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A POLLEN STUDY OF PEAT PROFILES FROM LOWER KLAMATH LAKE OF OREGON AND CALIFORNIA*

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INTRODUCTION

This study is concerned with pollen analyses of four peat profiles from Lower Klamath Lake, and the interpretation of the forest succession and climatic trends in adjacent regions as denoted by the pollen spectra. This problem has been undertaken in part with the purpose of correlating the pertinent interpretations with those of geologists and anthropologists in working out the history of early man in eastern Oregon. The principal relationship between the two problems is that of the climatic trend as evidenced by post-Pleistocene forest succession and the occurrence of artifacts in the lake sediments. The cultural horizon has been exposed on an older lake bed by the recent removal of 1.8–2.4 m. of fibrous peat (Cressman, 1940). The presence of the artifacts originally underlying the fibrous peat suggests the occupancy of an exposed lake bed by man during prehistoric time, estimated to be at least 4,000 years ago (Antevs, 1940). If the artifacts were deposited directly upon the surface of the fossil lake bed, the lake must have been either drained by faulting or dried up because of desiccation of the climate. This permitted early man to build his camp sites upon the exposed lake bed. Subsequent deposition of 1.8 m. of peat above the cultural horizon marks the reinundation of the lake bed and a resumption of hydrarch plant succession. This may have resulted from further adjustment of the drainage by earth movements or from an increase in precipitation. There are several lines of evidence suggesting the occurrence of a dry period followed by increased moisture. There is also evidence, in the pollen profiles here considered, of a similar climatic sequence. Pollen studies of peat deposits elsewhere substantiate the climatic interpretations of this study.

DRY

I have made fossil-pollen studies of other peat deposits in the Pacific Northwest, from which the post-Pleistocene history of vegetation and the climatic trends have been interpreted. Many of these peat deposits lie within the region of Pleistocene continental glaciation, and may record all or most of postglacial forest succession in adjacent areas. It does not seem possible to estimate the amount of time that elapsed between glacial retreat and the initiation of pollen-bearing sediments. The stage of forest succession as evinced by the pollen in the lowest levels, however, indicates that not a great deal of time had passed. Peat deposits located beyond the limits of Pleistocene glaciation have also been analyzed. These may usually be dated as postglacial in origin by the physiographic history of the region in which they lie. The physiographic conditions are often an indirect result of glaciation (Hansen, 1941*d*, 1941*e*). In all peat profiles thus far studied there is little or no evidence of unconformities. Charred horizons are occasionally present, but the stage of hydrarch plant succession at these strata indicates that charred vegetative remains were probably washed in from adjacent burned areas. In certain cases this is substantiated by sharp fluctuations in the pollen spectra, signifying a sudden change in the forest composition that was not a result of normal forest succession (Hansen, 1941*b*, 1941*d*). The surface of the bogs, however, has often been disturbed in recent time by draining, burning, clearing and cultivation, but peat samples were obtained where the surface had apparently been undisturbed. The peat profiles thus record a history of continuous postglacial forest succession in the region within range of pollen dispersal to the accumulating sediments.

FIRE

LOWER KLAMATH LAKE PEAT PROFILES

The Klamath Basin lies within but near the northern limits of the Basin and Range province (Meinzer, 1922). Lower and Upper Klamath Lakes were ponded in a broad structural basin of pre-Pleistocene age (Fenneman, 1931). Many of the lakes in the Great Basin reached their highest levels during the Pleistocene. There seems, from all the information we can gather, to be no evidence that there was a higher glacial shoreline of Lower Klamath Lake, but this can be explained in the control exercised by the Klamath River, which was able to keep

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the lake at a more or less constant level (Antevs, 1940). The sediments in Lower Klamath Lake, therefore, may have had their origin during the post-Pleistocene or earlier.

LAIRD'S BAY SERIES

Perhaps the most significant profile with respect to the history of early man in the region is that obtained from a site where artifacts were observed *in situ* by Cressman (1940). It is located in section 25, T. 47 N., R. 2 E., about 12 km. south of the Oregon boundary. This area of Lower Klamath Lake is known as Laird's Bay, and the peat profiles and pollen spectra will hereafter be referred to as L. B. Peat samples for all profiles were obtained with a Hiller peat borer. They were taken at 15-cm. intervals to a depth of 2.7 m., which was as deep as the borer would penetrate. Samples were obtained the latter part of August and the sediments were extremely dry and hard. The bottom of the profile was not reached, but the lowest level sampled consisted of silt and sand, suggesting that the bottom of at least the post-Pleistocene sediments was perhaps near at hand. The artifact horizon lay between the .91- and 1.04-m. levels. Sedimentary peat containing considerable glass and silt occurs from the bottom to about 90 cm., where it grades rather abruptly into fibrous peat consisting of cattail and bulrush remains. Volcanic glass is present at all levels of the sedimentary peat. The glass was carried to the lake by streams from the pumice mantles in the Cascade Range to the north and west. In addition to pollen grains, other microscopic organisms and parts noted are desmids, diatoms, ostracod and other crustacean shells, insect parts and eggs, fungus spores, and protozoan shells such as Arcella. Charred organic material occurs at the 2.3-, 1.8-, and 1.04-m. horizons. The sediments at the lower two levels denote that the stage of hydrarch succession was such as not to permit the occurrence of fire when they were being deposited. If the presence of artifacts between the .91- and 1.04-m. horizons indicates that the lake had dried up sufficiently to permit man to build his camp sites on the exposed lake bed, the charred material at 1.04 m. suggests the burning of fibrous peat if such existed at that time. Fire has likewise destroyed most of the fibrous peat that had accumulated prior to drainage in modern time. The exposure of the lake bed during the postulated dry period means that there is an unconformity representing an interval of time between the cessation of sedimentation and its resumption upon reinundation of the lake bed. The unrecorded interval was further lengthened by the destruction of the fibrous peat that must have existed if normal hydrarch plant succession occurred. If the lake slowly dried due to desiccation of the climate, a layer of fibrous peat was probably formed by the cattail-bulrush stage as the lake became shallower. If such occurred, the fibrous peat must have been destroyed by fire or removed by deflation during the dry period. If the lake was drained rapidly due to faulting, a cattail-bulrush stage of plant succession would not have had time to develop, and sedimentary peat would have been exposed at the surface. Although the exposure of Lower Klamath lake bed was evidently due to desiccation of the climate, a third explanation is possible for the occupancy by prehistoric man. The ultimate and inevitable fate of a lake is to be filled by sedimentation resulting from erosion and hydrarch plant succession. The final stage of such a process is usually the formation of fibrous peat by plant associes that thrive under the existing conditions. This will take place under a static climate without necessarily the lowering of the water level. If such a sequence of events did occur, the absence of fibrous peat may be explained by its destruction and removal during the dry period. An increase in precipitation at a later time, if sufficient, would cause reinundation of the lake bed and rebirth of the lake.

NARROWS SERIES

Samples at 2-dm. intervals were obtained by Carl Huffaker, University of Oregon, for two profiles at the Narrows, about 1.5 km. south of the Oregon-California line, in section 23, T. 48 N., R. 2 E. This area is also a site for artifacts (Cressman, 1940). One profile is 3.0 m. deep and will be referred to hereafter as the N1 profile; the other is 3.3 m. deep and will be denoted as the N2 profile. The lowest levels consist of sedimentary peat, which grades upward rather abruptly into fibrous peat at slightly less than 1 m. In the N1 profile, ostracod shells and fragments occur sparingly in the lower meter, and in the N2 profile they are present in greater abundance from 2.4 to 1.9 m. The vertical distribution and relative abundance of ostracod shells in the two profiles indicate that no correlation may be based on their presence. Charred organic material is present at 1.4 m. in the N1 profile. The abrupt gradation from sedimentary to fibrous peat at about 1 m. suggests an unconformity synchronous with that of the L. B. profile. It is not believed that these two profiles constitute the total depth of the sediments in this area. The artifacts exhumed at the Narrows site apparently lie at a lower stratigraphic position and in an earlier chronological sequence than those at the L. B. site (Cressman, 1940). The stratigraphic position of the artifacts in the profiles of this study, however, was not noted, and thus no correlation with other profiles can be made.

NEAR KLAMATH FALLS SERIES

Samples of a fourth profile were obtained about 16 km. southwest of Klamath Falls, Oregon, in section 23, T. 40 N., R. 8 E., in a recently drained area. This profile and its pollen spectra will be referred to as the K. F. At the time of drainage this area was apparently not in the cattail-bulrush stage of succession, so that the surface sediments may well represent those laid down in recent time. The depth of the sediments in the area of sampling is 2.5 m., and it is believed that the bottom of the profile was reached. Sedimentary peat with considerable glass and silt is present throughout the profile. Desmids are markedly abundant in the lower meter, and the amount of organic material increases upward. Fine fibrous material first appears at 0.6 m., and is sparsely present from this point to the surface. The fibrous remains have been washed into the lake. Charred organic fragments are also present at 0.6 m. The homogeneity of the sediments throughout the entire profile suggests that they constitute a continuous deposition. There is no evidence of an unconformity in the sequence. Although this profile is not so deep as the others, it may represent as much or more time, because of the absence of fibrous peat at the surface. Fibrous peat is deposited at a much faster rate than finer sedimentary types, and the depth of the latter in the K. F. profile is greater than that in the others.

ESTIMATES OF AGE OF SEDIMENTS

As previously shown, there seems to be little evidence for the age of the Lower Klamath Lake sediments, or at least for those constituting the profiles of this study. The lowest sediments of the lake probably had their origin during the Pleistocene, but what percentage of the profiles constitute post-Pleistocene sedimentation is indeterminable. A comparison of the average thickness of peat profiles throughout the Pacific Northwest may serve as a criterion upon which to base estimates for the age of the profiles of this study. The average depth of 16 post-Pleistocene peat deposits west of the Cascade Range in Washington, Oregon, and British Columbia, is about 9.5 m. as shown by profiles determined in an intensive study by Rigg and Richardson (1938). In six peat deposits east of the Cascade Range in Washington, which I have studied, the average depth is about 5.8 m. Deposits east of the Cascades are shallower because of the drier climate and the slower rate of deposition. The upper half or more of the profiles west of the Cascades consists of fibrous peat composed of Sphagnum or Hypnum moss, or sedge, or a stratum of each. Sedimentary or limnic peat usually underlies the fibrous types, and in turn is underlain with clay, silt, and sand. Pollen grains are usually present in the sand, silt, and clay, indicating immediate forest invasion of adjacent areas upon glacial retreat. There are a multitude of factors that control the rate of peat deposition, but fibrous probably has a more rapid rate than sedimentary peat. Estimates for the time required for the accumulation of 30 cm. of peat range from 2 to 1665 years (Sears and Janson, 1933). Assuming that about 18,000 years have passed since glacial recession in the Pacific Northwest, we find that 30 cm. of peat have required about 600 years for their deposition. The same depth of sedimentary peat would probably require at least 1,000 years and in some instances perhaps 1,500 years. With these figures as a basis, the profiles of this study represent from 12,000 to 15,000 years. The destruction and consolidation of the sediments during the postulated dry period, as well as the loss of the upper stratum of fibrous peat since its exposure in modern time, suggest an even longer time for the entire profile. The dry climate of the region is not favorable for rapid peat deposition, so these figures may be low.

Another method of estimating the rate of peat deposition may be based upon the thickness of peat that has accumulated since the eruption of Mount Mazama, resulting in the formation of the caldera holding Crater Lake in the Cascades of southern Oregon. Williams (1941) estimates that this eruption occurred not less than 5,000 nor more than 10,000 years ago. A peat deposit about 3.5 km. south and below the rim of Crater Lake has a depth of about 2 m. The peat bed is underlain with pumice and hence is post–Mount Mazama in origin. If sedimentation began soon after the eruption, the average rate of deposition has been from 1,000 to 1,500 years per 30 cm. A peat deposit located 48 km. north of Crater Lake also overlies the pumice mantle. A profile 1.75 m. deep from this bog suggests about the same rate of sedimentation as that near Crater Lake. A postglacial peat deposit 20 km. west of Bend, Oregon, about 145 km. north of Crater Lake, and at an elevation of 8,320 km. is 7 m. deep (Hansen, 1942*b*). A well-defined pumice layer occurs at 4.5 m. and a thinner one at 2.0 m. These layers probably had their sources from Newberry Crater 40 km. to the south and from Mount Mazama (Williams, 1935). The relative distances of these two craters suggests that the thicker pumice stratum came from Newberry Crater, the thinner from Mount Mazama. If this is true, about 2 m. of peat have been deposited since the eruption of Mount Mazama, which is consistent with that of the other two bogs. Thus upon the basis of these data, 12,000 to 15,000 years for the deposition of the peat profiles of this study do not seem unreasonable. This corresponds with the estimates made by Antevs and Cressman.

TABLE 25

CLIMATOLOGICAL DATA

Location	Elevation (in feet)	Annual Mean Precipitation (in inches)	Annual Mean Temp. (F.)	Life Zone
Klamath Falls	4100	12.81	47.7	Upper Sonoran
Merrill	4070	10.59	45.6	Upper Sonoran
Chiloquin	4200	17.54	42.4	Arid Transition
Fish Lake	4847	39.42	44.3	Humid Transition
Crater Lake	6475	53.95	38.6	Hudsonian
Yonna	4147	12.83	44.8	Arid Transition
Fort Klamath	4200	22.76	43.0	Canadian (near border)

VEGETATION IN ADJACENT AREAS

A brief discussion of the characteristic vegetation in regions surrounding a peat deposit is essential in order to present a general idea as to the possible sources of pollen preserved in the sediments. It also serves as a criterion in interpreting the forest succession from the pollen profiles. Lower Klamath Lake lies within the Upper Sonoran life zone (Bailey, 1936). The flora of this zone in the Klamath Basin may be separated into two general groups. These groups owe their distribution chiefly to the alkalinity of the soil. The dry lake basins and depressions have a highly alkaline soil, which supports the growth of halophytic flora. Some of the plants inhabiting these areas are greasewood *(Sarcobatus vermiculatus)*, hopsage *(Grayia spinosa)*, winterfat *(Eurotia lanata)*, seepweed *(Suaeda depressa)*, green molly *(Kochia americana)*, silver saltbush *(Atriplex argentea)*, shadscale *(A. confertifolia)*, saltgrass *(Distichlis stricta)*, tansy *(Tanacetum potentilloides)*, poverty weed *(Iva axillaris)*, and bulrush *(Scirpus nevadensis)*. The slopes and higher areas with a less alkaline soil support such plants as juniper *(Juniperus occidentalis)*, mountain mahogany *(Cercocarpus ledifolius)*, sagebrush *(Artemesia tridentata)*, horsebrush *(Tetradymia canescens)*, antelope brush *(Purshia tridentata)*, serviceberry *(Amelanchier utahensis)*, and rabbitbrush *(Chrysothamnus nauseosus* and *C. viscidflorus)*. Some of the more common grasses are *Poa nevadensis, Stipa thurberiana, S. comata, Bromus tectorum,* and *Elymus condensatus.*

The Upper Sonoran life zone is surrounded by the Arid Transition which is divided into the timberless and timbered portions. The timberless area occupies only a narrow zone to the west but is much more extensive to the east. This part of the Transition is in general coextensive with the bunchgrass prairie and is the principal wheat-raising section of Oregon and Washington. Characteristic species of grasses include *Agropyron spicatum, Poa secunda,* and *Festuca idahoensis,* but the bunchgrass prairie is not prevalent in the Klamath Basin because of the alkalinity of the soil and other unfavorable edaphic conditions. Other plants common in this area are balsam root *(Balsamorrhiza sagittata)*, black sunflower *(Wyethia amplexicaulis)*, sunflower *(Helianthus cusickii)*, prairie clover *(Petalostemum ornatum)*, and several species of Lupinus, Lomatium, and Erigeron.

The timbered Arid Transition lies a few kilometers to the west of Lower Klamath Lake and at greater distances to the north and east. This area is characterized by forests of western yellow pine *(Pinus ponderosa)*. Western juniper thrives at the lower limits, while at higher elevations and on other favorable sites Douglas fir *(Pseudotsuga taxifolia)*, sugar pine *(Pinus lambertiana)*, lodgepole pine *(P. contorta)*, white fir *(Abies concolor)*, lowland white fir *(A. grandis)*, and cottonwood *(Populus trichocarpa)* are common. Farther north in the Cascade Range, lodgepole pine covers large areas in the Transition and Canadian where the thick mantle of pumice from Mount Mazama has created unfavorable edaphic conditions for other species (Hansen, 1942*a*).

The rapid rise in altitude to the northwest permits the existence of the Canadian life zone within 48 km. of Lower Klamath Lake. An island of this zone also exists about the same distance to the north. The forests of this zone consist chiefly of western white pine *(Pinus monticola)*, western hemlock *(Tsuga heterophylla)*, Engelmann spruce *(Picea engelmanni)*, noble fir *(Abies nobilis)*, mountain hemlock *(T. mertensiana)*, western red cedar *(Thuja plicata)*, Douglas fir, and lodgepole pine. Again it should be noted that lodgepole pine occupies the pumice-covered areas. Western yellow and sugar pine are also present in the Canadian zone where drier conditions prevail. Other noteworthy plants present are mountain alder *(Alnus tenufolia)*, mountain maple *(Acer glabrum)*, mountain ash *(Sorbus sitchensis),* and aspen *(Populus tremuloides).*

There are several small areas of the Hudsonian life zone within 80 km. of Lower Klamath Lake. The nearest is on Mt. Harrison about 55 km. to the northwest. The principal species of trees found in this zone are whitebark pine *(Pinus albicaulis),* alpine fir *(Abies lasiocarpa),* and mountain hemlock. Thus it can be seen that there is a diversified flora with many species of forest trees within range of pollen dispersal to Lower Klamath Lake.

Lower Klamath Lake is located in the subhumid, microthermal climatic province, with a summer deficiency in precipitation (Thornthwaite, 1931). A few miles to the east is a semiarid, microthermal province with a summer deficiency in precipitation, while a few miles to the northeast lies a semiarid area with a deficiency in precipitation for all seasons. To the north and south a humid, microthermal zone with a summer deficiency of precipitation exists, and at higher elevations to the west, a humid, microthermal climate is present with adequate precipitation at all seasons. Table 25 gives very briefly climatological data as recorded at several stations in and adjacent to the Klamath Basin (Weather Bureau, U. S. D. A., 1936).

METHODS

The usual potassium hydrate method was used in the preparation of the sediments for microscopic study and pollen analysis. One hundred and fifty pollen grains of indicator species were identified from most levels, but 100 grains were identified from several horizons where the pollen frequency was low. The pollen of nonsignificant species was also identified but not used in the computing of percentages (see tables). Those species recorded to 1.5 per cent or less are listed in the tables as 1 per cent. The procedure used in the identification of Pacific Northwest winged conifer pollen has been described in recent papers (Hansen, 1941*a,* 1941*b,* 1941*d*). The fossil pollen of Pinus, Abies, and Picea is separated by measuring and then assigning it to that species within whose size range it falls. If the dimensions are within the limits of overlap of the size ranges of larger or smaller species, it is listed under its generic name only (see tables). The number of these pollen grains is not used in computing the pollen percentages. In this study, two species of pine in one group and three in another overlap in size range, as do also two species of fir. *Pinus monticola* and *P. albicaulis* have pollen of essentially the same size range and cannot be positively separated. The shape and relative proportions of the air bladders and cell of *P. albicaulis* pollen is quite distinct and may be distinguished from that of *P. monticola* if it is not broken or crumpled. The size ranges of *P. albicaulis, P. ponderosa,* and *P. lambertiana* also overlap, with that of the first being the smallest and the last the greatest. There is only a slight amount of overlap of whitebark with yellow pine, and their differences in shape and proportions probably result in a small amount of error. Pollen larger than that of yellow pine is identified as that of sugar pine, but it is not possible to know what percentage of pollen listed as yellow pine is that of sugar pine. The same conditions exist with respect to the size of the pollen of *Abies concolor* and *A. nobilis.* The former has a larger size range, but all pollen of these species cannot be separated. In this study it has been listed under *A. concolor,* as this species is probably more abundant and nearer to the site of the sediments than the other. The separation of white and noble fir pollen is of little consequence, however, because of the negligible proportions of fir pollen present. The separation of sugar and yellow pine pollen is desirable, but as they both exist in the same life zone and under a somewhat similar environment, their pollen profiles should depict similar climatic trends. Sugar pine plays a comparatively small part in the present forest complex.

The inseparability of *Pinus monticola* and *P. albicaulis* pollen is more significant in this study than that of the other groups. White pine is typically a Canadian zone species, whereas whitebark pine occurs chiefly in the Hudsonian zone and is often the timber-line tree. Most of the pollen listed as that from white pine, however, is probably from that species as it is more common and nearer to the site of the sediments. An increase in white pine pollen indicates an increase in moisture and a cooler climate, and an increase in whitebark pine should also denote at least a cooler climate. The latter would perhaps signify a more definite cooling trend because of its existence in a higher and cooler life zone. The overlapping of whitebark with yellow pine presents a more difficult problem and is of greater significance.

At least three species of chenopods are represented by their pollen as shown by the size and number of pores in the pollen grains. A few scattered pollen grains of *Juniperus occidentalis* were noted, but as the pollen of this species is thin-walled and fragile, it is perhaps underrepresented in the pollen profiles. Figures 57–62 show variation in percentages of our diagnostic series.

FOREST SUCCESSION

It should be remembered that the representation of the adjacent vegetation by its pollen in peat and other sediments is greatly influenced by a large number of obvious as well as intangible and incalculable factors that may tend to minimize the validity of the interpretation of forest succession and climate from the pollen spectra. The question arises as to what extent do fluctuations in the relative proportions of several species portray a change in forest composition, and to what degree do changes in the forest composition depict a climatic trend. In this study the existence of several life zones within range of pollen dispersal to the site of the sediments has probably been a significant factor in the proportions of specific pollen recorded therein. Migrations of life zones to higher or lower elevations and therefore farther or closer respectively to Lower Klamath Lake, should be representatively recorded by pollen of the chief dominant species. Upper Sonoran and timberless Arid Transition species are only sparsely represented, but this may be due to the prevailing westerly winds. The greater part of these zones lies to the east of Lower Klamath Lake so there would be little chance for the pollen from plants of this zone to reach the site of the sediments. The scarcity of this pollen is not due to its poor preservation, because pollen analysis of sediments in the Upper Sonoran life zone in east-central Washington shows chenopods, composites, and grasses to have been predominant in this region during postglacial times (Hansen, 1941*e*).

One factor that has perhaps tended to increase the degree of true representation of the adjacent vegetation by its pollen is the size of Lower Klamath Lake. Bogs are usually relatively small in size and the forests grow immediately to their margins. This may result in the over-representation of certain species that grow in abundance near the bog because of localized favorable conditions. In other cases bogs exist in deep depressions or narrow valleys. This may tend to prevent the upper air currents that carry pollen from greater distances to reach the surface of the accumulating sediments, and adjacent areas may not be represented proportionately. The vast size of Lower Klamath Lake has probably eliminated these sources of error in recording the surrounding vegetation by its pollen.

One of the most significant features of the four peat profiles of this study is their similarity with respect to the general fluctuations and the chief trends of the pollen profiles of indicator species. This of course is to be expected and, indeed, essential if pollen profiles are to be considered as reliable indices to forest succession in adjacent regions. The similitude of the pollen profiles also substantiates the feasibility of the size range in distinguishing the specific pollen of Pinus and Abies. Western yellow pine records the highest proportion of pollen in the lowest level of three profiles, while lodgepole pine is highest in the K. F. profile (figs. 57–60). It is not assumed, nor is it probable, that the lowest horizons of all profiles are synchronous. Although the K. F. profile is the shallowest, its lowest level may actually be older than those of the others. Yellow pine records a general increase from the lowest levels upward, to reach a maximum in each profile (fig. 61). This is the highest proportion recorded for yellow pine in each profile, and its consistency indicates a definite trend. The stratigraphic positions of these maximum percentages may not be synchronous, although their relative positions in the profiles suggest that they are nearly so. In all cases they are approximately the same distance from the bottom level. The horizons analyzed are at about 20-cm. intervals, which means that over 30 cm. of sediments are present between the levels immediately above and below that of the maximum percentage. If 30 cm. of sedimentary peat constitutes at least 1000 years of time, the highest proportion of yellow pine as recorded by its pollen may not represent the greatest abundance attained in this region. This may have been reached and recorded at some other point in the 30 cm. of sediments. Another factor that should be considered with respect to the maximum percentages in the pollen profiles of yellow pine is the unconformity that may exist as a result of the prehistoric exposure of the lake bed. Yellow pine may have reached its greatest abundance during the deposition of sediments later removed when the lake bed was exposed, or during the dry period when no sedimentation occurred. In either case its greatest predominance is not recorded in the profiles of this study. On the other hand, if the climate became desiccated to such an extent as to cause the yellow pine forests to migrate to higher altitudes westward in the Cascade Range, such xerophytic plants as chenopods, composites, and certain grasses may have attained their widest distribution during this period. Neither would they have been recorded by their pollen, because of cessation of sedimentation. This possibility is substantiated by pollen profiles of a peat deposit located in the yellow pine forest about 32 km. northeast of Spokane, Washington (Hansen, 1939*b*). They show a striking predominance of chenopods, composites, and grasses just preceding and during the deposition of almost 30 cm. of volcanic ash in the lake. These groups were soon replaced by yellow pine. This lake never dried up, so the postglacial vegetational history is completely recorded. The stratigraphic position of the ash and the predominance of these xeric indicators suggest that the dry period may have been synchronous with the period of yellow pine predominance or soon thereafter in the Klamath Basin region. If the K. F. profile represents a continuous sequence through the dry period, however, there is no predominance of these xeric indicators recorded by their pollen. The percentage of yellow pine pollen shows an immediately abrupt decline from its maximum upward in each profile, and then with fluctuations it generally decreases more gradually to the uppermost horizons. Again it should be noted that the highest levels are probably not synchronous, because the amount of sediments removed after the modern lake bed was exposed may have varied as to the amount of time they represented. The trend of yellow pine succession is perhaps best shown by the average of the four pollen profiles (fig. 62). The four levels averaged are not necessarily synchronous, but those recording the maximum proportions were correlated as being so, rather than the lowest or highest levels. The horizons above and below the maximum were averaged in order.

The pollen profiles of white pine show a slight general decline upward from the lowest level, with the exception of the K. F. profile (figs. 57–60). This decrease continues to the level of yellow pine maximum in each profile. White pine records an immediate increase above the yellow pine maximum, to reach its own several levels higher. The thickness of sediments between the white and yellow pine maxima varies in the four profiles, but there is not too much disparity to suggest a chronological correlation. The maxima of the two species are separated by two to four levels in the four profiles. The different rates of sedimentation in the same and in different profiles permit a certain degree of manipulation of them in order to correlate the significant trends of the pollen spectra. There is a sharp decline in white pine following its maximum and then, with fluctuations, a rather constant trend to the uppermost level. The four pollen profiles of white pine do not show much correlation level for level above its maximum. Unlike that of yellow pine, the greatest proportion of white pine in one profile may be exceeded by that in another at a different horizon. The average of the four profiles of white pine shows its general trend with a smoother curve than in each profile (fig. 62). At no level does the average percentage of white pine exceed that of yellow pine. This is to be expected, however, because the most extensive forests within range of pollen dispersal to Lower Klamath Lake consist of yellow pine. At greater distances white pine is not abundant either, because of the relatively small area occupied by the Canadian zone. Slight fluctuations in the western white pine profiles, however, are probably as significant as much greater ones for yellow pine, and indicate as definite climatic trends. The amount of pollen listed as that of white pine may be somewhat exaggerated by the presence of whitebark pine forests in the Hudsonian zone within range of pollen dispersal to the site of the sediments. The presence of whitebark pine pollen would tend merely to accentuate a similar trend of climate as signified by the pollen profile of white pine. One of the most important features of the white pine profiles is that they attain their maximum proportions after those of yellow pine (fig. 61).

Lodgepole pine has been one of the important forest trees in this region as is evinced by its pollen record in the profiles. The pollen profiles of this species, however, are not consistent in their correlation with one another (fig. 61). This is not of interpretive significance because it is not a critical indicator of either forest succession or climatic trends. It has been the chief, pioneer, postglacial invader both east and west of the Cascade Range in Washington (Hansen, 1938, 1939*a*, 1939*b*, 1940*a*, 1940*c*, 1941*a*). In unglaciated regions, pollen studies show that lodgepole was not predominant when the lowest pollen-bearing sediments were deposited (Hansen, 1939*c*, 1941*b*, 1941*d*, 1941*f*). This denotes that the forests had already reached a climax or had remained stabilized at least the latter part of the Pleistocene. Its initial invasion of deglaciated regions in the past is similar to its present role in forest succession. It invades areas where the edaphic conditions have been disturbed, or where fire has destroyed the climax forest. When conditions have been modified, other longer-lived and more shade-tolerant species soon replace lodgepole pine. Perhaps the most significant trend of lodgepole pine here, is its highest percentage attained between the levels of yellow and white pine maximum in three of the profiles (fig. 61). This may record its invasion of pumice-covered areas north of Crater Lake, suggesting that the eruption of Mount Mazama occurred during or soon after the postulated dry period. This volcanic activity is further corroborated by the stratigraphic sequence in a cave occupied by prehistoric man near Paisley, Oregon (Cressman, 1940). It should be noted, however, that there are pronounced increases in lodgepole pine proportions at other levels, although at no horizon do they appear in a single profile. In only the K. F. profile does it exhibit its usual postglacial trend in glaciated regions of the Pacific Northwest. Its low proportions at the bottom of the other profiles suggest that if lodgepole pine invaded deglaciated areas at higher altitudes to the west, it had already been replaced by other species by the time the lower horizons were deposited. Because of its local occurrence in at least three life zones, lodgepole pine has little indicator value in this study.

The profiles of sugar pine show little or no correlation

TABLE 26

PERCENTAGES OF FOSSIL POLLEN, LAIRD'S BAY

POLLEN	DEPTH IN FEET																		
	9.0	8.5	8.0	7.5	7.0	6.5	6.0	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0	0.5	0.0
Pinus contorta.	24	19	15	11	17	11	13	15	25	15	20	23	30	29	24	24	23	21	20
P. monticola...	22	28	24	26	31	31	24	21	20	17	12	14	28	31	22	30	27	25	26
P. ponderosa...	29	42	40	44	40	43	39	52	51	53	64	56	40	35	36	28	36	32	36
P. lambertiana.	6	4	9	2	4	5	2	3	...	1	...	1	2	...	5	8	4	2	3
Pseudotsuga taxifolia.....	1	1	1	1	...	...	...	...	2	...	...	...	...	...	...	...	...	...	1
Tsuga heterophylla.......	1	1	1	...	...	1	...	1	...	...	1	1	...	1	...	...	1	...	1
T. mertensiana	2	...	...	1	...	3	...	...	...	...	...	...	...	...	...	1	2	...	1
Picea engelmanni.......	...	...	2	...	...	1	2	...	...	...	...	...	...	...	...	1	...	1	1
Abies grandis..	1	...	...	1	1	...	...	...	...	2	...	...	...	...	3	1	...	1	...
A. concolor....	1	2	2	2	2	2	4	4	2	12	...	2	...	3	1	5	5	9	10
A. lasiocarpa...	...	...	1	...	2	...	...	...	...	...	...	...	...	...	1	1	...	1	...
Gramineae.....	11	2	2	6	2	1	14	3	...	...	2	2	...	1	4	...	...	...	...
Compositae....	...	...	...	...	...	1	...	...	...	...	...	...	...	...	3	...	1	1	1
Chenodiaceae..	2	1	3	6	1	1	2	1	...	...	1	1	...	...	1	1	1	7	...
Pinus spp.*....	24	11	13	18	19	21	9	25	16	6	14	10	9	15	18	13	10	13	21
Abies spp.*....	3	2	1	1	4	3	1	4	1	...	...	1	1	...	1	2	2	...	5
Alnus†........	1	...	2	2	...	2	...	...	...	...	...	...	...	...	...	...	...	...	1
Acer†.........	5	2	7	...	2	...	1	...	...	...	...	...	...	...	...	...	3	...	2
Salix†.........	3	2	2	...	...	4	1	...	6	...	3	...	...	...	...	2	2	...	2
Cyperaceae†...	4	2	1	5	4	1	2	2	6	3	2	2	...	...	3	...	2	1	10
Typha†.......	2	...	3	1	4	1	1	5	...	...	1	...	...	...	2	1	1	...	3

*Number of Pinus and Abies pollen grains unknown, not computed in the percentages.
†Number of pollen grains, not computed in the percentages.

with those of yellow pine (figs. 57–60). This species is not one of the chief dominants, but because of its somewhat similar ecological requirements to those of yellow pine, it should correlate with this species to some extent. Some of its pollen is undoubtedly listed under yellow pine because of overlap of their size ranges. White fir pollen, which probably includes some of noble fir, is present at most levels, but there is no correlation with other species or climatic trends portrayed by its pollen profiles. Other conifers recorded sporadically by their pollen are Douglas fir, western and mountain hemlock, Engelmann spruce, and lowland white and alpine fir (see tables). Their pollen profiles are of no significance except to mark the presence of these species within range of pollen dispersal to the site of the sediments.

The pollen of chenopods, composites, and grasses occurs at many horizons, but exhibits no correlation with that of others. As previously stated, these groups of plants may have reached their climax during the postulated dry period, and were thus not recorded because of the cessation of sedimentation during this period. Chenopods are most abundantly and consistently recorded, with 20 per cent at 1.2 m. in the N1 profile (table 26). An influx of this group would be an indirect evidence of a drier trend. Chenopods are largely halophytes that thrive in alkaline areas. The extent of such areas would be increased during a dry period because of the drying-up of lakes, leaving alkaline flats behind. Maple pollen is the most abundant of broadleaf trees, and probably is that of mountain maple that was carried into the lake by streams. Sedge and cattail pollen is present at many levels in all the profiles. It indicates that areas have been in the cattail-bulrush stage of hydrarch succession during most of the time that sedimentation occurred (see tables).

CLIMATIC CONSIDERATIONS

There is more evidence offered by pollen profiles east than west of the Cascade Range for post-Pleistocene climatic trends. Apparently the proximity of the Pacific Ocean has been responsible for maintaining a moderate climate during the postglacial. Forest succession as interpreted from pollen profiles marks only slight climatic changes west of the Cascade Range. There have been definite changes in forest composition, but these changes have occurred largely as a result of normal forest succession. This was due chiefly to competition between species

Table 27

PERCENTAGES OF FOSSIL POLLEN, NARROWS NO. 1 PROFILE

Pollen	Depth in Meters															
	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2	0.1
Pinus contorta	13	6	21	18	17	13	14	10	12	20	15	18	34	27	32	50
P. monticola	14	20	20	22	18	20	11	26	28	11	10	12	17	17	21	17
P. ponderosa	52	54	47	48	55	54	60	50	40	46	55	53	36	39	31	26
P. lambertiana	15	10	6	6	3	4	7	6	12	1	2	9	2	2	1	1
Pseudotsuga taxifolia	...	...	1	1	...	1	2	...	1	...	1	1	6	2	3	3
Tsuga heterophylla	...	1	...	...	...	1	1	1	...	1	...	...	1	...	1	...
T. mertensiana	2	1	...	1	2	...	1	...	2	...	2	...	...	1	...	...
Picea engelmanni	...	1	...	1	...	...	1	...	...	...	...	...	...	1	1	1
Abies grandis	...	2	1	...	1	...	1	1	1	...	1	1	1	...	1	...
A. concolor	2	1	...	1	1	3	...	2	3	1	9	3	...	4	3	2
A. lasiocarpa	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...
Gramineae	1	1	1	...	...	1	...	...	...	...	...	...	...	...	2	...
Compositae	...	1	2	2	1	1	1	2	...	...	...	2	...	1	2	...
Chenopodiaceae	...	2	...	...	2	2	1	2	1	20	5	1	3	6	2	...
Pinus spp.*	6	15	17	10	12	15	21	10	7	15	10	17	19	13	11	13
Abies spp.*	1	2	...	...	2	...	1	3	2	1	3	1	2	1	2	3
Alnus†	2	1	1	2	2	1	1	...	1	1	...	...	...	2	...	...
Betula†	...	1	...	...	...	...	1	...	...	...	...	...	...	...	...	...
Acer†	9	4	1	5	2	3	11	9	2	6	3	2	4	4	2	3
Salix†	1	...	...	...	...	1	...	...	...	2	2	...	...	...	...	...
Cyperaceae†	10	12	6	5	5	26	4	6	3	13	11	9	33	66	18	2
Typha†	2	5	...	1	2	3	3	2	6	2	3	...	11	12	1	1

*Number of Pinus and Abies pollen grains unknown, not computed in the percentages.
†Number of pollen grains, not computed in the percentages.

FIRE

and their reaction upon the environment. Fire also has been an important factor in forest succession in the Pacific Northwest. It has repeatedly interrupted forest succession toward a climax, and has permitted the persistence of subclimax and disclimax species throughout the post-Pleistocene (Hansen, 1938, 1939*a*, 1941*a*, 1941*b*). This has been especially true in the cedar-hemlock climax of the Puget Lowland, where Douglas fir, a subclimax species, has persisted as the chief dominant (Munger, 1940). The same has apparently occurred in northern Idaho, where western white pine has been able to persist in the cedar-hemlock-lowland white fir climax (Hansen, 1939*a*, Hubermann, 1935). The moist cool climate of the Puget Sound region has probably been at an optimum during most of the postglacial for the best development of western red cedar, western hemlock, Douglas fir, and their associates.

East of the Cascade Range in Washington and Oregon, climatic conditions have not been so nearly at an optimum for forest development, with the exception of western yellow pine in some sections. The precipitation in the Upper Sonoran and Transition has probably been at a critical minimum during all or most of postglacial time. Slight changes in precipitation and temperature would readily influence plant succession. This succession is definitely reflected by pollen profiles. As previously stated it is difficult to estimate the amount of time represented by the profiles of this study, but the rate of sedimentation and their depths suggest that they may record all or most of the post-Pleistocene. The pollen profiles of western yellow pine from the lowest levels to those of its greatest proportions indicate a gradual drying and warming of the climate. This is further substantiated by the less marked decline in western white pine from the bottom horizons upward to those of the yellow pine maximum. If Lower Klamath Lake dried up before the time of greatest desiccation, this period was not recorded by the pollen profiles of this study. This dry interval is also recorded by the previously mentioned peat profile near Spokane, Washington, and another located within the Upper Sonoran zone of east-central Washington (Hansen, 1941*e*). The latter records a relative trend of forest and grassland succession that depicts a warming and drying of the climate, succeeded by a cooling and increase in moisture to a point that has remained constant to the present.

There is other evidence for a maximum of warmth and dryness during the postglacial. It concerns the salinity of certain lakes in the Great Basin. The present salinity of these lakes is too low to constitute a continuous post-Pleistocene deposition of salts (Antevs, 1938). It is believed that the Pleistocene lakes dried up, and their precipitated salts were either removed by wind or buried. The present lakes were later re-formed in the freshened basins, about 4,000 years ago (Antevs, 1940). Antevs sug-

*

TABLE 28

PERCENTAGES OF FOSSIL POLLEN, NARROWS NO. 2 PROFILE

POLLEN	DEPTH IN METERS																
	3.3	3.1	2.9	2.7	2.5	2.3	2.1	1.9	1.7	1.5	1.3	1.1	0.9	0.7	0.5	0.3	0.1
Pinus contorta	9	16	14	11	11	9	8	12	26	14	12	18	16	28	26	25	22
P. monticola	26	23	18	21	20	13	13	29	37	38	45	32	33	41	38	36	31
P. ponderosa	48	50	50	55	52	65	71	50	31	38	33	31	35	23	25	26	30
P. lambertiana	12	5	4	7	6	8	4	4	2	5	6	5	4	4	5	7	9
Pseudotsuga taxifolia	...	...	...	...	...	...	...	1	1	2	...	2	1	1	...	...	3
Tsuga heterophylla	1	...	...	1	...	...	...	...	...	...	...	...	2	...	...	1	...
T. mertensiana	...	1	1	...	...	...	...	...	...	...	2	1	...	1	...	...	1
Abies grandis	...	1	1	...	...	...	...	...	...	...	...	...	...	...	1	...	...
A. concolor	3	3	1	1	1	3	...	3	1	2	1	10	8	2	3	2	3
A. lasiocarpa	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	1
Gramineae	1	...	...	...	...	...	...	...	1	...	...	...	...	...	1	...	...
Compositae	...	...	1	...	...	...	...	...	1	1	1	...	...	...	...	...	...
Chenopodiaceae	...	1	10	4	10	2	4	1	...	...	...	1	1	...	1	...	...
Pinus spp.*	11	10	16	12	17	16	11	7	17	14	12	15	13	13	12	16	5
Abies spp.*	3	2	1	4	1	2	3	1	1	2	2	1	6	1	...	1	1
Alnus†	...	...	...	1	1	...	2	1	...	...	...	...	...	...	...	...	...
Betula†	...	...	1	...	...	1	1	1	...	1	...	...	...	...	...	...	...
Acer†	3	2	2	2	2	2	3	6	2	4	2	3	2	5	3	2	1
Salix†	...	1	...	...	1	...	2	...	...	...	...	...	...	...	...	1	...
Cyperaceae†	8	4	12	16	15	7	7	4	7	5	4	8	7	3	11	22	15
Typha†	...	3	2	6	2	1	1	2	2	...	2	2	2	3	5	4	4
Nymphozanthus†	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...

*Number of Pinus and Abies pollen grains, not computed in the percentages.
†Number of pollen grains, not computed in the percentages.

gests that the drying of Lower Klamath Lake probably occurred between 7,500 and 4,000 years ago, and is to be correlated chronologically with a general decrease in precipitation on the entire continent. Another line of evidence shows that the remnants of some of the Pleistocene glaciers in the western mountains entirely disappeared during the early postglacial, and that the existing glaciers were formed only a few thousand years ago (Matthes, 1939). The salinity of the lakes and the rebirth of the glaciers indicate a cooling of the climate and an increase in precipitation following the dry period.

GLACIERS

The fact of reinundation of the Lower Klamath Lake bed and resumption of sedimentation is, in itself, evidence for an increase in moisture and a cooler climate. This is corroborated by the sharp increase in western white pine pollen soon after the yellow pine maximum, and a converse decline in the percentage of yellow pine pollen. The pollen profiles of white pine above their maximum proportions mark a slight decrease in moisture to a minimum which has probably persisted to the present. The amount of time represented by the upper sediments destroyed in modern time is unknown, but pollen studies in other parts of the Pacific Northwest indicate no climatic trends during the last few thousand years. According to Antevs (1940), the moist period resulting in reinundation of the Lower Klamath Lake bed began about 4,000 years ago. Pollen profiles in eastern North America suggest an initial cool damp period followed by warming and drying to a maximum, with a possible slight cooling and increase in moisture in the latter part of postglacial time.

SUMMARY

Pollen analyses have been made of four profiles of sediments from Lower Klamath Lake with the purpose of corroborating evidence for a dry period during the postglacial, as denoted by the occurrence of artifacts at certain horizons. The age of the sediments is not known with certainty, but the rate of peat deposition in the Pacific Northwest suggests that they represent all or most of the post-Pleistocene. An unconformity probably is present in one or more of the profiles due to the drying-up of Lower Klamath Lake and the cessation of sedimentation for an unknown period. The upper stratum of sediments, also constituting an unknown period of time, has been removed by wind and fire since the drainage of the lake in modern time. Thus the forest succession and climatic trend as interpreted from the pollen profiles do not represent a continuous sequence for the postglacial.

TABLE 29

PERCENTAGES OF FOSSIL POLLEN, KLAMATH FALLS PROFILE

POLLEN	DEPTH IN METERS												
	2.5	2.2	2.0	1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2	0.0
Pinus contorta	55	52	42	30	12	8	25	15	16	13	12	17	16
P. monticola	14	17	13	22	19	18	19	20	39	36	26	20	25
P. ponderosa	28	28	36	45	66	68	53	60	40	44	50	50	45
P. lambertiana	...	...	2	1	...	1	...	2	...	...	5	3	2
Pseudotsuga taxifolia	...	...	...	...	...	...	...	...	...	...	...	3	1
Tsuga heterophylla	...	...	3	...	...	...	1	...	...	3	...	...	1
T. mertensiana	1	...	1	2	...	1	...	1	2	1	4	1	1
Picea engelmanni	...	...	...	...	...	1	...	...	...	...	...	...	...
Abies grandis	...	...	...	...	...	...	...	...	...	...	...	1	3
A. concolor	2	3	2	...	3	1	1	2	...	2	2	5	6
A. lasiocarpa	...	...	...	...	...	1	...	...	...	...	...	...	...
Gramineae	...	...	...	...	...	1	...	...	3	1	1	...	...
Compositae	...	...	...	...	...	...	1	...	...	...	...	...	...
Chenopodiaceae	...	...	1	...	...	...	...	...	...	...	...	...	...
Pinus spp.*	4	5	6	6	8	13	9	14	11	7	16	8	6
Abies spp.*	1	...	...	...	...	1	...	...	...	...	1	...	1
Alnus†	...	...	...	...	...	...	...	1	1	...	1	...	...
Acer†	...	...	...	...	...	...	...	...	...	...	...	...	1
Cyperaceae†	...	...	...	...	...	1	...	...	2	2	4	2	2
Typha†	...	2	2	1	4	2	4	4	7	7	1	2	1
Nymphozanthus	...	...	...	...	...	...	4	...	1	...	...	...	...

*Number of Pinus and Abies pollen grains, not computed in the percentages.
†Number of pollen grains, not computed in the percentages.

The pollen of 11 or more conifers is preserved in the sediments, but the pollen profiles of western white pine and western yellow pine are the best indicators for both forest succession and climate. The respective pollen profiles for yellow and white pine are remarkably consistent in their general trends for the four peat profiles. Yellow pine shows a gradual increase to a maximum about half way up in each profile, and then it declines toward the uppermost level. White pine conversely decreases from the lowest level to that of the yellow pine maximum, and then abruptly increases several horizons higher to its own high. This is succeeded by a decline of lesser degree, and almost constant proportions are maintained to the top.

Climatically, the pollen profiles designate a gradual drying and perhaps warming to a maximum, and then an increase in moisture with some cooling to a degree which has persisted in general to the present. This evidence for a dry period substantiates that offered by the presence of artifacts in the L. B. profile, the history of certain lakes in the Great Basin, the oscillations of western mountains glaciers, and the pollen profiles of peat deposits in eastern Washington.

③ ② ① ④

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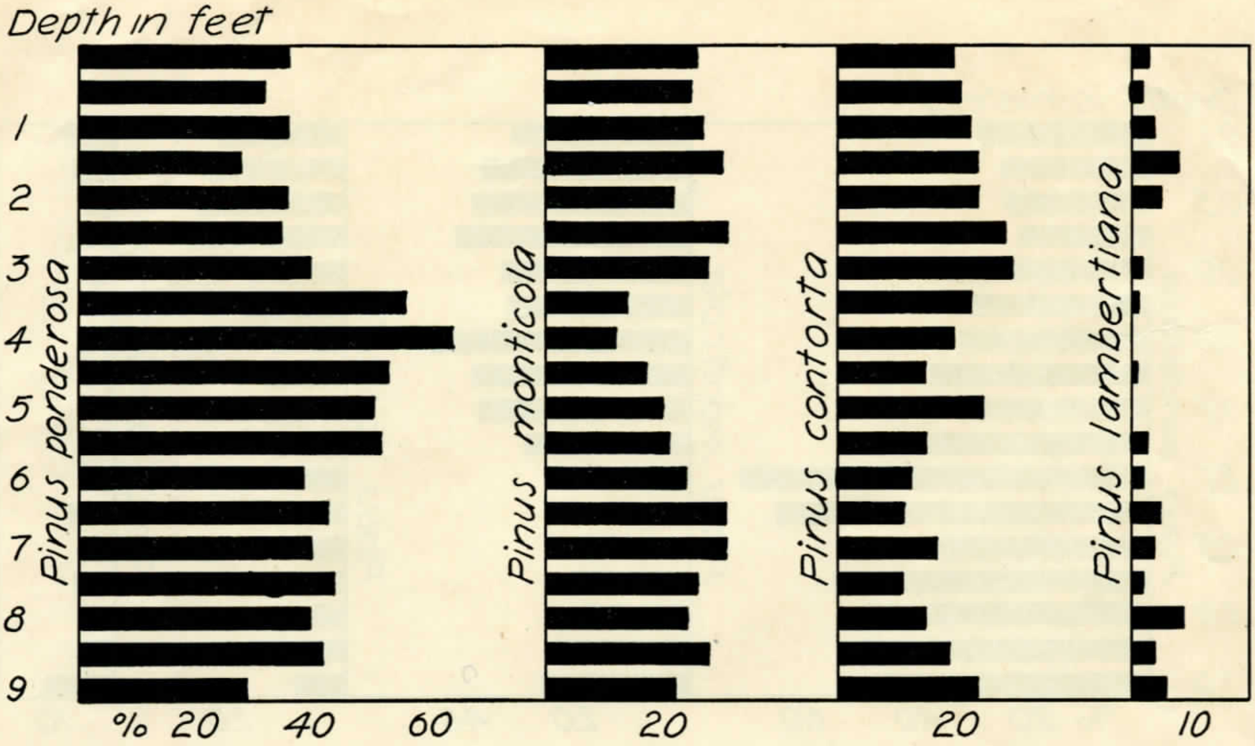

FIG. 57—POLLEN PROFILES FROM LAIRD'S BAY SEDIMENTS

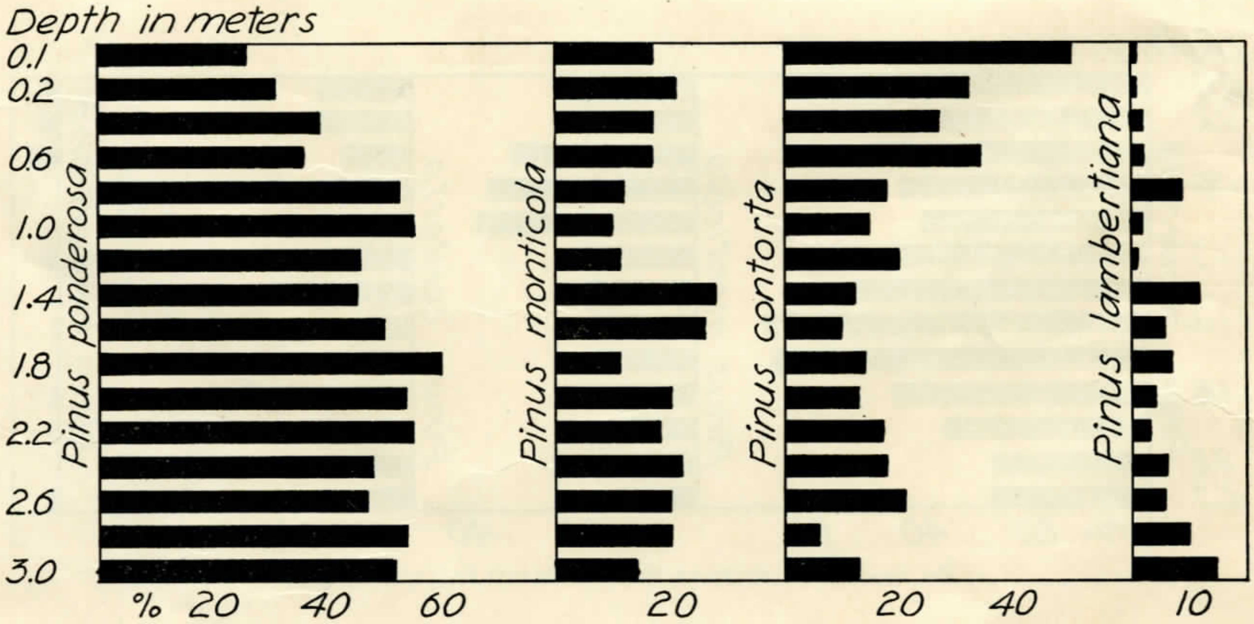

FIG. 58—POLLEN PROFILES FROM NARROWS No. 1 SEDIMENTS

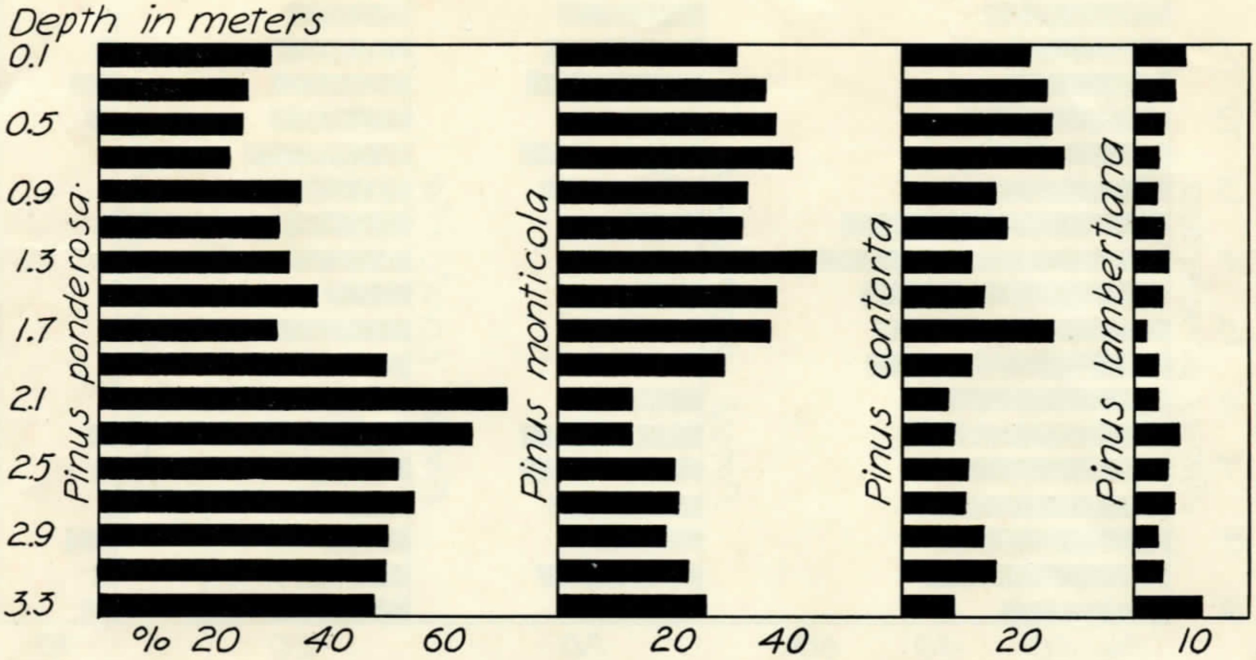

FIG. 59—POLLEN PROFILES FROM NARROWS No. 2 SEDIMENTS

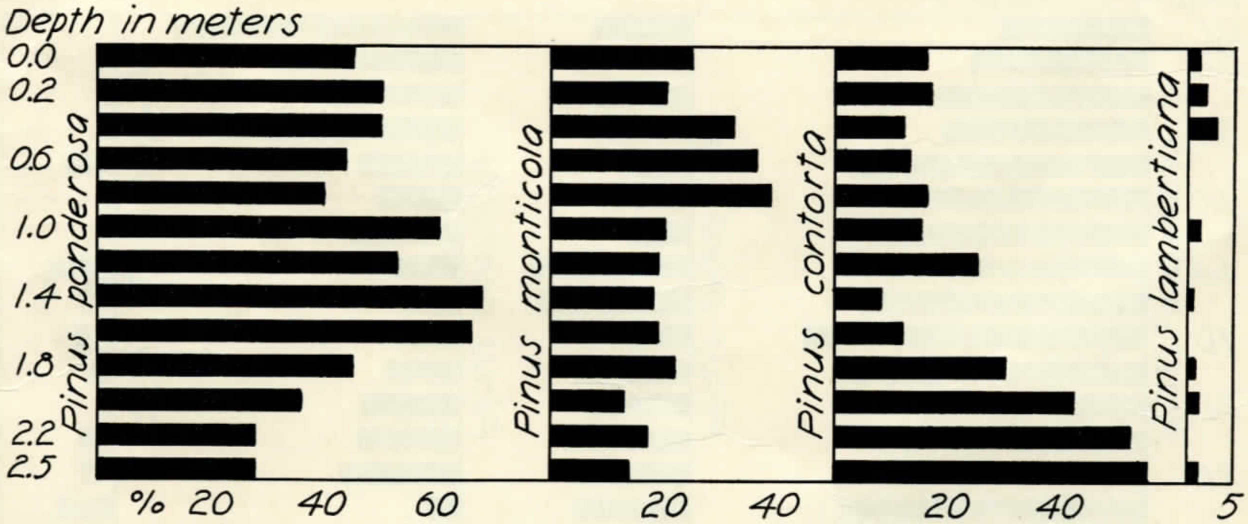

FIG. 60—POLLEN PROFILES FROM KLAMATH FALLS SEDIMENTS

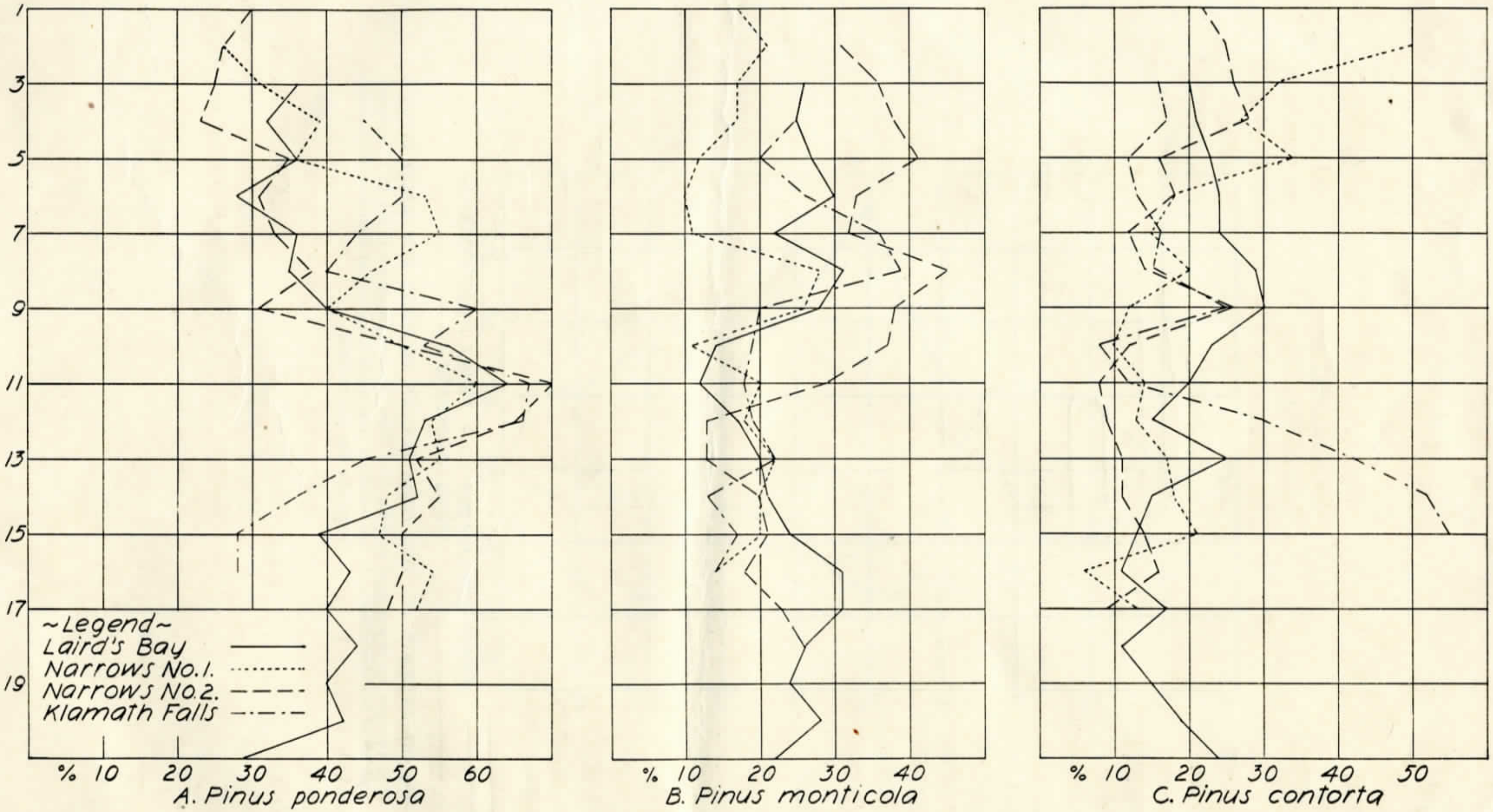

FIG. 61—POLLEN PROFILES OF YELLOW, WHITE, AND LODGEPOLE PINE SHOWING MAJOR TRENDS FOR EACH SPECIES IN THE FOUR PROFILES OF SEDIMENTS It is assumed that the levels of maximum percentages of yellow pine in the four profiles are approximately synchronous, as are also those of white pine. The numbers to the left are arbitrary and do not indicate depth, because the horizons of highest proportions for each species are not at the same depth.

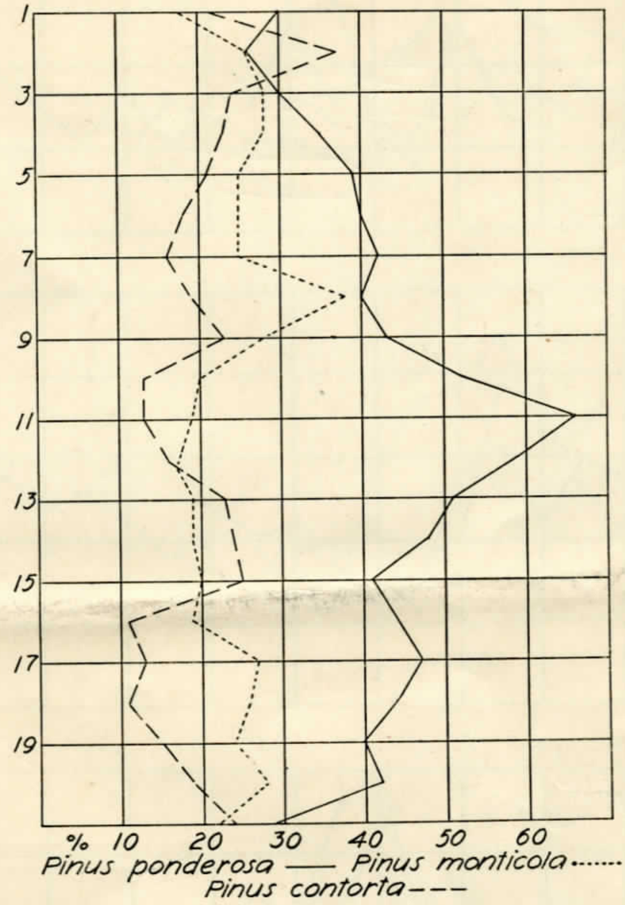

FIG. 62—AVERAGE OF THE FOUR POLLEN PROFILES FOR EACH SPECIES
The averages are determined level for level from the profiles shown in fig. 61. The upper and lower few percentages do not present a true trend, because less than four percentages determine the percentages.