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INTRODUCTION

The age and correlation of the pollen-bearing sediments in the Scablands of eastern Washington are to be largely determined by the relation of their sites to the time of deglaciation, although the scablands themselves were not covered by the ice sheets. The last Pleistocene glacier of Wisconsin age encroached upon the Columbia Basin in two main sectors. The Okanogan ice lobe extended down the Okanogan River valley and into the Columbia Basin between the Grand Coulee and the Columbia River to the west. It blocked the Columbia River and diverted its waters through the Grand Coulee. The Spokane ice lobe, possibly of earlier origin, pushed south of the Spokane River farther east and on a broader and more irregular front (Flint, 1937). For some time during the advance and retreat of the Spokane ice, glacial waters drained southwestward and were partially responsible for the formation of the Channeled Scablands (Bretz, 1923). This area is characterized by a system of anastomosing channels or coulees, cut into solid basalt and by the remnants of the former relief. Many of these channels, which carried great volumes of water in glacial time, carry no streams at present. Others still carry intermittent, and a few have permanent streams. Rockbound lakes are common where the coulee floors have been deeply excavated and scoured. Other lakes have been dammed in the larger valleys by delta deposits of tributary streams, in oxbows on aggraded floodplains, in plunge basins at the base of abandoned rapids, and in yet other types of depressions on the valley floors.

It can be assumed that the postglacial organic sedimentary columns in the Channeled Scablands are about the same age. It is possible, however, that those channels first abandoned by meltwater potentially hold the oldest pollen-bearing profiles. As the ice retreated from the Columbia Basin, and the Columbia and Spokane Rivers carried more and more of the meltwater, the scabland channels separated from the Spokane and Columbia river drainage system by the highest divides were probably first abandoned. It seems probable that postglacial sedimentary columns in the Channeled Scablands are as old or older than most in the entire Pacific Northwest. They are undoubtedly older than those north of the Spokane River.

LOCATION AND CHARACTERISTICS OF THE BOGS

This study is concerned with the pollen analyses of four sedimentary columns located in eastern Washington and their translation into postglacial vegetation and climate. Two of them are from swamps that have developed in scabland channels south of the Spokane ice border, while the other two are from sedimentary beds lying upon glacial drift within the glaciated region. One of the sedimentary sections was obtained from a swamp located about 15 miles due west of Harrington, Washington, on the floodplain of Lake Creek which flows in a scabland channel. The sediments have accumulated in an abandoned oxbow, probably formed when a greater volume of water was carried by the channel. The depth of the pollen-bearing sediments which rest directly upon basalt, is 6.5 meters. The sediments contain considerable inorganic material, mostly at the bottom and near the top. The upper six inches of sediments are somewhat mucky and oxidized because of grazing and flooding in more recent time. Limnic peat is present from the bottom to 3.8 meters, and fibrous peat composed of sedges, rushes, bulrushes, cattail, burreed, and water smartweed completes the profile. The volcanic ash stratum, typical of most Washington postglacial organic sedimentary columns, is present at 3.4 meters.

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A second sedimentary section was obtained from a swamp formed in a scabland channel about 10 miles east of Wilbur, Washington. This swamp is situated near the edge of the timbered zone, and an occasional western yellow pine (*Pinus ponderosa*) occurs on favorable local sites. The surface is covered with a swamp associes of plants, with standing water in the center. The latter contains both floating and submerged seres. The thickness of the organic sediments in the area of sampling is 2.6 meters, and they rest directly upon basalt. Silt is the principal component of the lowest decimeter of sediments, followed upward by 2 meters of limnic peat and about 0.5 meter of fibrous peat composed of sedges, cattails, bulrushes, and water smartweed. The volcanic ash stratum occurs at 1.2 meters, while a sharply defined layer of diatomite is present at 0.4 meter. To the naked eye, these two strata look very much alike, while palpably they are also similar. The relative stratigraphic position of the ash suggests that the age of these sediments is probably about the same as those near Harrington in spite of the difference in thickness. The former, lying nearer the border of the Spokane drift, may be slightly younger.

A third sedimentary section was obtained from a swamp at the head of Liberty Lake, located about 15 miles directly east of Spokane. The lake was ponded in a tributary of the Spokane River by aggrading of the main valley with glaciofluvial material during the retreat of the last glacier. The rate of deposition of pollen-bearing sediments has been augmented by deltaic sediments by the incoming stream at the head of the lake. The surface supports an associes of swamp plants. The thickness of the sediments in the area of sampling is about 7 meters. The lowest 1.5 meter consists of silts and clays, followed upward by 3.5 meters of limnic peat, which in turn is overlain with 2 meters of fibrous peat composed largely of sedge, cattail, and bulrush. The volcanic ash stratum occurs at 4.5 meters. At Newman Lake, across the Spokane River valley to the north, the thickness of a sedimentary column obtained is 7.3 meters with the ash at 4.5 meters (Hansen, 1939). As Liberty and Newman lakes are of the same genesis, and formed during the last glacial retreat, they are probably of about the same age.

A fourth sedimentary column was obtained from a sedge meadow at the south end of Eloika Lake, located about 25 miles northwest of Spokane. Eloika Lake has been ponded in a branch of the Little Spokane River which empties into the Spokane River near the city of Spokane. The sedge meadow comprises some 100 acres and the organic sediments are generally shallow. In the area of sampling, the maximum thickness is 5.0 meters, with about 2.5 meters of limnic peat overlain with about the same thickness of fibrous sedge peat. The volcanic ash stratum occurs at 1.75 meters, which is relatively higher in the section than in most sedimentary beds in Washington.

The Harrington and Wilbur profiles are probably older than those at Liberty and Eloika lakes, if permanently ponded water in the scabland channels was available for sedimentation soon after they were abandoned by glacial meltwater.

VEGETATION OF ADJACENT AREAS

The Harrington and Wilbur sediments are located in the timberless Arid Transition life area, while Liberty and Eloika lakes are situated in the timbered zone of the same life area (Piper, 1906). The Harrington swamp is located nearest to the warmer and dryer Upper Sonoran life zone, a few miles north of the boundary of the largest area of this zone in eastern Washington.

The characteristic vegetation of the Upper Sonoran life zone consists largely of grasses, Composites, and Chenopods. The most conspicuous plant of this area is sagebrush (*Artemisia tridentata*) which is anemophilous and represented by its pollen in the sedimentary columns. Other characteristic shrubs are antelope brush (*Purshia tridentata*), rabbit brush (*Chrysothamnus nauseosus* and *C. viscidiflorus*), wingscale (*Atriplex canescens*), hopsage (*Grayia spinosa*), winterfat (*Eurotia lanata*), horsebrush (*Tetradymia canescens*), greasewood

(*Sarcobatus vermiculatus*), and stiff sagebrush (*Artemisia rigidus*). Common forbs are silver saltbush (*Atriplex argentea*), seepweed (*Suaeda depressa*), and false tarragon (*Artemisia dracunculoides*), and various species of Eriogonum, Erigeron, Penstemon, Lupinus, and Astragalus. There is a large number of grasses that thrive in the Upper Sonoran life zone, but as their pollen is practically impossible to separate, there is no need for enumerating the many species that might be represented by their pollen in the sedimentary columns. The pollen of the above groups is the most abundant of non-arboreal species, and their recorded postglacial trends are significant climatic indicators. Although none of the sedimentary columns is located in the Upper Sonoran life zone, paleic expansion and contraction of this phytogeographic area are apparently recorded in the profiles.

The timberless Arid Transition area forms a belt between the Upper Sonoran and the western yellow pine forests that barely encroach on the northeastern part of the Channeled Scablands. This timberless area is also called the Bunchgrass Prairie. The principal grasses include *Agropyron spicatum, Poa secunda, Festuca idahoensis,* and several species of Bromus. Many other species are common. Characteristic forbs are *Balsamorhiza sagittata, Achillea lanulosa,* and *Wyethia amplexicaulis,* and several species of Lupinus, Lomatium, Astragalus, Erigeron, and many others.

Eloika and Liberty lakes lie within the timbered portion of the Arid Transition area. The principal arboreal species is western yellow pine, and this floristic province is called the yellow pine belt. This tree is the most xerophytic forest tree of the Pacific Northwest and extends farther down on the east slope of the Cascades and into the Columbia Basin than any other forest tree. Its postglacial pollen record is an important indicator of climatic trends. Other arboreal species in the yellow pine forests are lodgepole pine (*Pinus contorta*) and Douglas fir (*Pseudotsuga taxifolia*).

The Canadian life zone lies to the north and east of the Arid Transition at higher elevations. Here the forests are composed of Douglas fir, lodgepole pine, western larch (*Larix occidentalis*), lowland white fir (*Abies grandis*), western white pine (*Pinus monticola*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), and Engelmann spruce (*Picea engelmanni*). With the exception of western red cedar, all of these species are represented by their pollen in the sedimentary columns. Mountain hemlock (*Tsuga mertensiana*) of the Hudsonian life zone at higher elevation is sparsely and sporadically recorded in all of the profiles, in spite of its present great distance from the sites of the sediments.

POSTGLACIAL VEGETATION HISTORY

In addition to the four sedimentary sections of this study, three others in the same general area, upon which the author has published, will be correlated with them. These are located at Newman Lake, about 20 miles northeast of Spokane across the Spokane River valley from Liberty Lake (Hansen, 1939), at Fish Lake, a few miles northeast of Cheney (Hansen, 1943a), and at Crab Lake, about 30 miles southwest of the Harrington section (Hansen, 1941). The first two lie within the yellow pine forests, while the last is located within but near the northern border of the main body of the Upper Sonoran life zone. These seven sedimentary columns contain pollen profiles which are generally similar with respect to the indicated climatic trends.

Lodgepole Pine

In all four sedimentary columns lodgepole pine was the predominant arboreal species as the ice retreated from the Columbia Basin and in areas to the north (figs. 1, 2, 3, 4). In the other three profiles it likewise was the predominant pioneer arboreal invader. Although lodgepole pine may be generally over-represented in many sediments because of its enormous amount of pollen produced at an early age, its consistently well-defined majority in most Pacific Northwest columns at the lower levels suggests its initial postglacial predominance. Its ability to thrive under un-

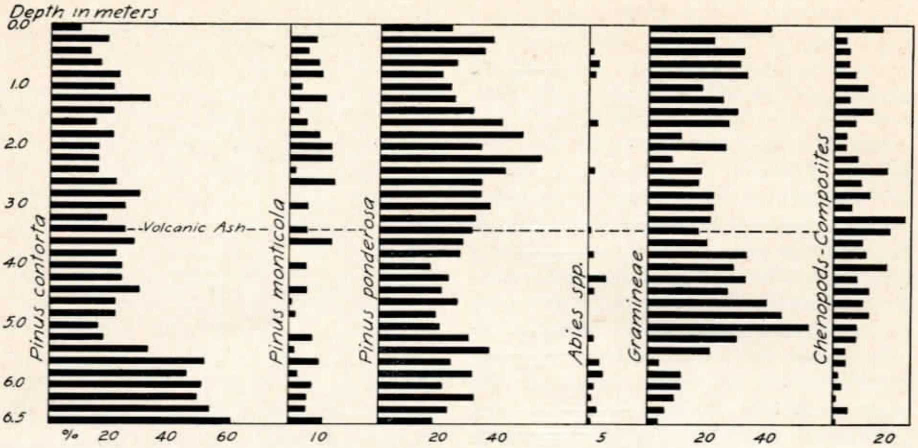

Fig. 1.—Pollen diagram of Harrington sedimentary column.

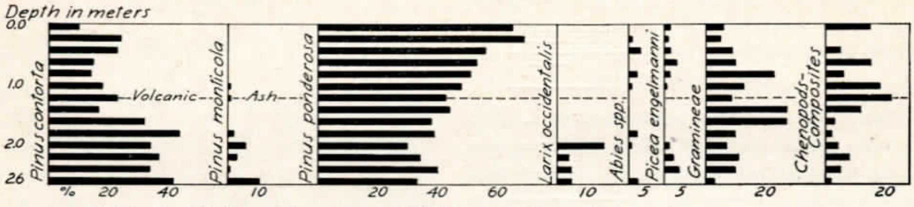

Fig. 2.—Pollen diagram of Wilbur sedimentary column.

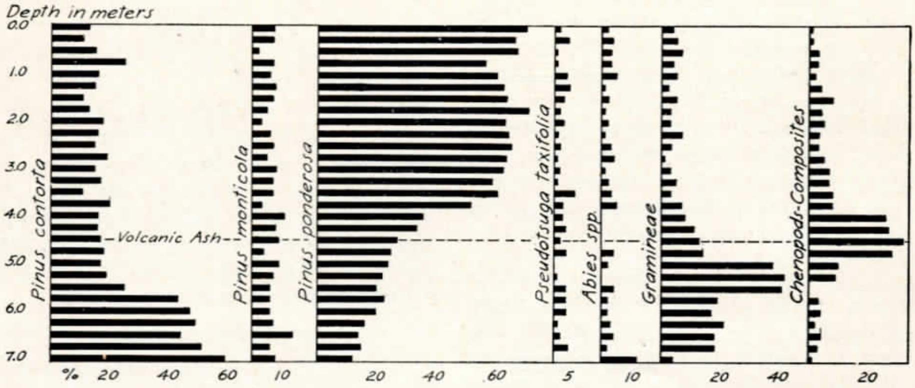

Fig. 3.—Pollen diagram of Liberty Lake sedimentary column.

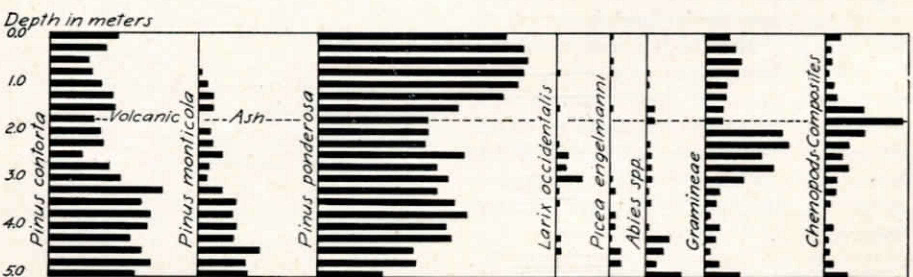

Fig. 4.—Pollen diagram of Eloika Lake sedimentary column.

stable physiographic and edaphic conditions, unfavorable for other species, as shown by its present distribution and habits suggests that its early postglacial pollen record is fairly indicative of its actual status. In those sedimentary sections south of the timbered area and drift border of eastern Washington, the abundance of lodgepole pine pollen in the lower levels and its gradual decrease upward to its minimum suggests that this species was pushed southward into the Columbia Basin by the advancing ice. It persisted for some time after the maximum ice advance. As the physiographic and edaphic conditions became stable, and the climate warmer and dryer, it was replaced by other species. The average of seven profiles in this region shows the consistence of the early postglacial lodgepole predominance and maximum (fig. 5). In other areas of the Pacific Northwest, lodgepole has likewise been a pioneer postglacial invader, particularly in the Puget Sound region and the Willamette Valley (Hansen, 1941a, 1942).

Western White Pine

Western white pine, a characteristic tree of the Canadian life zone, is slightly more abundant in the lower than the middle or upper levels (figs. 1, 2, 3, 4). This species requires a cooler and moister climate than lodgepole pine, Douglas fir, or western yellow pine. In general its maximum proportions occur in the lower levels of most Pacific Northwest sedimentary columns, which is consistent with its climatic requirements. It is not as aggressive as lodgepole pine under unstable physiographic and edaphic conditions, and therefore was not predominant during early postglacial time. This is true even in northern Idaho, where at present western white pine attains its maximum development (Hansen, 1939a, 1943). The average of the seven pollen profiles of western white pine shows that it has been most abundant in early postglacial time, but apparently conditions were not as favorable then as they are now in northern Idaho (fig. 5).

Western Yellow Pine

As the influence of the retreating glacier waned, and the climate became warmer and dryer, western yellow pine expanded at the expense of lodgepole. In the lower levels it is appreciably represented, but not so well as lodgepole (figs. 1, 2, 3, 4). Apparently the unstable physiographic and edaphic conditions were more favorable for the latter. The smallest representation of yellow pine is in the lower levels, indicating that as a forest it did not retreat southward before the advancing ice. It was

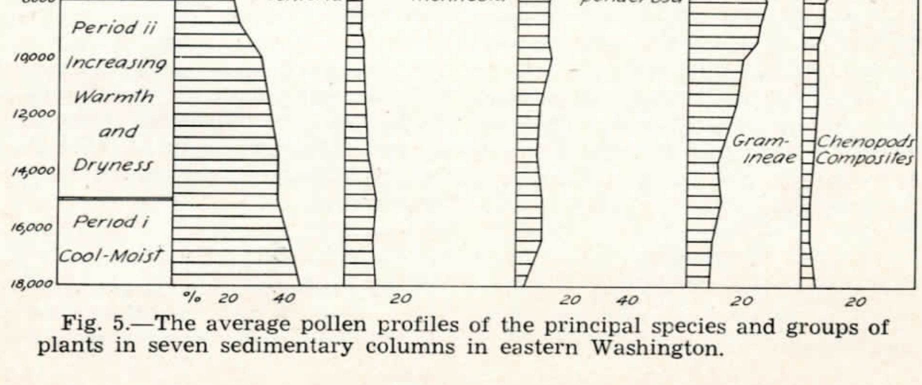

Fig. 5.—The average pollen profiles of the principal species and groups of plants in seven sedimentary columns in eastern Washington.

largely destroyed or occupied interlobate areas. If it had retreated beyond the southernmost profile of this study, then its readvance should be recorded by its maximum pollen proportions at some point between the bottom and the volcanic ash horizon. In three of the profiles, yellow pine did expand immediately from the bottom and then decline below the ash layer, but this was probably in response to warming and drying that reached a maximum about the time of the volcanic activity (figs. 1, 2, 4). Although it may have persisted closer to the sites of the more southern swamps during the glacial period, its present existence at great distance is apparently in much greater abundance. In the Crab Lake profile, farthest removed from the present-day forests, yellow pine is most poorly represented throughout, with a maximum of 28 per cent at a point above the volcanic ash stratum (Hansen, 1941). In the other six sections the maximum ranges from 54 to 71 per cent. It is significant that in the Harrington profile, next farthest south, the next lowest maximum is attained, also above the ash stratum (fig. 1).

The average of the seven profiles of yellow pine reveals a more or less constant trend from the bottom to the ash horizon (fig. 5). The early postglacial expansion was arrested by warming and drying which reached a maximum during the Middle Postglacial about the time of the recorded volcanic activity. Its expansion to the status of climax dominance, as it holds at present, was held in abeyance until increased moisture and lower temperature in more recent time. This is most clearly shown in the Harrington and Eloika Lake sedimentary sections (figs. 1,4). Its most rapid rate of expansion occurred soon after the time of the volcanic activity. In all columns the yellow pine maximum occurred sometime after this geological event. In all but the Harrington profile it attained its greatest proportions at or near the top.

Grasses

Although grasses are an important group in the present vegetation of the non-timbered areas of eastern Washington, they attained their postglacial maximum before the volcanic eruption recorded by the ash stratum (figs. 1, 2, 3, 4). The highest proportion of grasses is attained in the Harrington profile, where it reaches 54 per cent. In only the Crab Lake profile does this group attain its maximum representation above the volcanic ash horizon. This trend of grass succession suggests that the gradual drying and warming of the climate favored its expansion at the expense of western yellow pine. Its decline before the volcanic activity suggests that warming and desiccation progressed beyond the optimum and it was partially replaced by Chenopods and Composites. Grass is probably under-represented by its pollen in the sedimentary columns so that its highest proportions become more significant.

Chenopods-Composites

Although the warm, dry Middle Postglacial had reached a significant degree before the recorded volcanic activity, as disclosed by the grass maximum, it may not have attained its peak until the time of volcanic activity. This is denoted by the maximum of Chenopods and Composites at or near the ash level (figs. 1, 2, 3, 4). This trend may reflect the culmination of the xerothermic interval in two ways. First, the dry conditions in themselves would have encouraged the expansion of Chenopods and Composites, especially those of the Upper Sonoran life zone. Second, continued warmth and dryness would have tended to evaporate many of the more shallow lakes, leaving alkaline areas which may have been taken over by halophytic species of these two plant groups. Although the second condition was probably local, it contributed to the record of these two groups. About the time of the recorded volcanic activity they were the predominant flora within range of pollen dispersal to the sites of the sediments of this study (fig. 5). After their maximum they are not abundantly represented.

Other Species

Other arboreal species recorded by their pollen in the sedimentary columns include Douglas fir, two or three species of balsam fir, Engelmann spruce, western larch, western hemlock, and mountain hemlock. All these species require more moisture than western yellow pine, and with the exception of western larch, their general higher proportions in the lower levels, their decrease through the middle horizons, and their slight rise in the upper levels, supports the other evidence for a Middle Postglacial xerothermic stage. In the Eloika Lake profile an influx of larch near the middle suggests severe fires in the forests to the north, while in the Wilbur profile, an abundance of larch in the lower four levels is also indicative of pyric influence within range of pollen dispersal. Temporary, but marked expansion of this species in profiles in northern Idaho, at Newman Lake, and at Fish Lake also denotes periods of fire sufficiently severe and frequent to destroy the climax forest and also temporarily check the development of a subclimax forest of western white pine (Hansen, 1939, 1943).

CLIMATE AND CHRONOLOGY

The maximum of glaciation in the Pacific Northwest probably occurred about 25,000 years ago (Antevs, 1945). After the ice began to retreat, an unknown period of time elapsed prior to organic sedimentation. Presumably sedimentation began first on those sites that were earliest freed of ice, or if located beyond the maximum ice advance, as soon as physiographic conditions became favorable. Thickness of sediments is no criterion for age, because of the great variation in thickness of sediments overlying the volcanic ash stratum, a common chronological marker. Upon the basis of the thickness of 60 Pacific Northwest sedimentary columns, the forest succession, and the position of ash and pumice strata, it is estimated that organic sedimentation on glacial drift or its chronological equivalent began on an average from 18,000 to 20,000 years ago (Hansen, 1945). Postglacial time is divided into 4 periods in light of the interpreted forest succession and climate (fig. 5). The first was moist and cool, and persisted until about 15,000 years ago. The second interval was one of increasing warmth and dryness, and is more or less arbitrarily considered to have endured until 8,000 years ago. The third period, from 8,000 to 4,000 years ago, was one of maximum warmth and dryness. It is during this period that the maximum of grasses and Chenopods-Composites was attained. The volcanic ash stratum common to so many Washington postglacial sedimentary columns is estimated at about 6,000 years, or about the middle of the warm, dry period. The fourth period, from 4,000 years ago to the present saw a return to cooler and moister conditions.

There is additional evidence for the occurrence of warm and dry climate during the Middle Postglacial. Profiles in the Puget Sound region disclose that western hemlock, a climax dominant, was unable to attain predominance until after the volcanic activity. In early postglacial time it was unable to replace lodgepole pine and Douglas fir because of unfavorable edaphic conditions due to sterile mineral soil. The incidence of warmer and dryer climate, especially during the summers, then arrested its development in normal forest succession, and it was not until the last four thousand years that it was able to expand and attain predominance (Hansen, 1941a). In the Willamette Valley of western Oregon, an influx of Oregon white oak (*Quercus garryana*), in the upper half of three sedimentary columns, replacing Douglas fir and lowland white fir, denotes the influence of the xerothermic interval (Hansen, 1942).

Further evidence for the occurrence of warmer and dryer climate from 4,000 to 8,000 years ago is shown by the fluctuation of Great Basin lakes, present salinity of certain lakes in the Great Basin, modern glaciers in the western mountains, pollen profiles of eastern North America, and postglacial climatic trends of Sweden and England. The present salinity of Owens Lake in California and of Abert and Summer lakes in southcentral Oregon is such that it need not have required more than 4,000 years for its development (Gale, 1915; Van Winkle, 1914). These lakes have lacked outlets in postglacial time, so their present low degree of salinity indicates that their pluvial antecedents dried up, and the accumulated salts thereof were removed by wind or buried before the modern lakes came into existence. Antevs (1938, 1945) interprets this to mean that these lakes, as well as others in the Great Basin, dried up during the Middle Postpluvial (Postglacial) and then were reborn about 4,000 years ago with the advent of increased moisture. Allison (1945) has shown that Lake Chewaucan, antecedent of Summer Lake, stood at several tens of feet higher than the modern lake during early postglacial time. This indicates that Lake Chewaucan dried up during the warm dry period as did other lakes of the Great Basin. Subsequently Summer Lake was re-established in the lowest part of the basin.

It is believed that the modern cirque glaciers of the Sierra Nevada came into existence about 4,000 years ago, after a period of dryness which caused the remnants of the Pleistocene glaciers to entirely disappear (Matthes, 1939, 1942). Pollen profiles of eastern North America reveal that there was at least one period of warmth and desiccation (Sears, 1942; Deevey, 1943, 1944; Wilson, 1944). von Post (1933) believes that the postglacial vegetation history of Sweden depicts a period of maximum warmth which attained its maximum between 7,000 and 6,000 years ago, Godwin (1940) believes that postglacial forest succession in England also reveals evidence for a warm, dry interval about the same time.

CONCLUSIONS

Pollen analytical data from postglacial sedimentary columns in eastern Washington reveal evidence for the occurrence of a warm, dry interval between 8,000 and 4,000 years ago. Lodgepole pine apparently retreated southward into the Columbia Basin as the ice advanced, and persisted as the predominant arboreal species until well into postglacial time. Western yellow pine evidently did not retreat southward as a forest, because it is more abundantly represented near the top of the columns than the bottom in those sections that are removed from present-day yellow pine forests. The replacement of the early forests of lodgepole by yellow pine was arrested by warming and drying, which were more favorable for grasses, Composites, and Chenopods. The maximum warmth and dryness may have occurred about 6,000 years ago, near the time of volcanic activity recorded by a stratum of volcanic ash in many Washington sedimentary columns. Soon after this geologic event, yellow pine expanded to its maximum and predominance, a position which it retains today in the timbered Arid Transition area. This suggests a return to moister and cooler conditions in more recent time, perhaps beginning about 4,000 years ago.

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