades vary considerably due to the great topographic relief and the influence of the mountain range itself upon the marine climate that spreads eastward from the Pacific Ocean. Although the air loses much of its moisture in traversing the Coast Range, on moving up the west slope of the Cascades it is again cooled so as to provide an annual precipitation of 90 inches in certain localities. Continuing to flow beyond and down the east slope of the Cascades the air is warmed dynamically and gives up little of its remaining moisture. Consequently the climate becomes more and more arid on the leeward slopes and out upon the Columbia Plateau and the northern Great Basin, where in some areas the annual rainfall is as low as ten inches. The continental influence becomes more pronounced eastward. In addition to the influence of the wide range in precipitation on the vegetation of the Oregon Cascades, the altitude and exposure also have a profound effect upon the forest composition due to variation in temperature.

On the west slope up to an elevation of 3,000 to 4,000 feet is the Humid Transition life zone (Bailey, 1936). Here the forests are luxuriant because of the comparatively warm climate and abundant rainfall. The principal arboreal species include Douglas fir (*Pseudotsuga taxifolia*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), lowland white fir (*Abies grandis*), noble fir (*A. nobilis*), incense cedar (*Libocedrus decurrens*), and sugar pine (*Pinus lambertiana*). The most common and widespread of these species are Douglas fir and western hemlock.

The Canadian life zone lies above the Humid Transition and with the exception of about a dozen of the highest peaks covers the crest of the Cascade Range. It extends down the east slope but not so far as on the west, because of the lesser precipitation and the warmer summers on that side. In the region of Crater Lake and for a distance of 60 miles to the north, the Canadian zone extends farther east than in the rest of the Cascades because of the greater altitude and precipitation. In the extreme southern part of Oregon the Canadian zone is very narrow and entirely absent in places, and the Humid Transition grades eastward directly into the Arid Transition with no intervening life zone. The principal forest trees in the Canadian life zone in the Oregon Cascades are western pine (*Pinus monticola*), lodgepole pine (*P. contorta*), Engelmann spruce (*Picea engelmanni*), western hemlock, Douglas fir, silver fir (*Abies amabilis*), and lowland white fir. In the southern part of the Oregon Cascades white fir (*Abies concolor*) and red fir (*A. magnifica*) are present, while in the northern half, western larch (*Larix occidentalis*) is not uncommon. Pollen analysis of the Tumalo Lake sedimentary column reveals that this species was more abundant in early postglacial time than at any time since (Hansen, 1942). The most abundant tree in the Canadian zone on the crest and east slope of the Cascades of central Oregon is lodgepole pine. It owes its great abundance to the pumice mantle that extends north and east from Crater Lake for a distance of 100 miles. The deposition of Mount Mazama pumice during postglacial time interrupted forest succession toward the climatic climax of the region, and has permitted lodgepole to thrive in the absence of competition of the other species that would normally forest the area under the existing climatic conditions (Hansen, 1942, 1942a). It has persisted since as an edaphic climax.

The Hudsonian life zone circumscribes the higher mountain peaks while some of the lower peaks are covered by this zone. It ranges from 5,000 up to 6,000 feet on the cold slopes in the northern part of the Cascades and from 7,000 up to 8,000 feet on the warmer slopes and in the southern part of the range. Forests are sparse and consist of alpine fir (*Abies lasiocarpa*), mountain hemlock (*Tsuga mertensiana*), whitebark pine (*Pinus albicaulis*), and Alaska cedar (*Chamaecyparis nootkatensis*). In the lower reaches of the Hudsonian zone within the pumice-covered region, lodgepole pine is abundant. The highest peaks of the Oregon Cascades support the Arctic-alpine zone in which there are no forest trees.

The timbered Arid Transition zone covers the broad basal slopes of the Cascades and in the southern half continues for some distance out upon the plateau due to the higher altitude and greater precipitation. The most characteristic tree of this life area is western yellow pine (*Pinus ponderosa*). It is the most xerophytic of Pacific Northwest forest trees and is able to survive farther out upon the plateau and at lower elevations than other species. In the southern half of its range in the Oregon Cascades it forms patchwise stands with lodgepole pine, the latter, however, being much in the majority because of the thick pumice mantle. South and east of Crater Lake scattered stands of yellow pine occur due to differences in relief. It occupies the higher ridges and windward slopes wherever there is sufficient moisture. In the northern part of the Oregon Cascades, beyond the pumice mantle northward to the Columbia River, yellow pine forms a narrow and almost continuous zone due to the steep easterly slope and the absence of pumice. In this area lodgepole pine is confined largely to burns in the upper part of the Arid Transition and in the Canadian life zones. In the southern part of Oregon the range of yellow pine extends well west of the Cascades in the Rogue River valley and its tributaries. A few stands occur within 50 miles of the Pacific Ocean. Adjacent to the yellow pine forests on the east, western juniper (*Juniperus occidentalis*) occurs in sparse stands where soil and moisture conditions are favorable.

Postglacial Forest Succession.

LODGEPOLE PINE.

The general trends of forest succession as recorded in the Clear and Clackamas lakes sections are similar to those portrayed by pollen profiles in the Puget Lowland of western Washington where the bogs likewise overlie glacial drift (Hansen, 1941). In the lowest levels of both sections lodgepole pine is predominant, being recorded to 45 and 52 per cent in the Clear and Clackamas lakes sections respectively (Figs. 3, 4).

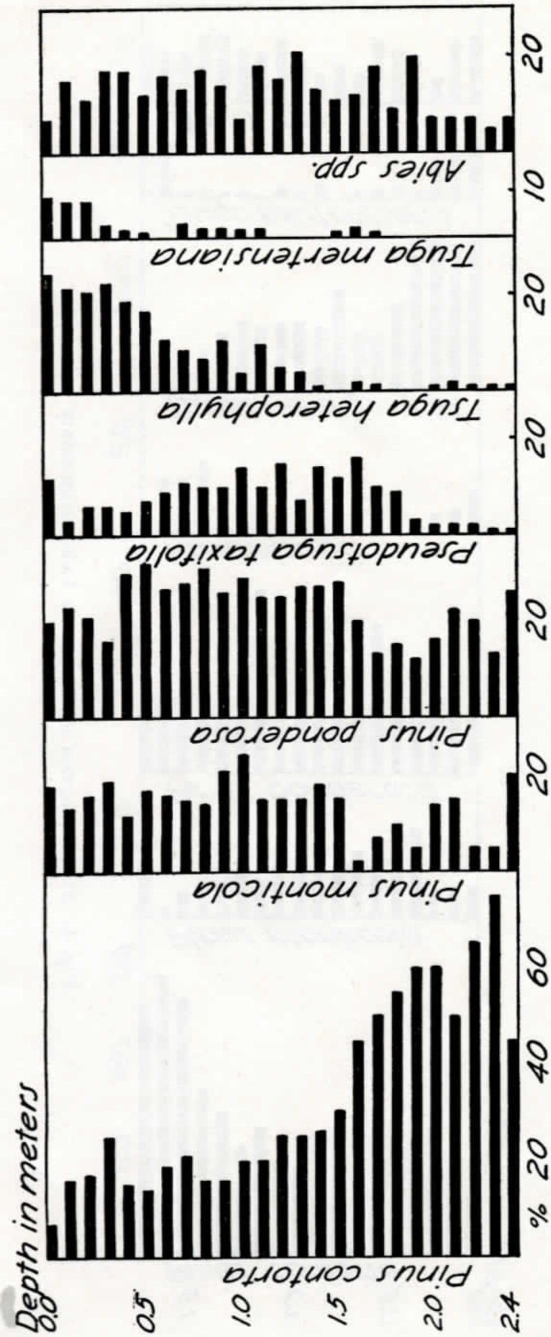

Fig. 3. Pollen diagram of Clear Lake sedimentary column.

Fig. 4. Pollen diagram of Clackamas Lake sedimentary column.

In the level immediately above it increases to 75 and 58 per cent, which are its maximum proportions in the columns. This postglacial pioneer invasion of lodgepole pine on deglaciated terrain is characteristic over most of the Pacific Northwest. As the glaciers retreated the climate was still cool and moist and the edaphic and physiographic conditions unstable. Lodgepole, being an aggressive species, of prolific seeding habit, and producing seed at an early age, was able to persist close to the ice front. As the terrain was freed of ice, lodgepole was able to take advantage of the lack of competition and rapidly colonized the sterile mineral soil. Other species of greater longevity and with more tolerance for shade, however, replaced lodgepole as the soil was modified and the physiographic conditions became stabilized. The sharp increase in lodgepole immediately above the bottom is similar to that in most sedimentary columns in the Puget Lowland. Such an increase in so many profiles distributed over such a wide area suggests that the response was due to some systematic environmental change. It may reflect a slight readvance of the ice, causing unfavorable conditions for other species that had gained a substantial foothold and begun to replace lodgepole. From this maximum in the second lowest level of each section lodgepole generally declines upward and in both profiles reaches its lowest proportions at the top. An accelerated decline in the middle third of the profiles suggests a response to increased warming and drying which is so well depicted by many profiles throughout the Pacific Northwest. A slight expansion in the upper-third denotes a return to moister and cooler climate during the past several thousand years.

The forest succession as recorded in the Rogue River profiles is somewhat different from that revealed in the Clear and Clackamas lake sections. This is to be expected because the influence of Mount Mazama pumice was not felt as far north as these two lakes. Also the record is presumably older in these sections because they rest directly on glacial drift, while the Rogue River sections are underlain with Mount Mazama pumice. Local differences in climate, soil, and topography also have been contributing factors in causing different trends of forest succession. In the Rogue River sections lodgepole is slightly predominant in the lowest horizons, but its probable over-representation in pollen profiles suggests that western yellow pine was actually the most abundant arboreal species (Figs. 5, 6).

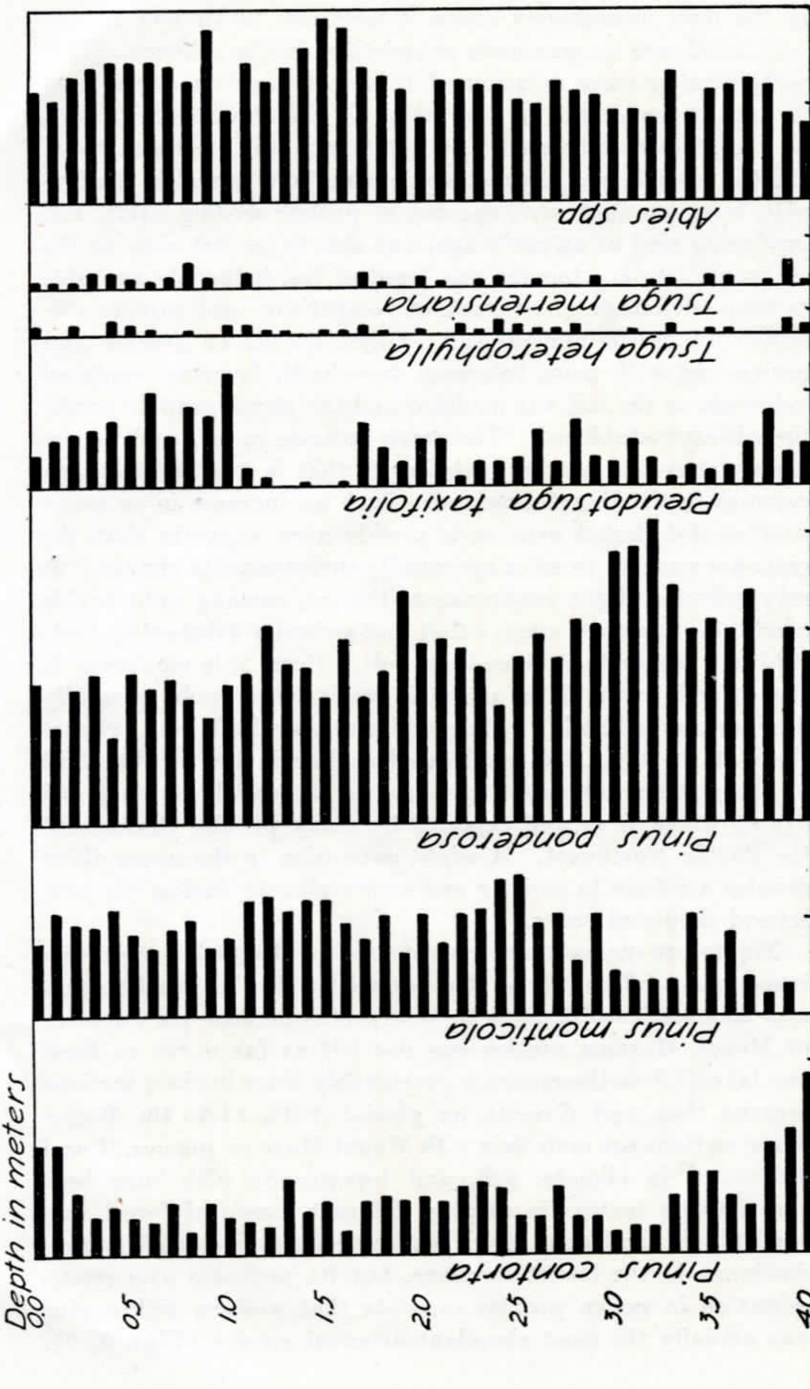

Fig. 5. Pollen diagram of the Rogue River sedimentary column.

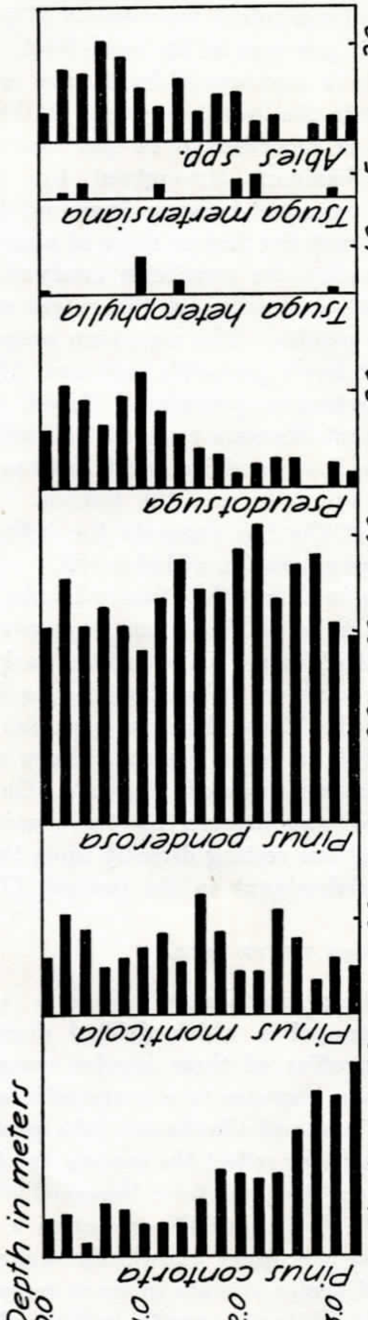

Fig. 6. Pollen diagram of the Prospect sedimentary column.

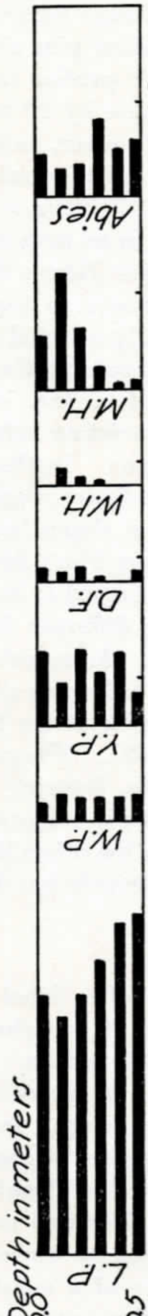

Fig. 7. Pollen diagram of the Diamond Lake sedimentary column, L. P., lodgepole pine; W. P., white pine; Y. P., yellow pine; D. F. Douglas fir; W. H., western hemlock; M. H. mountain hemlock.

In the Rogue River section lodgepole is recorded to 37 per cent while yellow pine attains 35 per cent at the same level. In the Prospect profiles lodgepole is represented by 40 per cent and yellow pine by 39 per cent in the lowest horizon. At Diamond Lake, however, lodgepole is recorded to 71 per cent at the bottom and remains predominant throughout the sections (Fig. 7). This is to be expected because Diamond Lake is located in an area covered with five feet or more of pumice. In the upper Rogue River valley the pumice is confined to the valley floors so that forest succession on the ridges was not materially affected by the pumice. The maximum proportions of lodgepole at the lowest levels probably represent the remnants of a once more extensive postglacial forest of this species existing before Mount Mazama erupted and sedimentation began. In the Rogue River and Prospect sections lodgepole declines irregularly upward from the bottom. In the former a sharp increase at the top suggests the influence of recent fire which favored an expansion of lodgepole.

This record of lodgepole in all but the Diamond Lake section is quite different from that in the five other bogs previously studied. As revealed in the Tumalo Lake profiles early postglacial lodgepole pine forests were being replaced rapidly by yellow pine at the time of the Mount Mazama eruption (Hansen, 1942). The pumice fall, however, caused a sharp reversal of trends, favoring a rapid expansion of lodgepole. On Willamette Pass lodgepole also was favored by the pumice fall, while in the other three sections resting directly upon the pumice, lodgepole has been predominant to the present (Hansen, 1942a).

WESTERN WHITE PINE.

The pollen listed as white pine probably includes a fair proportion of whitebark pine pollen which drifted down from higher elevations. The profiles of these species reveal little that can be interpreted as a response to a systematic environmental change. In the Clear and Clackamas lake profiles an expansion in the upper third may reflect the cooling and humidifying of the climate during the past four thousand years as will be discussed later. In the Rogue River section a similar expansion of white pine in the upper two-thirds suggests the influence of a moister and cooler climate in more recent time. In the Prospect section, the white pine profile indicates little or nothing in the way of a climatic trend. At Diamond Lake white pine is represented only sparsely throughout the section.

WESTERN YELLOW PINE.

The pollen profiles of western yellow pine from sedimentary columns located on the east slope of the Cascades, in the Columbia basin of both Oregon and Washington, and in the northern Great Basin of south central Oregon are good indicators of postglacial climatic cycles. The yellow pine forests of today lie between the timberless Arid Transition zone and the cooler and moister Canadian zone. The precipitation is and probably has been at a critical minimum so that slight increases or decreases have resulted in expansion or contraction of yellow pine forests, or downward or upward movements of the yellow pine zone on the east slope of the Cascades. In the Clear and Clackamas lakes sections, yellow pine is recorded to 26 and 20 per cent respectively in the lowest level (Figs. 3, 4). It declines for a few levels and then increases to attain its maxima of 32 to 38 per cent in the middle third of each profile. It generally declines again toward the top. The greatest proportions in the middle third of both profiles reflect postglacial warming and drying to its maximum degree. The total yellow pine proportions are low as compared with those in sedimentary columns located within or near the yellow pine zone of eastern Washington or the northern Great Basin of south central Oregon (Hansen, 1944, 1946). This is probably due to the proximity of the Canadian and Humid Transition life zones westward and windward from the sites of the bogs.

In the Rogue River sections yellow pine is more strongly represented due to the location of the bogs in yellow pine forests or forests containing a high proportion of this species. The bogs also lie at greater distance from mesophytic forests than do Clear and Clackamas lakes. The highest proportions of yellow pine occur in the lower half of each profile, thus reflecting the influence of the warm, dry period which reached its maximum after the eruption of Mount Mazama (Figs. 5, 6). As these sedimentary columns rest directly upon Mount Mazama pumice and are younger than the other two, the period of yellow pine maximum and predominance is contemporaneous in both sections.

In the Tumalo Lake bog yellow pine expanded rapidly in response to early postglacial warming and drying but its expansion to predominance was interrupted by the pumice fall. Although the pumice mantle in this is only from six inches to a foot thick, it favored an influx of lodgepole to supersede yellow pine, which has persisted in predominance until today (Hansen, 1942). In those sediments lying directly upon Mount Mazama pumice yellow pine never was able to gain predominance (Hansen, 1942a). In four sections from Lower Klamath Lake yellow pine attained its maximum and predominance at a stratigraphic position that is consistent with other sedimentary columns in portraying the warm, dry stage which occurred after the eruption of Mount Mazama (Hansen, 1942b).

DOUGLAS FIR.

The pollen profiles of Douglas fir are not always indicative of climatic trends, because it has such a great geographic range and occurs in several formations with different phytosociological status in each. In the Clear lake profile its highest proportions are concurrent with those of yellow pine, suggesting that it responded in the same way to a drying climate. In the Rogue Valley sections the maximum proportions of Douglas fir in the upper third suggests its positive response to the cooler and moister climate of the past several thousand years.

WESTERN HEMLOCK.

The different interpretations placed on the maximum of Douglas fir in the two northernmost sections as compared with the two southern columns are supported by the profiles of western hemlock in the Clear and Clackamas lakes profiles. In this area Douglas fir and yellow pine evidently have been competing with western hemlock, mountain hemlock, and lodgepole pine. The limiting factor has been moisture but the precipitation is greater in this area than farther south. Also the influence of the Canadian and Humid Transition zones is more apparent because these zones are nearer the sites of the sediments. Furthermore, the prevailing winds from the west result in a stronger representation of forests of these two zones than of the yellow pine zone lying eastward and leeward from the sites of the sediments. In these moister zones Douglas fir competes with western hemlock, which in the absence of fire thrives better than Douglas fir. During dry periods Douglas fir is favored even in the absence of fire. Hemlock was unable to take advantage of the moister conditions of early postglacial time because of the unstable and poor edaphic conditions which in the absence of competition by other species permitted lodgepole to predominate. As postglacial time passed the soil may have become modified but then the dry period hindered expansion of hemlock. During the last several thousand years, however, an increase in moisture has favored a marked expansion of hemlock, which attains its maximum at the top in both profiles. Mountain hemlock also reveals a similar trend but to a lesser degree. In the Rogue Valley profiles western and mountain hemlock are insufficiently represented to depict postglacial trends.

FIR.

The pollen profiles of the true firs do not portray any postglacial trend in the Clear and Clackamas lakes region. The species of fir pollen have not been separated, but in general most species require more moisture than yellow pine. In the Rogue Valley profiles fir is represented better than elsewhere and its trends are consistent with those of the other species. In general fir is more abundant in the upper half of the sections, indicating a positive response to cooler and moister conditions which have prevailed during the past several thousand years.

POSTGLACIAL CLIMATE AND CHRONOLOGY.

The climactic eruption of Mount Mazama resulting in the formation of the caldera holding Crater Lake occurred sometime after the maximum of the last Wisconsin glaciation (Williams, 1942). Williams estimates that the eruption took place between 4,000 and 7,000 years ago. Pleistocene glaciers advanced and retreated many times while Mount Mazama was rising. Ice tongues extended at least 10 miles from the summit and one extended 17 miles from the peak. In some canyons the ice was 1,000 feet thick and probably at times the entire mountain was covered with a system of glaciers. How much time passed between the time of maximum glaciation and the climactic eruption is hard to estimate, but according to Williams the glaciers had retreated until only three small tongues of ice extended beyond what is now the rim of Crater Lake. By comparing its remnant profiles with those of other cascade volcanoes formed of similar materials, the maximum height of

Mount Mazama is estimated by Williams to have been 12,000 feet. The forests on the slopes of Mount Mazama were scantier than they are today although they apparently consisted of the same species. Ring growth studies of charcoal logs buried by the pumice suggest that the local climate at the time of the eruption was similar to that of today (Williams, 1942).

The maximum of the last glaciation in the Puget Lowland of western Washington is dated at about 25,000 years (Antevs, 1945). This is correlated with the Mankato maximum of the last Wisconsin glaciation and with the Tioga glacial stage in the Sierra Nevada. Bogs resting upon glacial drift or its chronological equivalent are necessarily younger due to a lapse of time between deglaciation and the beginning of pollen-bearing sedimentation. The average age of 30 or more sedimentary columns resting upon glacial drift or materials of the same age in Washington, Oregon, and Idaho is estimated to be about 18,000 to 20,000 years. These figures are more or less arbitrary but they have been chosen upon several bases, including rate of ice retreat in other parts of North America, the depth and type of sediments, the climate in the several areas where the sediments have accumulated, the physiographic history of the region as well as that of the lake basin itself, the occurrence of volcanic strata in the sedimentary columns and their chronological correlation with one another, and the application of climatic and chronologic data from other sources to the pollen analytical data, chiefly the climatic stages as interpreted from the pollen profiles. Also the postglacial climatic trends and chronology as interpreted from pollen profiles in other parts of the world by many workers have served as a compromising factor.

Using Antevs' figures of 33 years per mile for the retreat of the Labrador ice from Long Island to the White Mountains (Antevs, 1922), from 5,000 to 7,000 years must have been required for the ice in the Puget Lowland to waste from its southernmost terminus to the Canadian border, a distance of about 200 miles. This leaves a figure of about 18,000 years since the present-day bog sites were freed of ice. Some may be older and some younger, depending upon the location of their sites with respect to the rate and method of glacial retreat and subsequent geomorphic changes. Mountain deglaciation probably lagged somewhat and so 15,000 years is estimated to be the age of montane pollen-bearing sections that rest on glacial drift. In the state of Washington the occurrence of a volcanic ash stratum apparently from a single, contemporaneous source in most postglacial organic sedimentary columns correlated with the depth and types of sediments and the recorded plant succession provides an excellent common time marker and a chronological indicator. It is dated at about 6,000 years, or during the middle of a warm, dry postglacial stage. In Oregon the occurrence of one or more pumice strata in bogs in the Willamette Valley, the Cascades, and the northern Great Basin serves to segregate postglacial time into units which correlated with the forest succession and the climatic interpretation provides relative dates.

The Postglacial, which is here defined as the time since the last glacial maximum, has been divided into four climatic periods upon the basis of the pollen record from about 70 sedimentary columns well distributed throughout the Pacific Northwest. The first stage persisted until about 15,000 years ago and was cooler and moister than the present. Some of the sections may represent 5,000 to 10,000 years of this initial stage while others may have hardly begun before it ended. The second stage was one of warming and drying and lasted until about 8,000 years ago. During this stage, perhaps about 10,000 years ago, the temperature reached a level similar to that of today. The third stage, lasting from about 8,000 years ago to about 4,000 years ago, was one of maximum warmth and dryness, while the final stage of about the last 4,000 years has been cooler and moister.

A postglacial period of maximum warmth evidently was general throughout the north temperate zone, as is suggested by pollen profiles and peat stratigraphy from northern Europe, England, eastern North America, and the Great Lakes region (Blytt, 1881; Sernander, 1908, 1910; von Post, 1930, 1933; Godwin, 1940; Antevs, 1931, 1933; Sears, 1942, 1942a; Deevey, 1943, 1944; Potzger, 1942; Potzger and Richards, 1942; Wilson and Webster, 1942). The chronologic interpretations by these various workers for the duration of this thermal stage range from 6,500 to as low as 2,500 years.

Pollen profiles from 30 or more postglacial sedimentary columns in the Pacific Northwest that overlie glacial drift reveal consistent and definite evidence for a xerothermic stage during postglacial time. This is best revealed in profiles from eastern Washington, the northern Great Basin of south central Oregon, and the Willamette Valley of western Oregon. It is less strongly pronounced in profiles from the Puget Lowland of western Washington and from northern Washington and Idaho.

The correlation of the time and duration of this warm, dry period with chronological data from other parts of the world, aids in constructing a time scale for the postglacial climatic sequence in the Pacific Northwest. The nearest links with European chronology are concerned with the fluctuations of the Great Basin lakes and the oscillations of western mountain glaciers. Antevs (1931, 1933) using summer temperatures for long distance correlation, dates the postglacial age of distinctly higher temperature in Sweden and Denmark from 6,000 to 2,000 B. C. He designates this age of warmth as the Middle Postglacial and uses it as a starting point in correlating the Swedish varved clay chronology (De Geer 1910, 1940) with North American postglacial climatic sequences. This chronology may be applied to the Pacific Northwest through the interpretations of the fluctuations of lake levels in the Great Basin. These lakes expanded and contracted in response to the Pleistocene glacial and interglacial stages. The highest stages of lakes Bonneville and Lahontan are correlated with the Iowan-Tahoe glacial stage, while the lower stages represented by the Provo shoreline in the Bonneville Basin and the Dendritic terrace in the Lahontan Basin are correlated with the Late Wisconsin (Mankato-Tioga) glacial stage (Antevs, 1941, 1945). In the Summer Lake basin of south central Oregon the highest levels of Pluvial (glacial) Lake Chewaucan are probably to be correlated with the Tahoe (Iowan or Early Wisconsin) glacial stage of the Sierra Nevada, and lower beach levels of Winter Lake with the weaker Tioga (Mankato or Late Wisconsin) stage (Allison, 1945). Continued fluctuations of Great Basin lakes during the Postglacial probably in response to climatic cycles is suggested by their present salinity. The present salinity of Owens Lake in California and Abert and Summer lakes in south central Oregon is such that it need not have required more than 4,000 years to have been reached (Van Winkle, 1914; Gale, 1915), indicating that they are not direct descendants of the Pleistocene lakes that occupied their basins.

The earlier lakes apparently dried up during the xerothermic interval of the Postglacial and their saline sediments were either buried or removed by deflation. Antevs (1945) dates this dry stage between 8,000 and 4,000 years ago. About 4,000 years ago an increase in moisture caused these lakes to be reborn and attain higher levels than at present. In Summer Lake basin an abandoned sandy beach ridge from 10 to 20 feet higher than modern Summer Lake suggests an expanded lake stage resulting from the increase in moisture a few thousand years ago (Allison, 1945).

Further support for the time and occurrence of the postglacial warm, dry stage is revealed by the history of modern glaciers in the western mountains. Modern cirque glaciers in the Sierra Nevada, most of the glaciers in the Rocky Mountains within the United States, and all of the lesser glaciers of the Cascade Range and Olympic Mountains probably represent a new generation of glaciers that came into existence in recent time, probably about 4,000 years ago (Matthes, 1939, 1942). The almost complete absence of ice in the mountains prior to this time denotes a long, warm interval.

Although the eruption of Mount Mazama took place after the maximum of the last Pleistocene mountain glaciation, the stratigraphic position of its pumice in sedimentary columns in the Oregon Cascades and northern Great Basin indicates that the volcanic activity occurred some time before the maximum of the warm, dry Middle Postglacial. In the Oregon Cascades western yellow pine had reached an advanced stage of expansion by the time of the eruption. This is indicated in sedimentary columns that rest directly upon Mount Mazama pumice as well as those that contain an interbedded stratum. Postglacial sections in the northern Great Basin reveal an interbedded stratum of Mount Mazama pumice above the maximum of yellow pine but below the maximum of grasses, Chenopods, and Composites (Hansen, 1946). This denotes that yellow pine expanded as the postglacial climate became warmer. Continued increase in temperature became unfavorable for yellow pine and favored an increase of grasses, Chenopods, and Composites, indicating that the eruption took place before the maximum of the drouth, but probably soon after the climate became somewhat similar to that of today.

The stratigraphic relationships of Mount Mazama pumice and Newberry Crater pumice in the former bed of Lake Chewaucan and Winter Lake, pluvial antecedents of modern Summer Lake in south central Oregon, lend a clue as to the time of the Mount Mazama eruption (Allison, 1945). Pluvial Winter Lake, which is correlated with the Tioga (late Wisconsin) glacial stage, was still in existence several tens of feet above modern Summer Lake at the time of the major eruption. It must have persisted for some time afterwards because the Mount Mazama pumice is overlain by additional lake sediments including a layer of pumice from Newberry Crater. The final eruption of both volcanoes occurred before the culmination of the warm, dry interval in the northern Great Basin. Presumably the Pleistocene lakes dried up during the warm, dry Middle Postglacial, and Summer Lake was re-established in the lower part of the basin as the climate became moister in the last 4,000 years.

By correlating the Pleistocene and postglacial lake levels in the Summer Lake basin with those in the Lake Lahontan basin of Nevada, as interpreted by Antevs, Allison (1945) dates the eruption of Mount Mazama between 10,000 and 14,000 years ago.

On the contrary the thickness of the bog sediments overlying Mount Mazama pumice, the stratigraphic position of the interbedded pumice in relation to the warm, dry stages as interpreted from pollen profiles, and the correlation of many pollen profiles from the Pacific Northwest indicate to the writer that the eruption of Mount Mazama took place between 8,000 and 10,000 years ago.

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