(ratio of mass to charge m/e was 606) was the largest peak; other prominent peaks nearby were M −28 and M −59, the first due to the loss of a two-carbon fragment and the latter probably due to a loss of -$COOCH_3$. Background noise became noticeable near m/e 300.

It is unusual to find methyl pheophorbide a in sediments as old as the middle Eocene because in almost all fossil sediments further reduction and decarboxylation have produced highly stable porphyrins, such as commonly occur in oil, coal, and fossil-rich shale. In the Eocene the Geisel valley was a poorly drained shallow basin (*7*), receiving organic sediments from plants and animals living along its swampy margins. In this swampy environment extensive deposits of peat accumulated and were subsequently slightly altered, producing brown coal. The amount of compression that occurred during the formation of the brown coal does not seem to have been excessive, and it is unlikely that the brown coal has ever been altered by high temperatures. The preservation of such fossils as frog epidermal cells containing nuclei and bacteria in the Geisel brown coal suggests an anaerobic environment with relatively rapid deposition, in which organic decay was slow and organic accumulation extensive. The rapid burial of plant material in an anaerobic environment and the fact that brown coal has a history of low temperatures may account for the preservation of this phorbin from the middle Eocene.

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Pollen Sequence from Late Quaternary Sediments in Yellowstone Park

Abstract. *A radiocarbon-dated pollen diagram from a depression near the end of the southeast arm of Yellowstone Lake, Wyoming, records the vegetation sequence from the retreat of Late Wisconsin (Pinedale) ice to the present time. The tundra* Picea-Abies-Pinus albicaulis *(spruce–fir–whitebark pine) parkland vegetation inferred during late glacial time changed rapidly to a* Pinus contorta *(lodgepole pine) forest shortly before 11,550 carbon-14 years ago, suggesting a warming trend at that time. The* Pinus contorta *forest persisted with minor modification throughout postglacial time.*

A series of depressions at the end of the southeast arm of Yellowstone Lake were cored for pollen and seed analysis. The most suitable core was from an abandoned lagoon 15 feet (1 foot= 0.3 m) above Yellowstone Lake level (elevation, 7750 feet). The present vegetation surrounding the site is *Pinus contorta* Dougl. (lodgepole pine) forest. A small forest opening characterized by *Artemisia tridentata* Nutt. (big sagebrush) occurs along the north edge of the fen. *Picea engelmannii* Parry (Engelmann spruce), *Abies lasiocarpa* (Hook.) Nutt. (subalpine fir), and *Pinus albicaulis* Engelm. (whitebark pine) are dominant on nearby slopes less than 100 feet above the coring site. The altitude of the present tree line averages about 9800 feet on adjacent plateaus.

The pollen and seed diagrams were divided into two pollen-assemblage zones. The late glacial *Picea–Juniperus–Pinus albicaulis* zone is overlain by the postglacial *Pinus contorta* zone. A radiocarbon date on sediment near the base of the upper zone is 11,550 ± 350 years B.P. (W-2285) (Fig. 1). The lower zone is characterized by maxima of *Pinus albicaulis*–type (*1*), *Picea, Abies, Juniperus, Salix* (willow), *Betula* (birch), *Populus* (poplar), Gramineae, *Artemisia,* and Compositae pollen percentages. Two other pollen diagrams from Yellowstone Park show a similar late glacial sequence (*2*, *3*). The relatively low percentage of *Pinus* pollen (about 40 percent), the high percentages of *Artemisia* and Gramineae pollen, and the presence of rare grains of *Bistorta* (bistort), *Polemonium* (Jacob's ladder), Caryophyllaceae, Rosaceae, and *Selaginella densa* Rydg. (rock selaginella) are characteristic of late-glacial assemblages. This pollen assemblage is found only in those modern samples from alpine areas in Yellowstone Park and the Beartooth Plateau (*3*). Surface samples from tundras contain 45 to 65 percent tree pollen in this area, probably because tundra plants do not produce much pollen and high winds in alpine areas carry up pollen from lower tree-covered areas. Macrofossils of trees are rare at the bottom of the *Picea–Juniperus–Pinus albicaulis* zone, but they are more common in the upper half of this zone (Fig. 1). The pollen and macrofossils indicate that the first woody plants to be established in the area were *Pinus albicaulis* Engelm., *Picea engelmannii* Parry, *Abies lasiocarpa* (Hook.) Nutt., *Populus balsamifera* L. (balsam poplar), and *Juniperus communis* L. (prostrate juniper).

The vegetation was a subalpine parkland or alpine tundra near the tree line during late glacial time. Either interpretation allows for an estimated lowering of the tree line by about 2000 feet during the late phases of Pinedale glaciation. A cold, moist climate is implied by such vegetation. If a lapse rate of 3.5°F per 1000 feet is applied, the average annual temperature in the late glacial would have been about 7°F cooler than at present. The closest weather station on the north side of Yellowstone Lake has an average annual temperature of 32.8°F. A rough approximation of the late glacial mean annual temperature is thus about 26°F.

The *Pinus contorta* zone is characterized by pollen and needles of this species, and it was certainly a dominant tree during the postglacial. *Pseudotsuga* (Douglas fir) pollen occurs discontinuously at low percentages in the postglacial. But in surface samples, even where *Pseudotsuga* grows locally, its pollen is rare (*4*). Presence of its pollen in this zone probably means that *Pseudotsuga* was at least occasionally present in the area. The many taxa that show maxima in the late glacial all fall off to low percentages in the postglacial. Three subzones are defined within the

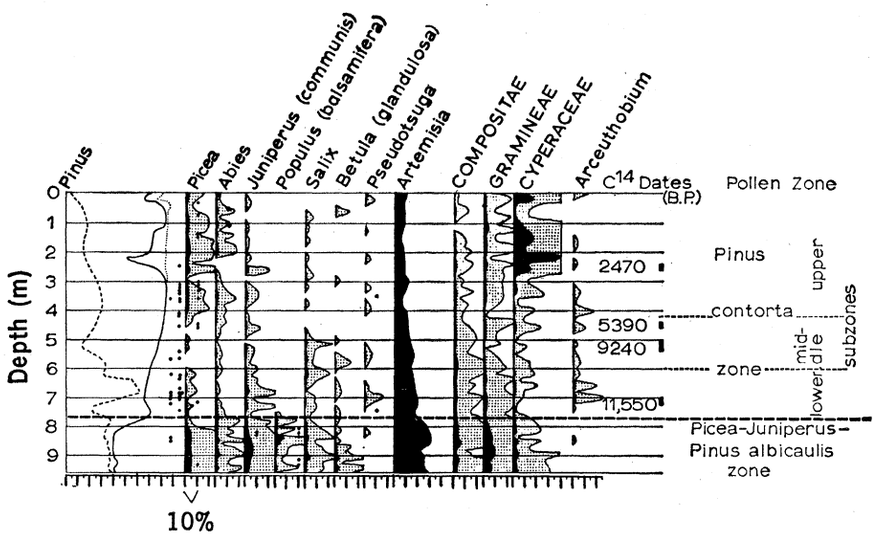

Fig. 1. Generalized pollen diagram from an abandoned 15-foot lagoon at the tip of the southeast arm of Yellowstone Lake, Wyoming. Pollen sum generally exceeds 300 grains and includes all pollen except that of aquatic plants; spores of ferns and fern allies are also excluded. Black curves give pollen percentages; stippled curves are these percentages times ten. The total amount of *Pinus* pollen is shown by solid line; proportion of *Pinus albicaulis*–type pollen is shown to left of dashed line, and proportion of *Pinus contorta*–type pollen is to right (between dashed line and total pine curve) based on 40 to 100 *Pinus* identifications from each stratum. Dotted line at top of total *Pinus* curve excludes Cyperaceae from the pollen sum. Black dots indicate single needles of *Pinus albicaulis* (left row), *Pinus contorta* (right row), other conifer needles, and bracts of *Populus balsamifera*. Names in parentheses are species identified from macrofossils, not from pollen.

Pinus contorta zone on the basis of minor pollen fluctuations. The lower subzone is characterized by a resurgence of *Pinus albicaulis*–type pollen. Needles of both *Pinus albicaulis* and *Pinus contorta* suggest that these two pines grew together in the early postglacial, in the absence of *Picea* and *Abies*. Occasionally pollen of *Pseudotsuga* is also present. The subzone dates from slightly before 11,550 to 10,160 (interpolated) years ago.

The inferred vegetation for the lower subzone, a *Pinus contorta–Pinus albicaulis* forest, is not a major forest association in Yellowstone Park at present. *Pinus contorta* is the dominant tree over most of the Yellowstone Plateau from 6500 to 8500 feet. *Pinus albicaulis* grows in the spruce fir forest from about 8000 feet up to timberline, but it grows on drier, more exposed sites than do spruce and fir. *Pseudotsuga* may also have been present in the forest at this time.

This vegetation suggests a cooler, but especially drier climate than at present. The presence and distribution of *Arceuthobium* (dwarf mistletoe) pollen in the section suggests another rough temperature approximation. The upper altitudinal limit of *Arceuthobium americanum,* a parasite on *Pinus contorta,* seems to coincide with the 30°F mean annual isotherm at five stations in Colorado and Wyoming (*5*). It first occurs continuously where *Pinus contorta* needles first occur (Fig. 1), and it was probably at its maximum altitudinal limit at that time. The mean annual temperature was approximately 30°F about 11,550 ± 350 B.P. (W-2285), or about 3°F cooler than at present.

The middle subzone is more strongly dominated by *Pinus contorta* pollen and needles than any other part of the diagram. Pollen spectra in this subzone resemble those of modern pure *Pinus contorta* forests (*4*) and may indicate that spruce and fir retreated up the slopes of the nearby uplands. This forest suggests the warmest, driest climate of the postglacial, the Altithermal period.

The middle subzone represents approximately the time between about 5000 and 10,160 years ago (dates interpolated). Strata dated at 9240 ± 300 (W-2284) and 5390 ± 250 (W-2281) are separated by less than 3 feet of sediment in this subzone and suggest that a hiatus may be present (Fig. 1).

The upper subzone is characterized by slight increases in *Picea* and *Abies* and much higher percentages of Cyperaceae pollen. All three taxa are present as macrofossils; the Cyperaceae is comprised of several species of *Carex* (sedge) typical of fens (*4*). The vegetation was probably a *Pinus contorta* forest similar to the modern one, but with occasional *Picea* and *Abies* locally in favorable habitats along Yellowstone Lake or elsewhere nearby. The increase in percentage of sedge pollen indicates a change in the aquatic habitat from a small pond to a fen.

Interpolation of radiocarbon dates suggests that this subzone represents the last 5000 years. A radiocarbon date of 2470 ± 250 years B.P. (W-2280) occurs slightly above the increase in *Picea* and Cyperaceae pollen. Interpolation suggests that increase in these pollen percentages occurred about 2800 years ago. Pollen and macrofossils of *Picea* and *Abies* suggest a climate slightly cooler and moister than that of the middle subzone. These cooler pulses at about 5000 and 2800 years ago agree with dated glacial advances in many mountainous areas of the world (*6*). The younger correlates with the Temple Lake Stade of the Neoglaciation in the Rocky Mountains (*6, 7*), and deposits morphologically similar to Temple Lake deposits occur in Yellowstone Park (*8*).

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References and Notes

1. *Pinus albicaulis*–type pollen includes that species which grows near the upper tree line (forest-tundra boundary) and *Pinus flexilis* James which grows near the lower tree line (forest-steppe boundary) in the Yellowstone Park region. Pollen of both species has verrucae on distal face. *Pinus contorta* is the only likely pine species without distal verrucae in that region.
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