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A 35,000 Year Vegetation and Climate History from Potato Lake, Mogollon Rim, Arizona

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A new record from Potato Lake, central Arizona, details vegetation and climate changes since the mid-Wisconsin for the southern Colorado Plateau. Recovery of a longer record, discrimination of pine pollen to species groups, and identification of macrofossil remains extend Whiteside's (1965) original study. During the mid-Wisconsin (ca. 35,000–21,000 yr B.P.) a mixed forest of Engelmann spruce (*Picea engelmannii*) and other conifers grew at the site, suggesting a minimum elevational vegetation depression of ca. 460 m. Summer temperatures were as much as 5°C cooler than today. During the late Wisconsin (ca. 21,000–10,400 yr B.P.), even-cooler temperatures (7°C colder than today; ca. 800 m depression) allowed Engelmann spruce alone to predominate. Warming by ca. 10,400 yr B.P. led to the establishment of the modern ponderosa pine (*Pinus ponderosa*) forest. Thus, the mid-Wisconsin was not warm enough to support ponderosa pine forests in regions where the species predominates today. Climatic estimates presented here are consistent with other lines of evidence suggesting a cool and/or wet mid-Wisconsin, and a cold and/or wet late-Wisconsin climate for much of the Southwest. Potato Lake was almost completely dry during the mid-Holocene, but lake levels increased to near modern conditions by ca. 3000 yr B.P.

INTRODUCTION

Only a handful of pollen records from western North America have served as key sites in our early understanding of paleoenvironments of the American Southwest. Whiteside's (1965) analysis of sediments from Potato Lake, on the Mogollon Rim of central Arizona, is one of those sites. Whiteside analyzed pollen, microalgae, and sediment chemistry from a 2.86-m core from the lake. He concluded that high percentages of spruce (*Picea*), fir (*Abies*), and Douglas-fir (*Pseudotsuga*) pollen in the lower portions of the core indicated pluvial conditions, when the climate was cool and moist. Little change in the pollen spectra of the upper meter of the core (dominated by pine (*Pinus*) suggested relatively stable vegetation and climatic conditions during the entire Holocene.

In general, key sites have not been reanalyzed by paleoecologists, even though advances in methodology and perspective might warrant such reexamination. However, by using techniques unavailable to Whiteside in his original study, a reinvestigation of sediments from Potato Lake (a) extends the paleoecologic record back to the mid-Wisconsin, with a 9.4-m core, (b) includes discrimination of pine pollen to species or speciesgroups (e.g., Jacobs, 1985), (c) adds macrofossil identifications, and (d) estimates the magnitude of paleoclimatic changes between the mid- and late Wisconsin, and the mid-Holocene.

Specific identification of pine pollen and plant macrofossils throughout the core determines a species' local presence, as well as its presence regionally for an area of the American West where other kinds of investigations (e.g., packrat midden analysis) would probably be unproductive. For example, Potato Lake lies within the middle of the largest ponderosa pine (*Pinus ponderosa*) stand in North America. Comparison of the Holocene and Wisconsin records from this lake suggests that ponderosa pine was considerably reduced during the last glaciation. Furthermore, additional radiocarbon dates obtained here for the Holocene deposits suggest that Potato Lake was essentially dry during the mid-Holocene.

Reconstructions of Wisconsin-age paleoclimates for the western United States have varied from region to region, as well as among different types of proxy data. For the late Wisconsin, Brackenridge (1978) and Galloway (1970) inferred cold, dry conditions using paleolake levels, snowline data, and cryogenic deposits. Using pollen and lake-level data, COHMAP project members (1988) considered greater effective moisture to have prevailed compared to modern conditions. From packrat (*Neotoma*) midden data, Van Devender (1977) inferred colder summers than today, with wetter winters. Using similar data, Wells (1979) also hypothesized colder conditions than today, but with an enhanced monsoonal (summer) influence.

Mid-Wisconsin paleovegetation and climates have been reconstructed based on more meager data. In the Great Basin (Thompson, 1990) and Mojave Desert (Spaulding, 1990) regions, conditions were warmer and perhaps somewhat more mesic during the mid-Wisconsin than the late Wisconsin. Van Devender (1990a,b) suggested that areas of the modern Sonoran Desert, as well as lowlands of the modern Chihuahuan Desert, were

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warmer and somewhat drier than during the late Wisconsin; higher Chihuahuan Desert locations were probably as wet if not wetter than during the late Wisconsin. Cave faunal remains from southern New Mexico were interpreted as indicating conditions cooler than today, but with greater seasonal equability (Harris, 1987). Although Jacobs (1985) provided qualitative estimates, no study has provided quantitative estimates for mid-Wisconsin climates for the Colorado Plateau. New data from Potato Lake allow quantitative estimates to be made.

STUDY AREA

Potato Lake is a small solution depression within the Coconino Sandstone (Permian) in Coconino County, Arizona, at 2222 m (7290 ft) elevation (Fig. 1). Maximum area of the lake is ca. 1.7 ha. In February 1988, maximum water depth was 2.1 m. Average annual temperature and precipitation for the Blue Ridge Ranger Station (2080 m elevation), ca. 21 km northeast of Potato Lake, are 7.9°C and 49.4 cm, respectively (Sellers and Hill, 1974).

Northern Arizona is a region of topographic and climatic extremes. North of the San Francisco Peaks (4203 m), the elevation falls to below 390 m at the bottom of the Grand Canyon only 85 km away, where elements of the Mojave Desert reach their easternmost limit. Remnants of the Sonoran and Chihuahuan Deserts occur within the Verde Valley at ca. 975 m, 85 km to the south.

The region encompasses at least 10 distinct biotic communities (Brown and Lowe, 1977). Potato Lake today is surrounded by the largest ponderosa pine stand in western North America (Hanks *et al.*, 1983). Growing locally around the lake are minor amounts of gambel oak (*Quercus gambellii*), aspen (*Populus tremuloides*), and New Mexico locust (*Robinia neomexicana*). At higher elevations (ca. 2440–2900 m), a mixed forest of Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and aspen occurs. Subalpine forests of Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) exist at elevations of ca. 2900–3500 m. Alpine vegetation is found above ca. 3500 m. A pinyon (*Pinus edulis, P. monophylla*)-juniper (*Juniperus osteosperma, J. monosperma*) woodland (ca. 1370–1980 m) is found elevationally below Potato Lake. Desert grassland is generally found below ca. 1370 m, and Sonoran desertscrub occurs below ca. 1000 m elevation (Turner and Brown, 1982).

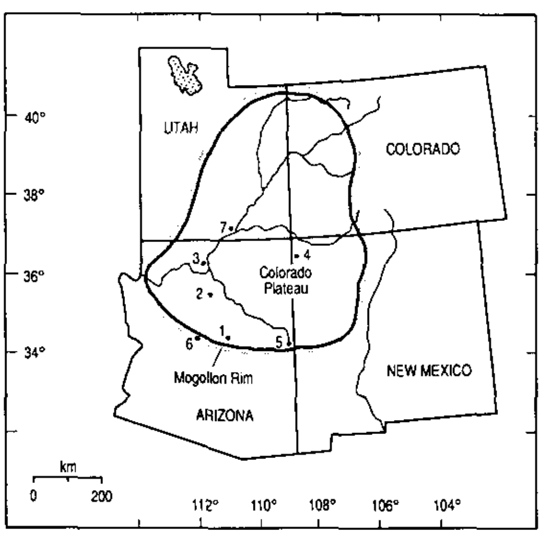

FIG. 1. Map showing location of the Colorado Plateau, Potato Lake, and other sites mentioned in the text. 1, Potato Lake, Arizona (this study; Whiteside, 1965); 2, Walker Lake, Arizona (Hevly, 1985); 3, Grand Canyon, Arizona, caves (Cole, 1980); 4, Deadman Lake, New Mexico (Wright *et al.*, 1973); 5, Hay Lake, Arizona (Jacobs, 1985); 6, Montezuma Well, Arizona (Davis and Shafer, 1992); 7, Bechan Cave, Utah (Davis *et al.*, 1984).

METHODOLOGY

Two overlapping sediment cores were collected in February 1988 from the center of the frozen lake; a 1.1-m core of upper, undisturbed sediment, and a 9.4-m continuous core were collected with a Livingstone corer. The composite core represents 9.34 m of sediment (Table 1).

Pollen was processed by the Faegri and Iversen (1989) technique, with addition of *Lycopodium* spores for calculation of pollen concentration. Additionally, subsamples with abundant silts and clays were sieved (Cwynar *et al.*, 1979). An average of 325 grains was identified for 59 levels within the cores.

Where identifiable, *Pinus* grains were subdivided into subgeneric categories, after Jacobs (1985). Pinyon-type pine (trees predominating in low-elevation woodlands today) included grains with verrucae on the leptoma (i.e., haploxylon) and were <70 μm in total length. The large haploxylon-type pine (mostly high elevation pines in the mixed conifer zone) included grains >70 μm long, with verrucae on the leptoma. A third category included grains without verrucae on the leptoma (i.e., diploxylon). In the Southwest, the first category may include *P. edulis, P. monophylla*, and *P. californiarum;* the second includes

TABLE 1
Sediment Description for Potato Lake Cores 1 and 2

Depth (cm)	Description
	Core 1
0–16	Black, organic-rich clays
16–97	Dark brown peat
97–106	Greenish clay with peat
	Core 2
20–77	Coarse peat with clays
77–99	Finer-grained peat with clays
99–120	Inorganic-rich peats
120–934	Clayey gyttja, continuous to discontinuous laminations throughout section

limber, southwestern white, and bristlecone pines (*P. flexilis*, *P. strobiformis*, and *P. aristata*, respectively); and the third includes ponderosa pine and lodgepole pine (*P. contorta*). Because of pollen preservation factors, however, the percentage of total pine grains identified to category is often low (only 16.5% were reported by Hansen and Cushing, 1973).

Sixty macrofossil samples were sieved from ca. 100 cc of sediment through 20 and 80 mesh soil sieves; these were then sorted and identified. Needle fragments were identified according to external and internal anatomy. For example, identification of *Abies* needles was based upon the placement of the resin canals within the needle. In white fir, the resin canals are ventral, touching the epidermis. However, for subalpine fir, the resin canals are lateral within the parenchyma (Durrell, 1916). For *Picea* needles, identification was based upon characteristics of the leaf tip (blunt in Engelmann spruce and sharp-tipped in Colorado blue spruce, *P. pungens*), the size of the resin ducts (larger in Engelmann spruce), and the absence (Engelmann) or presence (Colorado blue) of a separation within the vascular bundle (Durrell, 1916). While many needles could not be identified to species, those identified are referred to white fir and Engelmann spruce. Needles were tallied as total length of whole and broken fragments for each species and reported as numbers per 100 cc.

Identifications of pollen and macrofossils were checked against reference collections and published sources available at the Laboratory of Paleoecology, Northern Arizona University.

RESULTS

Core Lithology

Black, organic-rich clays occur from the core top to 16 cm depth (Table 1). Below this to 77 cm are coarse, black (10YR 2/1) peats. Finer peats (10YR 3/1) are found to ca. 99 cm. Inorganic content increases from ca. 99–120 cm, but includes interspersed plant fragments. Silt content visibly increases below ca. 120 cm. The remainder of the core to 934 cm consists of an alternation of distinctly and indistinctly laminated sections with more massive silty clays. Colors in this section range from very dark grayish brown (10YR 3/2) to grayish brown (10YR 4.5/2).

Whiteside (1965) noted a similar stratigraphy in his core. Black, organic sediment was described from the core top to ca. 93 cm, with transition sediments from ca. 93 to 119 cm. Grayish green, inorganic sediments were found to the core bottom (280 cm). Laminations were not reported.

Chronology

Eight radiocarbon dates were obtained for this study (Table 2), utilizing half-core segments. An additional date of 14,400 yr B.P., obtained by Whiteside (1965) for sediments associated with the decline in spruce (*Picea*) pollen in his core, was used for the analogous palynologic level in the present study. Dates lie in stratigraphic order except Beta-28325 (450–480 cm; 22,420 yr B.P.) and Beta-29344 (605–623 cm; 21,180 yr B.P.). When originally described, sediments within these two portions of the core did not reveal any obvious disconformities or evidence of redeposition. Partial drying of the remaining core segments, however, revealed an abrupt sedimentary change within the Beta-28325 sample, suggestive of redeposition. On this basis, Beta-28325 was excluded from the age-curve plot (Fig. 2).

Pollen and Plant Macrofossils

Pollen Zone I (ca. 35,000 to 21,000 yr B.P.). Within the mid-Wisconsin interval, dominant pollen types are spruce, fir, large haploxylon pine, Cupressaceae (juniper or *Cupressus*), oak (*Quercus*), sagebrush (*Artemisia*), other Compositae, and grasses (Gramineae) (Fig. 3). Pollen concentrations vary from <100,000 to nearly 300,000 grains/cc. Macrofossils of spruce (probably Engelmann), fir (probably white; see above), and Douglas-fir are found. Conspicuously absent are pollen and macrofossils of ponderosa pine. Pollen percentages of aquatic plants are low (specifically Cyperaceae and *Potamogeton*) and macrofossils (virtually all types) are rare, compared to the Holocene section of the cores (Fig. 4). This indicates that aquatic macrophytes grew farther from the coring location during this time, or were absent. Percentages of the alga *Pediastrum* are low compared to the late Wisconsin, yet somewhat higher than during the Holocene.

Pollen Zone II (ca. 21,000 to 10,400 yr B.P.). In the late Wisconsin section, dominant pollen types are spruce, sagebrush, fir, large haploxylon pine, and Chenopodiaceae–*Amaranthus*. Late in the period (after ca. 19,000 yr B.P.) pinyon pine and juniper increase. Other nonarboreal pollen types (other Compositae, Gramineae, *Am-*

TABLE 2
^{14}C Dates for Potato Lake Cores 1 and 2[a]

Core	Depth (cm)	Laboratory no.	Age (yr B.P.)
1	75–80	Beta-33179	3300 ± 90
2	25–30	Beta-53864	1430 ± 80
2	52.5–55	Beta-53865	1860 ± 90
2	72.5–75	Beta-53866	2890 ± 70
2	90–95	Beta-33180	9890 ± 240
2	450–480	Beta-28325	22420 ± 160
2	605–623	Beta-29344	21180 ± 480
2	900–925	Beta-29345	34850 ± 950
Whiteside (1965)	142–172	A-513	14400 ± 300

[a] Lake sediments comprised all dated materials.

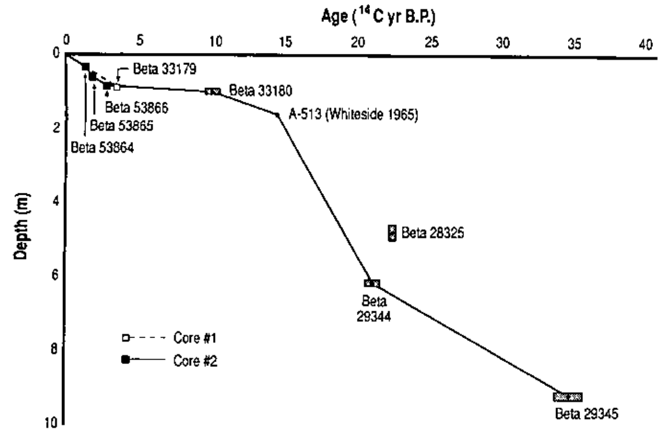

FIG. 2. Age-depth curves for the Potato Lake cores. Beta-28325 was excluded from the curve when sedimentological evidence suggested redeposition within this core section.

brosia) decline to reach their lowest percentages. Pollen concentrations are the lowest of any pollen zone. Engelmann spruce is found as a macrofossil in this zone; white fir and Douglas-fir are essentially eliminated as macrofossils in sediments <20,000 yr old (Fig. 3). The aquatic fossil record again shows low percentages of Cyperaceae and *Potamogeton* pollen, as in Zone I, but percentages of *Pediastrum* are high (Fig. 4).

Pollen Zone III (ca. 10,400 yr B.P. to present). Pollen percentages of spruce, fir, large haploxylon pine, and sagebrush decrease. The dominant pollen types are diploxylon pine, oak, grasses, and other Compositae. Macrofossils of ponderosa pine dominate the terrestrial plant assemblage. Pollen and/or macrofossils of pondweed (*Potamogeton*), brasenia (*Brasenia schreberi*), cattail (*Typha latifolia*), water plantain (*Alisma plantago-aquatica*), and sedge (Cyperaceae) are abundant.

DISCUSSION

Vegetation History Near Potato Lake

Vegetational reconstructions for Potato Lake are based on modern pollen rain studies of Hevly (1968) and the occurrence of plant macrofossils. An open forest of Engelmann spruce, white fir, and Douglas-fir, with an understory of sagebrush, grass, and composites, existed around Potato Lake during the mid-Wisconsin interstade. Macrofossil evidence suggests that this forest was probably the most diverse of any to grow around Potato Lake during the last ca. 35,000 yr. Similar plant assemblages are found today in the American Southwest ca. 800 m higher in elevation (Moir and Ludwig, 1979). Locally, today, ponderosa pine rarely grows higher than ca. 2650 m (Fig. 5). Rare populations grow as high as 2800 m, but at this elevation Engelmann spruce, white fir, and Douglas-fir are more abundant. Apparently, climatic conditions were not warm enough to allow the establishment of

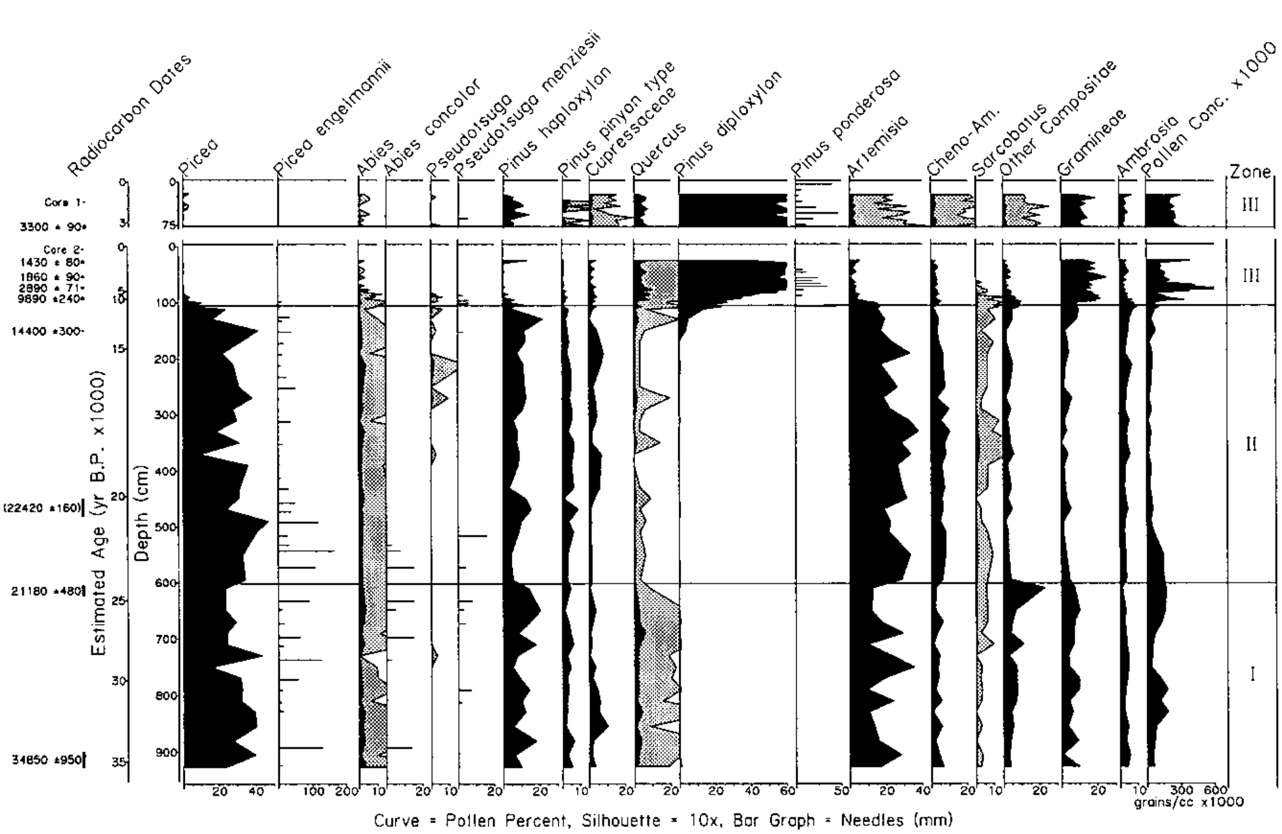

FIG. 3. Summary pollen and plant macrofossil diagrams for both short core 1 and long core 2.

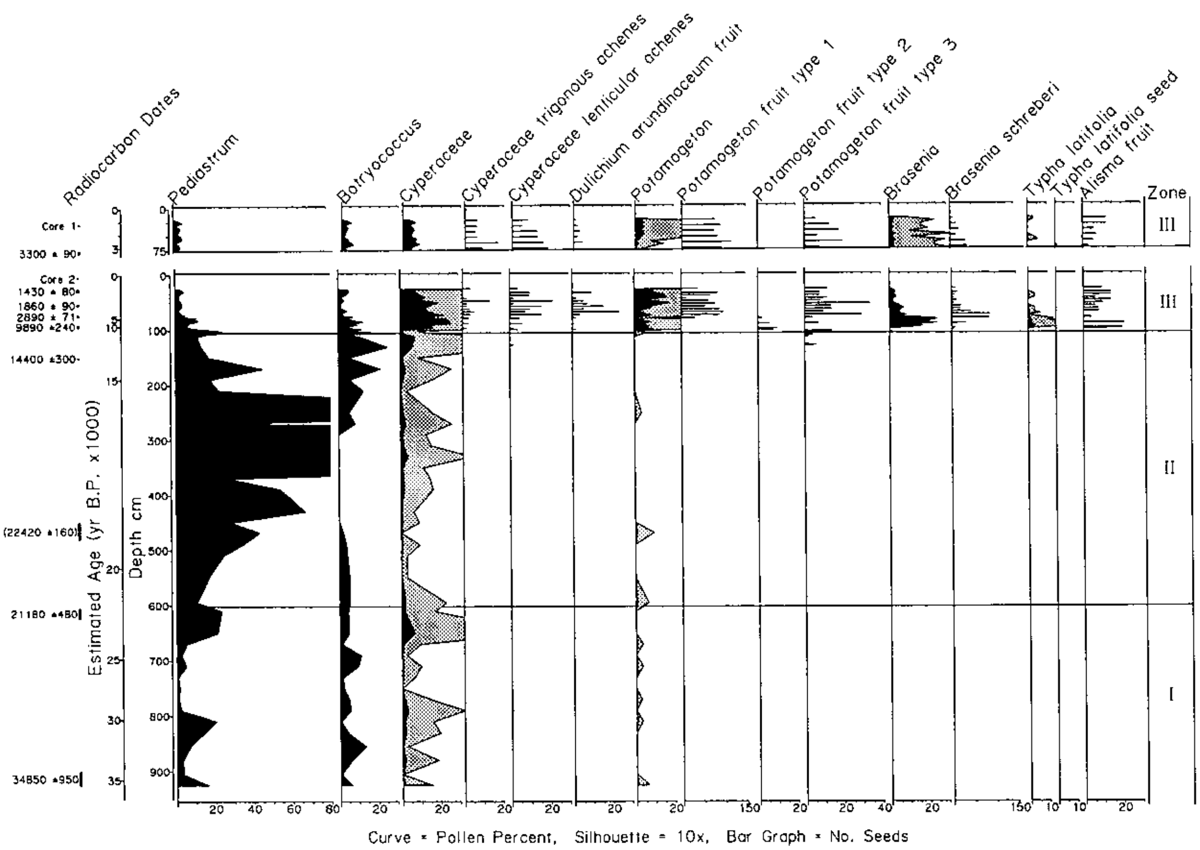

FIG. 4. Summary aquatic fossil diagrams for both short core 1 and long core 2.

ponderosa pine at this elevation. Low pollen percentages and lack of macrofossils of common aquatic plants suggest relatively high lake levels during this time. Alternatively, water temperatures may have been too cold to support extensive macrophyte populations. Whiteside (1965) interpreted higher-than-modern levels of *Pediastrum* as a function of higher lake levels. Using this criteria, the lowest lake levels during the mid-Wisconsin may date to between 25,000 and 30,000 yr ago.

During the late Wisconsin (ca. 21,000–10,400 yr B.P.), white fir and Douglas-fir were largely eliminated near the lake. A decline in nonarboreal pollen types suggests a

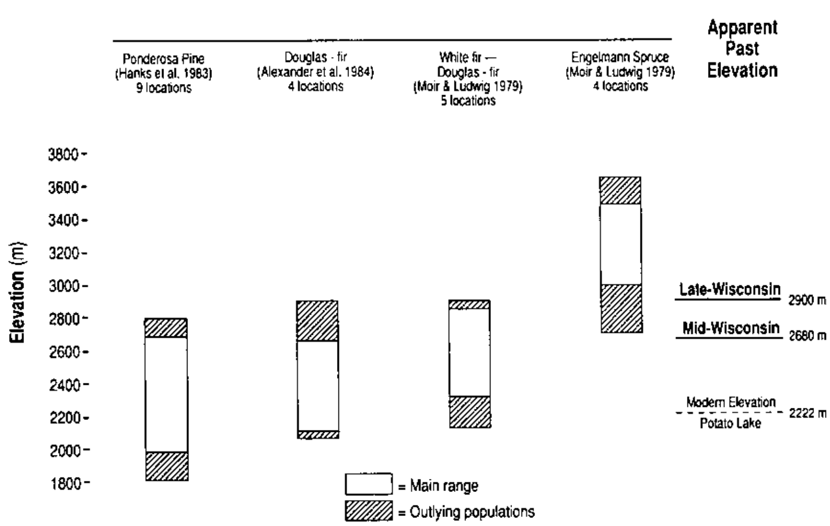

FIG. 5. Changes in apparent elevation of Potato Lake, based on the occurrence of modern vegetation and sedimentary macrofossil assemblages.

closing of the forest, which consisted predominantly of Engelmann spruce. The vegetation during the late Wisconsin reflected colder conditions than during the mid-Wisconsin. The pollen increase in Chenopodiaceae–*Amaranthus,* pinyon pine, and perhaps sagebrush could have resulted from expansion of those plants at lower elevations (see below). Aquatic fossils (low sedge and *Potamogeton* pollen) indicate that lake levels were probably at their highest during this period.

Near-modern vegetation was established ca. 10,400 yr B.P. with the immigration of ponderosa pine to the area. During the early Holocene, this forest may have been somewhat different than that of today, including a greater representation of oak. The forest may also have been more open, as evidenced by higher percentages of grasses and composites. This interpretation is similar to that of Whiteside (1965), although new radiocarbon dates suggest that Whiteside's interpretation is in need of modification (see below).

Paleoclimates Near Potato Lake

The occurrence of macrofossils within the Potato Lake core permits paleotemperatures to be estimated. Today, the nearest continuous Engelmann spruce forest grows on the San Francisco Peaks, generally above 3050 m (Moir and Ludwig, 1979; Rominger and Paulik, 1983), although isolated populations occur as low as ca. 2700 m. Mixed conifer forests including white fir and Douglas-fir are generally found below 2925 m. In northern Arizona today, a relatively narrow gradient exists where Engelmann spruce, white fir, and Douglas-fir co-occur. Based on the presence of these conifers in the mid-Wisconsin, Potato Lake had an "apparent elevation" of ca. 2680–2900 m, fully 460–675 m higher than today (Fig. 5). Considering the modern elevational distribution of Engelmann spruce, a maximum apparent elevational difference between today and the late Wisconsin of ca. 830 m is suggested.

Using the estimated modern annual lapse rate of Beschta (1976), the average annual temperature during the mid-Wisconsin was ca. 2.9–4.3°C colder than today. The temperature differences were greater in summer than in winter (Table 3). The apparent elevational difference between today and the late Wisconsin implies a lowering of average annual temperature of 5.2°C. Taking the paleotemperatures and lake level changes into account, the Potato Lake record suggests that, relative to modern conditions in this area, the mid-Wisconsin was cooler and/or wetter, while the late Wisconsin was colder and/or wetter.

Whiteside (1965) interpreted the Holocene pollen sequence at Potato Lake as indicating a general warming from the glacial period to the present. Additional radiocarbon dates from this study suggest that Holocene climates were more complex. Sediment at 90–95 cm depth with an age of 9890 yr B.P. is overlain by sediment dating to 2890 yr B.P. at 72.5–75 cm, suggesting that much of the Holocene record is missing. The general abundance of aquatic and wetland plants in the Holocene part of the core indicates much lower lake levels than during the Wisconsin, while the near cessation of sedimentation during the early and middle Holocene suggests that the lake dried out frequently during that time. An increase in effective precipitation allowed higher lake levels after ca. 3000 yr B.P.

Environmental Changes on the Colorado Plateau

Although little is known regarding mid- to late-Wisconsin vegetation and climate history of the southern Colorado Plateau, the interpretations of the Potato Lake record are consistent with other records. Spruce and fir pollen dominate mid- and late-Wisconsin spectra from Walker Lake (Fig. 1; north-central Arizona at 2700 m; Hevly, 1985). Studies of the mid-Wisconsin interval (>37,000 to ca. 26,000 yr B.P.) at Hay Lake (east-central Arizona at 2780 m; Jacobs, 1985) suggest a mixed conifer forest of Rocky Mountain bristlecone, limber, and/or southwestern white pine, pines with spruce, and either lodgepole or ponderosa pine. Mid-Wisconsin (ca. 34,000–26,000 yr B.P.) records above 2700 m in the Chuska Mountains, New Mexico (Wright *et al.*, 1973) document a spruce parkland with an understory of sagebrush, subsequently converted to alpine vegetation. Each study implies considerably colder and effectively moister condi-

TABLE 3
Estimated Differences in Temperature Since the Mid-Wisconsin

	Temperature change (°C)		
	Relative to modern		
	Mid-Wisconsin	Late Wisconsin	Late Wisconsin–mid-Wisconsin
Annual (LR = 0.63°C/100 m)	−2.9 to −4.3	−5.2	−0.9 to −2.3
Summer (LR = 0.84°C/100 m)	−3.8 to −5.7	−7.0	−1.3 to −3.2
Winter (LR = 0.46°C/100 m)	−2.1 to −3.1	−3.8	−0.7 to −1.7

Note. LR, lapse rate; summer is June, July, August, and September; winter is November, December, January, and February.

tions than those of today. These conclusions are based on a more southerly distribution of high-elevation conifers and high amounts of pinyon and ponderosa pine pollen (hypothesized as long-distance transport from a large population at lower elevation).

During the late Wisconsin, spruce increased in abundance near Hay Lake, while subalpine pines dominated the Chuska Mt. record (Wright *et al.*, 1973). Wright *et al.* (1973) considered the Chuska Mt. record to indicate a position above treeline and, thus, intensified cold. In the eastern Grand Canyon north of Potato Lake, Cole (1985) recovered spruce needles in middens as low as 2000 m, but which disappeared after ca. 12,000 yr B.P. Today the region lies within the ponderosa pine forest. Colorado blue spruce was found in mammoth dung from Bechan Cave, Utah, that dates ca. 11,850–12,400 yr B.P. (Davis *et al.*, 1984). Modern vegetation is a juniper (*Juniperus osteosperma*)–oak (*Quercus gambellii*) woodland.

Biogeographic and Paleoclimatic Implications

The occurrence of pinyon pine pollen in high-elevation records from the Wisconsin is problematic. Wright *et al.* (1973) and Jacobs (1985) considered higher percentages of pinyon pine to represent a broad distribution at low elevation. The two-needled pines (*P. edulis* and *P. remota*) occurred largely to the southeast, in west Texas (Van Devender, 1987a). There is no mid-Wisconsin record for these species near the southern Colorado Plateau. Van Devender (1990b) considered the single-needled pinyon (*P. monophylla*) to have been more widely distributed in the modern Sonoran Desert at this time. However, recent studies (Bailey 1987; LaHood and Keim, 1991) suggest that *P. edulis* var. *fallax* or *P. californiarum* var. *fallax* is a likely source of pinyon pollen. *P. edulis* remains of late-Wisconsin age were recovered from Wupatki National Monument (ca. 1630 m elevation, ca. 65 km north of Potato Lake; Cinnamon and Hevly, 1988). Van Devender (personal communication, 1992) suggests that this provides evidence for a possible mid-Wisconsin population there as well.

The occurrence of ponderosa-type pine pollen during the Wisconsin is even more problematic. Using slightly different techniques on pollen assemblages only, Wright *et al.* (1973) separated ponderosa-type from lodgepole-type pine pollen, while Jacobs (1985) lumped the two types together. Both studies suggested that during the Wisconsin ponderosa pine grew at elevations lower than the sites studied. However, late-Wisconsin macrofossils of ponderosa pine are known from only two locations in the southwest (Van Devender, 1990a,b), and mid-Wisconsin records are completely lacking. The lack of both ponderosa pollen and macrofossils at Potato Lake suggests its absence in this part of the Colorado Plateau during Wisconsin time. Migrational lag effects (Davis, 1984) may account for the absence of ponderosa pine during the mid-Wisconsin. However, very rapid expansion across the southern Colorado Plateau during the latest Wisconsin and early Holocene (Anderson, 1989) argues against this hypothesis.

The timing and direction of Holocene paleoclimatic change in the American Southwest has generated considerable controversy. Shafer (1989) and Davis and Shafer (1992) suggested an early Holocene monsoonal maximum for northern Arizona and areas to the north and west, with driest conditions (lower lake levels) occurring ca. 7000–4000 yr B.P. Walker Lake (Hevly, 1985) also dried completely at ca. 6000 yr B.P. In contrast, Martin (1963) and Van Devender (1987b, 1990) believed that monsoonal conditions in southern Arizona reached maximum development during the mid-Holocene. Although an early Holocene monsoonal maximum cannot be confirmed from the Potato Lake record, the virtual absence of sediment at Potato Lake during the early and middle Holocene suggests that dry conditions persisted there from the early Holocene until ca. 3000 yr ago.

CONCLUSIONS

Analysis of pollen and plant macrofossils from Potato Lake extends the paleovegetation record for the southern Colorado Plateau back to ca. 35,000 yr B.P. Plant macrofossils suggest that the mid-Wisconsin interstade was ca. 0.9–2.3°C warmer than the late Wisconsin, and yet 2.9–4.3°C colder than today. Summer temperatures were as much as 5.2°C colder. The lowered summer temperature may explain why ponderosa pine has not been recovered from mid-Wisconsin deposits on the southern Colorado Plateau, and was apparently confined to enclaves at lower elevations to the south and perhaps to the east (Betancourt *et al.*, 1990).

The Holocene climatic record from Potato Lake, including a dry mid-Holocene, is similar to those from Montezuma Well (Davis and Shafer, 1992) and sites farther north and west. Sites from lower elevations in the modern Sonoran Desert apparently do not fit this pattern. The reason for this discrepancy is not clear, but further study at sites in central Arizona may illuminate the nature of a paleoclimatic tension zone for the region.

Although the pollen stratigraphies of Whiteside (1965) and this study are nearly identical for the overlapping time periods, interpretations differ slightly between the two studies, particularly with respect to the mid-Holocene. Radiocarbon dates obtained for this study demonstrate a Holocene disconformity not recognized in the earlier study. Contrary to Whiteside's (1965) interpretation of Holocene stability, this study demonstrates a major dry period during the mid-Holocene. In addition, differentiation of pines, firs, and spruces has allowed a more detailed picture of vegetation change to emerge.

This is a powerful argument for reinvestigation of certain key sites, using the newer tools available to paleoecologists.

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