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POSTGLACIAL VEGETATION OF THE NORTHERN GREAT BASIN

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POSTGLACIAL VEGETATION OF THE NORTHERN GREAT BASIN [1]

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A SMALL portion of the Basin and Range Province extends into south central Oregon (fig. 1). During the Miocene the Columbia lava flows spread over the region, and since then considerable uplifting has taken place resulting in the present system of fault scarps and basins with interior drainage. During the Pleistocene these basins were occupied by deep lakes owing to the greater amount of precipitation concurrent with the glacial stages farther north. These lakes rose and fell in response to variations in rainfall, and well-defined shore lines today mark the sustained levels attained probably during the maximum of the Iowan (early Wisconsin) and the late Wisconsin glaciations. At present some of these basins are dry, others contain playa lakes, while a few hold water throughout the year. In the absence of exterior drainage evaporation has resulted in alkaline lakes, some of them so saline as to inhibit all visible signs of life. Where the lakes have entirely disappeared, alkali beds are extensive and support only halophytic vegetation, and in some areas no plant life whatsoever. After the maximum of the late Wisconsin glaciation, represented by pluvial stages in the Great Basin, the lakes subsided. Some of them became too alkaline for vegetation, but others with drainage into interconnected fault basins favored hydrarch succession, and appreciable thicknesses of pollen-bearing organic sediments accumulated. These sediments hold a record of adjacent plant succession which in some instances goes back almost to the maximum of the last pluvial stage which is dated at about 25,000 years (Antevs, 1945).

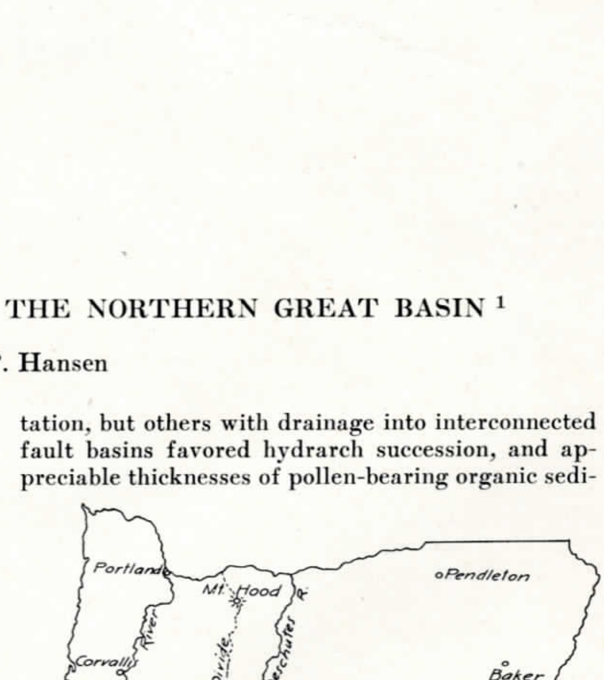

Fig. 1. Map of Oregon showing sites of the sedimentary columns, the northern Great Basin, Crater Lake, and Newberry Crater.

Perhaps the most cataclysmic geologic event in

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Oregon since the late Wisconsin glaciation was the eruption of Mount Mazama which formed the caldera holding Crater Lake in the Cascades of southern Oregon. A blanket of pumice 6 inches or more thick covers an area of 5,000 square miles to the north and east of Crater Lake, and thinner deposits extend for many miles beyond (Williams, 1942). The evidence of Pleistocene glaciation in relation to the position of pumice and other volcanic materials indicates that the eruption of Mount Mazama occurred well after the maximum of the last Wisconsin glaciation. During maximum glaciation one tongue of ice extended down 17 miles from the peak, but at the time of the eruption the glaciers had receded until only three small tongues of ice extended beyond what is now the rim of the crater. Williams estimates that the eruption took place between 4,000 and 7,000 years ago. The dating of the Mount Mazama eruption is of considerable importance, because the occurrence of its pumice in postglacial sediments serves as an excellent time marker. Also the stratigraphic position of Mount Mazama pumice in relation to that of other volcanoes in the Oregon Cascades provides a relative chronology for postglacial volcanic activity. This chronology applied to pollen profiles and their interpreted forest succession and climatic trends, to the fluctuations of Great Basin lakes, and to other chronological evidence from various sources, furnishes a fairly detailed recent chronology.

The pollen analysis of about seventy postglacial sedimentary columns in the Pacific Northwest and the interpretation of the climatic trends from the recorded vegetational history, correlated with climatic and chronologic data from several other sources, have led the author to divide postglacial time into four climatic stages. The first, ranging from the time of the glacial maximum to about 15,000 years ago was cool and moist. The second period was one of increasing warmth and dryness and prevailed from 15,000 to about 8,000 years ago. The third stage marks a time of maximum warmth and dryness and endured from about 8,000 to 4,000 years ago, while the final period saw a return to cooler and moister climate which with minor fluctuations has persisted to the present. This increase in moisture about 4,000 years ago has been called the Late Pluvial by Antevs (1938). This study is concerned with the pollen analysis of three sedimentary columns in the northern Great Basin of south central Oregon, and the interpretation of the pollen profiles into terms of forest succession and climatic trends. The data in this study provide strong support for the occurrence of the xerothermic stage between 8,000 and 4,000 years ago.

Location and characteristics of the sediments.—The site of the sedimentary column nearest to Crater Lake is Klamath Marsh, about 15 miles to the east (fig. 1). Klamath Marsh covers more than two townships at an elevation of about 4,500 feet. It is a shallow marsh with standing water in some places, and the surface is covered largely with swamp-plant communities, consisting of cat-tails, bulrushes, and sedges known locally as tules. The marsh is naturally drained by the Williamson River which empties into the Sprague River, and the latter flows into Upper Klamath Lake about 20 miles to the south. The marsh is also drained by ditches, and owing to the grazing of cattle much of the virgin and natural aspects of the surface have been destroyed. The pollen-bearing sediments are underlain with about 3 meters of Mount Mazama pumice. Their thickness in the area of sampling is 2.5 meters. The lowest 0.1 meter consists of silty pumice grading upward into limnic peat 1.9 meters thick which is overlain with 0.5 meter of sedge peat.

A second section of sediments was obtained from Upper Chewaucan Marsh about 80 miles east-southeast from Crater Lake and about 60 miles in the same direction from Klamath Marsh (fig. 1). This marsh lies at an elevation of about 4,300 feet in one of three interconnected fault troughs, all of which have had a similar physiographic history. The southern end of Summer Lake basin lies about 10 miles to the north while Abert Lake basin is located a few miles to the east. Chewaucan Marsh was originally a tule swamp so characteristic of the northern Great Basin. Vegetation consisted chiefly of cat-tails, bulrushes, sedges, and other marsh plant species usually associated with these dominants. At present most of the marsh is mowed annually for hay. The sediments are comparatively shallow and more or less mucky, suggesting oxidation due to a fluctuating water table. The thickest section that could be located is 2.4 meters, with Mount Mazama pumice at 1.2 meters. The lowest 0.4 meter lies on pebbly gravel and consists of silty sediments grading upward into 1.7 meters of mucky limnic peat, which in turn is overlain with 0.3 meter of fibrous sedge peat.

A third section was obtained from Warner Lake basin, located about 110 miles east-southeast of Crater Lake and about 40 miles east-southeast of Chewaucan Marsh (fig. 1). Warner Valley is a fault basin with Hart Mountain on the east forming the uplifted block. The basin extends in a general north-south direction for a distance of more than 50 miles, and contains a series of lakes, the largest of which are Crump, Hart, and Flagstaff. The elevation of the valley floor is about 4,460 feet, and it is covered with organic sediments formed by swamp vegetation, which in some areas is halophytic. Unreclaimed portions of the marsh indicate that it was originally covered with tules before drainage and cultivation. A large number of scattered borings were made over about 20 miles of the length of the marsh, but the thickest section obtained is 3.5 meters. The lowest 0.1 meter overlying sand consists of silt, grading upward into 2.2 meters of limnic peat, which in turn is overlain with 1.2 meters of fibrous sedge peat. A layer of Mount Mazama pumice is interbedded at 2.6 meters. The pumice in both the Chewaucan Marsh and Warner Lake basin is from the same eruption of Mount Mazama and also is similar to pumice occurring at 4.5 meters in a 7-meter peat section from Tumalo Lake in the Cascades about 13 miles west of Bend.[2]

In the preparation of the sediments for microscopic analysis, the potassium hydrate method was used (Hansen, 1940). Between 150 and 200 pollen grains of indicator species were identified from most levels, and in the others 100 grains were identified. Separation of the several species of pine pollen was effected by the size-range method (Hansen, 1941a).

Age of the sediments.—Although the sites of many postglacial pollen-bearing sediments in the Pacific Northwest are located beyond the limits of Pleistocene glaciation, they usually can be dated indirectly by the maximum of the last Wisconsin glaciation. The geomorphic cycles and the physiographic setting resulting indirectly from glaciation to the north indicate that organic sedimentation began during or soon after the last glacial maximum. The forest succession recorded in the sedimentary column supports the geological evidence that sedimentation began when the influence of the receding glaciers was prevalent and near at hand. Perhaps the best starting point for chronological correlation is glaciation in the Puget Lowland of western Washington. The maximum of the last glaciation in this region is correlated with the Mankato maximum of the last Wisconsin about 25,000 years ago (Antevs, 1945). There was no continental glaciation in Oregon, but Thayer (1939) found three glacial stages in the Oregon Cascades which he named Mill City, Detroit, and Tunnel Creek stages. These are tentatively correlated with the Sherwin, Tahoe, and Tioga stages in the Sierra Nevada of California (Blackwelder, 1931). In the Great Basin the maximum of the late Wisconsin glaciation is well defined by old shore lines about some of the lakes, situated many tens of feet above the present-day level of the lakes that occupy these basins. A much moister and perhaps cooler climate than at present must have existed for these lakes to have reached such high levels. These humid and subhumid periods are thought to have been chronologically correlative with the glacial stages farther north and in the mountains, and are known as Pluvial stages. Antevs (1945) correlates the highest stages of Lakes Bonneville and Lahontan, attained during the Bonneville Pluvial, with the early Wisconsin-Tahoe glacial stage, and the Provo shore line in the Bonneville basin and the Dendritic terrace in Lahontan basin with the late Wisconsin-Tioga glacial stage. In the Mono Valley of California the two highest water stages are believed to correspond with the two high water stages of Lakes Bonneville and Lahontan.

In the Summer Lake basin of south central Oregon a shore line about 355 feet higher than the present level of Summer Lake is assigned to the Bonneville Pluvial, and a lower, less prominent shore line is attributed to the Provo Pluvial (late Wisconsin) stage (Allison, 1945). Both of these lakes extended through a gap at the southeast corner of Summer Lake basin and inundated the sites of Upper and Lower Chewaucan Marshes. The earlier, deeper lake is called Lake Chewaucan and later one, Winter Lake. In the Warner basin, shore lines well above the level of the present lakes attest to the influence of the Bonneville and Provo pluvial stages and to the presence of deep lakes over the sites of the sediments of this study.

[2] Pumice identified by I. S. Allison.

The age of the pollen-bearing sediments from Chewaucan Marsh and Warner basin, then, is distinctly correlated with the maximum of the late Wisconsin glaciation. During both the pluvial and the interpluvial stages, undoubtedly sediments accumulated in these basins. During the deeper stages of the lakes, inorganic sediments were probably deposited, while during the shallower stages, hydrarch succession may have resulted in the accumulation of organic sediments which may underlie the postpluvial sediments. In the Summer Lake basin soft, blue lake muds have been penetrated to depths as much as 1,286 feet in unsuccessful attempts to obtain artesian water, suggesting a long history (Allison, 1945). The composition of the forests within range of pollen dispersal at the time the lowest sediments of this study were deposited, however, and their recorded persistence upward in the columns indicate that the pollen-bearing sediments would hardly seem to date earlier than postpluvial time. Also the stratigraphic position of Mount Mazama pumice in relation to their thickness and postpluvial climatic trends suggests that 20,000 years or less are represented. If these lakes were still at their maximum levels 25,000 years ago, they must have shoaled rapidly in order to permit deposition of sediments containing a high fraction of organic materials and only a few meters thick, representing from 15,000 to 20,000 years. Klamath Marsh can readily be dated as post-Mount Mazama, because it overlies Mount Mazama pumice.

Vegetation of the northern great basin.—In south central Oregon the basin floors lie well above 4,000 feet elevation while the ridges rise above 6,000 feet. Many higher ridges and fault blocks rise above 7,000 feet, while the Steens Mountains have elevations of over 9,000 feet. The average of the mean annual precipitation of eighteen stations ranging in altitude from 4,055 to 5,730 feet is about 14.5 inches, with a range of 7.8 to 17.66 (Climatic Summary of eastern Oregon, 1936). In general, the heaviest precipitation occurs at higher elevations and on the windward slopes, and decreases slightly toward the east for stations located in similar topographic situations. More than half of the precipitation occurs between October and April and the summer months are very dry.

The most abundant and widespread tree in the northern Great Basin is western yellow pine (*Pinus ponderosa*) which occupies most of the higher slopes and ridges. On some of the highest ridges a few specimens of western white pine (*Pinus monticola*) can be found, but, in general, moisture is too limited for this tree to thrive in any great abundance. Below the yellow pine zone, western juniper (*Juniperus occidentalis*) thrives on the rocky slopes, while in the upper limits of the yellow pine forests, Douglas fir (*Pseudotsuga taxifolia*) is abundant locally. Lowland white fir (*Abies grandis*) occurs sparingly along the river bottoms in the forested areas. Next to yellow pine, lodgepole pine (*Pinus contorta*) is the most abundant tree in the northern Great Basin. It is of local occurrence, however, and owes its abundance to fire and the presence of pumiceous soil. To the north and east of Crater Lake lodgepole forests cover vast areas where the pumiceous soil is unfavorable for yellow pine and for white pine at higher elevations. Klamath Marsh is half encircled by stands of lodgepole, which has probably resulted in its over-representation in the sedimentary columns for the region as a whole.

Although the precipitation over much of the non-timbered area of the northern Great Basin is sufficient for the bunchgrass prairie, characteristic of the Columbia Basin of Oregon and Washington, the thin, rocky, and, in many places, the alkaline soil, is unfavorable for many of the species for this association. Consequently such indicators as *Agropyron spicatum, Poa secunda,* and *Festuca idahoensis* are not common. The non-timbered zone may be divided into three vegetation areas based largely on soil conditions. They are (1) the rocky slopes and ridges with non-alkaline soil, (2) the basin floors covered with alluvial or lacustrine deposits, some of which are extremely alkaline, and (3) the basin floors which are covered with organic sediments or tule swamps. A fourth area, more localized than the other three, is that covered to various depths with pumice, the most extensive being in the more western part which is mantled with Mount Mazama pumice. In valleys where lakes have existed in the past or where playas are formed in the spring the soil may be so strongly alkaline as to favor only halophytic vegetation, or in some areas no vegetation whatsoever.

The most characteristic and widespread plant of the non-timbered areas is sagebrush (*Artemisia tridentata*). It occupies the valley floors and lower slopes and ridges where the soil is not too alkaline. Other less common species of sage are *A. spinescens* and *A. rigida*. Associates of the sagebrush are mountain mahogany (*Cercocarpus ledifolius*), antelope brush (*Purshia tridentata*), rabbitbrush (*Chrysothamnus nauseosus* and *C. viscidiflorus*), and *Tetradymia canescens*. In addition to the bunchgrasses mentioned above, other grasses that are often associated with the sages include *Hordeum murinum, Poa nevadensis, Stipa Thurberiana, S. comata, Elymus condensatus,* and *Koeleria cristata. Bromus tectorum* is the most common grass in the region, but since it is introduced it has played no part in postglacial plant succession, except in very recent time.

The flora of the alkaline areas is characteristic and includes such plants as greasewood (*Sarcobatus vermiculatus*), green molly (*Kochia americana*), shadscale (*Atriplex confertifolia*), saltbush (*A. Nuttallii*), silver scale (*A. argentea*), winterfat (*Eurotia lanata*), hopsage (*Grayia spinosa*), pahute weed (*Suaeda depressa*), and *Monolepis pusilla,* all of which belong to the Chenopodiaceae. Typical grasses that grow in alkaline soil are saltgrass (*Distichlis stricta*), alkali grass (*Puccinellia Nuttalliana* and *P. Lemmoni*), *Agropyron Smithii,* and *Spartina gracilis.* Other important herbaceous plants of slightly alkaline or non-alkaline areas are poverty weed (*Iva axillaris*), woolly sunflower (*Wyethia mollis*), and many species of *Eriogonum, Lomatium, Astragalus, Lupinus, Pentstemon,* and *Erigeron.* The species listed above are only a few of the typical indicators, but they are the most common and they probably were the chief contributors of pollen to the postglacial sediments. A more detailed account of the flora of this region may be had from Peck (1941).

Postglacial vegetation.—There is no reason to assume that the Great Basin was not forested during the Pleistocene. In fact pollen analysis indicates that during the late Pleistocene and early Postglacial forests covered a greater area than at present owing to the moister climate that persisted for some time after glacial retreat in the north. As the postglacial climate became warmer and dryer the forests apparently retreated upward on the slopes and upon the higher ridges and were reduced in their areal extent. The maximum contraction of postglacial forests was probably reached during the warm, dry interval between 8,000 and 4,000 years ago. Since then the forests have slightly expanded but have never regained their early postglacial abundance.

Lodgepole pine.—The early postglacial forests in the northern Great Basin did not invade deglaciated terrain as in the glaciated regions of northern Washington and Idaho and the Puget Lowland of western Washington (Hansen, 1941, 1941a, 1943, 1944, 1944a). In those areas lodgepole pine was the pioneer invader which was replaced by the present-day climax and subclimax dominants as the soil became modified and the climate was ameliorated. Lodgepole probably existed closer to the ice front than the species that replaced it because of its ability to thrive under unstable edaphic conditions, and its trait of producing large seed crops at an early age. In the northern Great Basin, however, absence of edaphic disturbances permitted western white and western yellow pine to persist as predominant during late Pleistocene and well into the Postglacial. Lodgepole pine was abundant only locally where fire occurred or where small areas were covered by volcanic ejecta. In the lowest levels of the Warner and Chewaucan sections lodgepole is recorded to only 25 and 21 per cent, respectively (fig. 2, 3). This is low compared with 65 per cent or more to which it is consistently recorded in organic sediments resting upon glacial drift. It then declines upward in both profiles and attains its lowest pro-

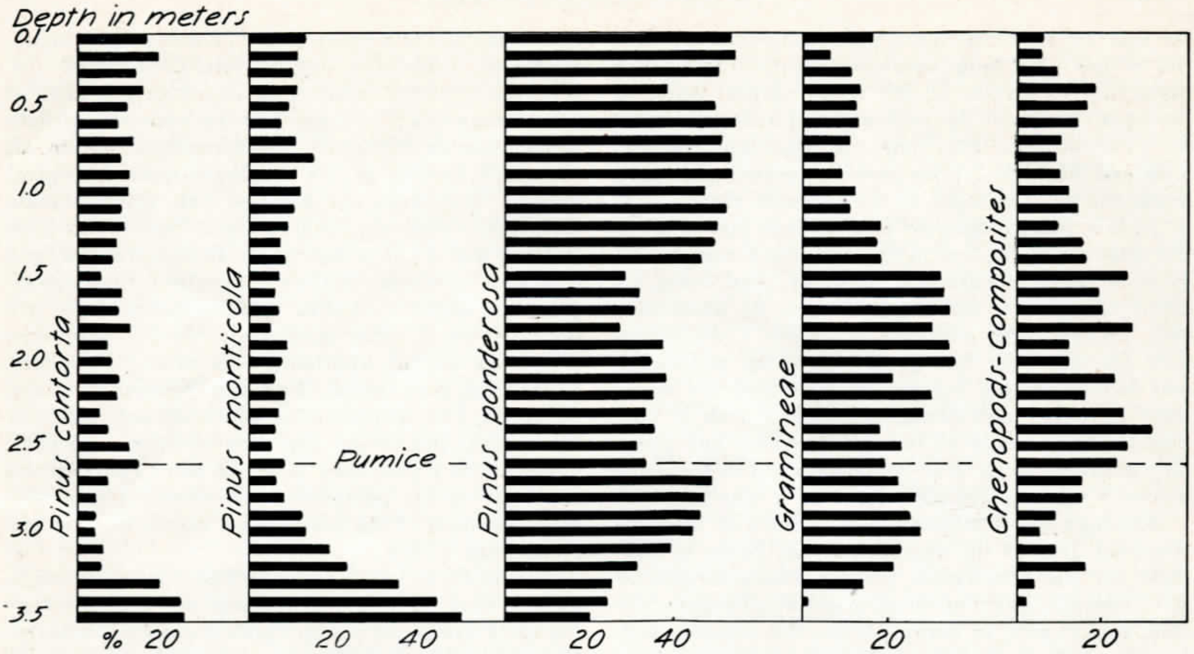

Fig. 2. Pollen diagram of Warner Lake sedimentary column.

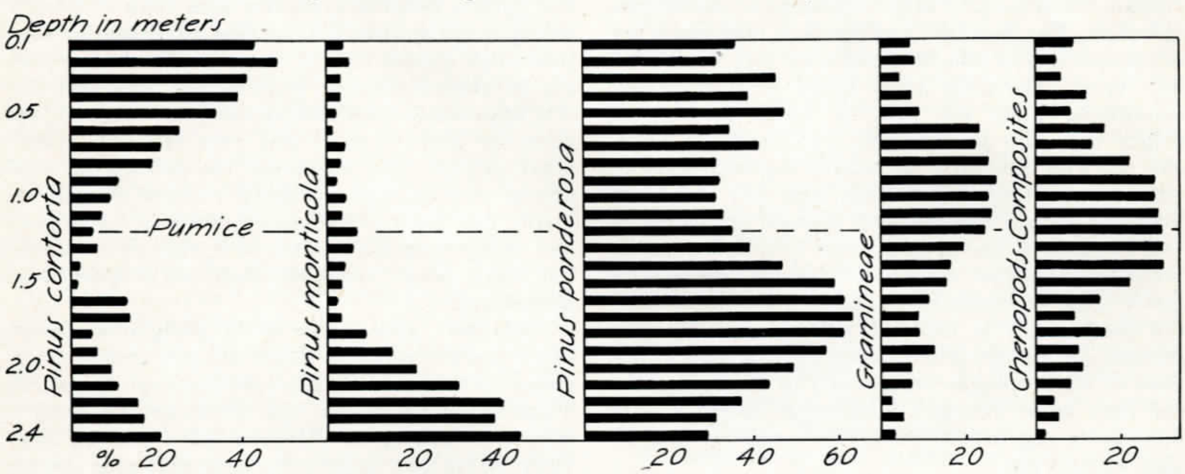

Fig. 3. Pollen diagram of Chewaucan Marsh sedimentary column.

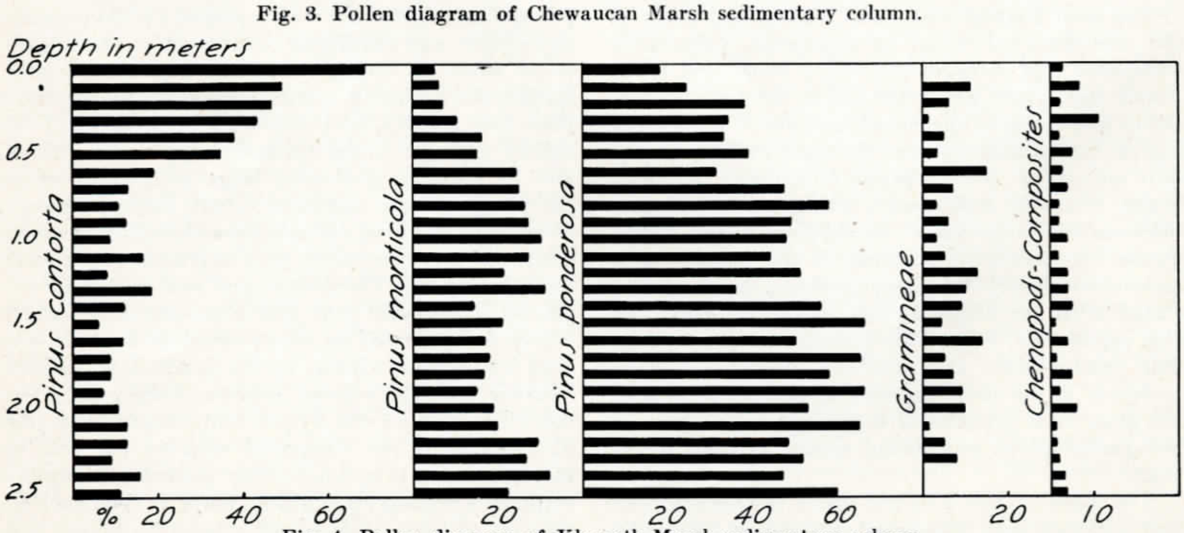

Fig. 4. Pollen diagram of Klamath Marsh sedimentary column.

portions in the middle third. In the Chewaucan Marsh region lodgepole increases sharply in the upper third of the profile, recording its maximum of 48 per cent at 0.2 meter. This significant influx suggests the occurrence of fire or volcanic activity. A stand of lodgepole pine covering about four townships surrounding Bald Butte about 12 miles west of Chewaucan Marsh may be the source of this influx, although the author has been unable to determine whether this lodgepole stand has resulted from fire or volcanic activity. Another explanation for the source of this pollen is an expansion of lodgepole upon the pumice mantle distributed by the eruption of Newberry Crater to the northwest. This eruption occurred after that of Mount Mazama and the pollen profiles show the expansion of lodgepole sometime after the latter event (fig. 3). In the Warner section absence of fire or nearby volcanic activity is reflected by a static representation of lodgepole in the upper two-thirds of the profile (fig. 2). At Klamath Marsh lodgepole is not significantly represented below the upper-third of the section (fig. 4). This is inconsistent with the lodgepole pine record in sections lying upon Mount Mazama pumice to the west, where it apparently has been strongly predominant since the eruption (Hansen, 1942, 1942a, 1946). Fire may account for the recent influx of lodgepole.

Western white pine.—Western white pine is strongly represented in the lower levels of the Warner and Chewaucan sections, reflecting the cool, moist, early postglacial climate (fig. 2, 3). It is recorded to 50 and 45 per cent respectively, which are among the highest proportions for this species in Pacific Northwest sedimentary columns except those located in the white pine forests of northern Idaho (Hansen, 1939, 1944). It rapidly declines upward to only a few per cent and remains generally static to the present. This sharp decline denotes its response to warming and drying of the climate. In the Warner section a slight increase in the upper third may reflect the influence of more moisture during the little Pluvial, beginning about 4,000 years ago. In the Klamath Marsh section white pine is well represented throughout except in the uppermost levels (fig. 4). This abundance of white pine pollen may be due to the proximity of the Cascade Range to the west where it is fairly abundant at higher elevations and to the prevailing westerly winds. It decreased slightly during the warm, dry interval and then expanded with the advent of moister and cooler climate 4,000 years ago. Its decline in recent time is probably relative owing to an influx of lodgepole adjacent to the site of the sediments.

Western yellow pine.—Yellow pine is recorded as having been predominant in the northern Great Basin during postglacial time with the exception of the early part when white pine was the most abundant. It is not presumed that yellow pine existed in stands immediately adjacent to the site of the sediments. Most of the pollen is probably from yellow pine forests on the slopes and ridges where there were sufficient moisture and non-alkaline soil. In the Warner and Chewaucan sections yellow pine is recorded to 20 and 29 per cent, respectively, in the lowest levels, which are the lowest proportions throughout (fig. 2, 3). It rapidly increases upward to 63 per cent at Chewaucan Marsh, its maximum of the profile, and to 49 per cent in the Warner profile. This rapid expansion of yellow pine denotes its response to warming and drying of the climate as postglacial time progressed. In the middle third of the columns it significantly declines, suggesting progressive desiccation of the climate to an unfavorable degree. An expansion in the upper third of the sections is indicative of increased moisture during the past 4,000 years. In the Warner profile yellow pine attains its maximum of 54 per cent at the top.

In the Klamath Marsh section yellow pine is predominantly represented throughout except in the higher levels where lodgepole attains its maximum (fig. 4). Yellow pine is recorded to 60 per cent during the earliest sedimentation soon after the eruption of Mount Mazama, indicating that the climate had already reached a significant degree of desiccation. A maximum of 65 per cent several horizons above the bottom and continued high proportions denote a protracted dry period, and its decline in the upper half of the column in favor of lodgepole and white pine signifies a return to moister climate and/or the influence of local fires.

Grasses.—The pollen record of grass in the northern Great Basin is significant because it supports the evidence for the occurrence of the warm, dry interval. In the Warner Basin and Chewaucan Marsh sediments grass is recorded to low proportions in the bottom levels, but rapidly increases as postglacial warming and drying occurred (fig. 2, 3). It attained its highest proportions after the eruption of Mount Mazama, denoting the climatic maximum after this event. Its decline in the upper third of both sections signifies the influence of moister and cooler climate and forest expansion during the past 4,000 years. In the Klamath Marsh region grass was never so abundant as farther east because of the pumice and the greater precipitation nearer the Cascade Mountains.

Chenopods and Composites.—The pollen profiles of these two families, like that of grass, are very significant and support the evidence for the xerothermic interval. In the Warner and Chewaucan sections composites are more strongly represented than chenopods, suggesting that the latter group was confined largely to alkaline lake beds which were probably more extensive during the xeric interval. These xerophytic and halophytic indicators are sparsely represented in the lowest horizons and then reveal a rapid expansion as the climate became warmer and dryer (fig. 2, 3). They reach their maximum about the time of the Mount Mazama eruption or soon after, suggesting that the eruption did not occur until the climate had almost reached its temperature maximum. In the Warner section chenopods and composites attained their maximum expansion after the volcanic activity while in the Chewaucan Marsh region they apparently attained their greatest abundance about the time of the volcanic activity. Higher proportions of chenopods in the Chewaucan basin suggest greater expanses of alkaline areas exposed owing to evaporation, and also suggest more arid conditions in this region than in the Warner basin. In the upper third of the columns the proportions of these groups decline in response to moister and cooler climate. In the Klamath Marsh section low proportions of chenopods and composites throughout indicate that forests have been largely predominant in the areas within range of pollen dispersal (fig. 4).

Discussion.—The high proportions of grasses, chenopods, and composites in the northern Great Basin during the warm, dry Middle Postglacial find a close parallel in eastern Washington. There, these groups attain their greatest abundance in the middle third or lower half of several sections studied, expressing the regional occurrence of the xerothermic period (Hansen, 1941, 1943, 1944a). In the Willamette Valley of western Oregon an influx of white oak (*Quercus garryana*) partially replacing Douglas fir in the upper half of three sedimentary columns portrays the influence of a xeric stage which was probably contemporaneous with that recorded east of the Cascade Range (Hansen, 1942b). Further support for the warm, dry postglacial climatic stage is provided by the sedimentary record of certain Pleistocene lakes in the northern Great Basin. In the Summer Lake basin, Mount Mazama pumice strata occur in sediments laid down in pluvial Winter Lake of late Wisconsin age when it was several tens of feet deeper than modern Summer Lake (Allison, 1945). This lake persisted until some time after the eruption of Newberry Crater as shown by the position of its pumice above that from Mount Mazama. Since then, pluvial Winter Lake receded and entirely disappeared during the warm, dry interval. With an increase in moisture during the little Pluvial about 4,000 years ago, modern Summer Lake was formed in the lower part of the basin. The comparative youthfulness of both Summer and Abert Lakes is shown by their present salinity which need not have required more than 4,000 years to be attained (Gale, 1915; Van Winkle, 1914). Apparently the pluvial antecedents of these lakes dried up during the xerothermic stage and the accumulated salts were removed by wind or buried before the modern lakes were reborn. More remote evidence for a post-Wisconsin, dry period is found in the occurrence of wind-polished rocks in the mountains of Trans-Pecos Texas which are ascribed to the Neville-Calamity period between 7,500 and 5,000 years ago (Bryan and Albritton, 1942).

The eruption of Mount Mazama must have occurred sometime before the period of maximum warmth and dryness. The stratigraphic position of the Mount Mazama pumice in the sedimentary columns in relation to the recorded xerothermic stage indicates that the volcano probably erupted between 10,000 and 8,000 years ago. The presence of Newberry pumice in the pluvial Winter Lake sediments suggests that the maximum of the drouth was not reached until after the eruption of Newberry Crater. Further support for dating the eruption of Mount Mazama before the peak of the dry period is shown by pollen analysis of two peat sections overlying Mount Mazama pumice in the Rogue River valley south and west of Crater Lake (Hansen, 1946). In this region, where the pumice is confined largely to the valley floors owing to pumice avalanches, yellow pine attained its maximum soon after the eruption of Mount Mazama. As yellow pine is the most xerophytic species in the area, its maximum denotes the peak of the xeric stage. The chronological relationship between the dry period and the eruption of Mount Mazama is also revealed in a 7-meter peat section from Tumalo Lake on the east slope of the Oregon Cascades. An early postglacial expansion of yellow pine was interrupted by the pumice fall and then it was partially replaced by lodgepole. Yellow pine had expanded sufficiently to be recorded to 44 per cent immediately preceding the eruption, denoting that postglacial warming and drying was well advanced by the time of the eruption (Hansen, 1942).

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