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Grassland Vegetation in the Southern Great Plains during the Last Glacial Maximum

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New pollen records from White Lake in the Southern High Plains and from Friesenhahn Cave on the southeastern Edwards Plateau of Texas indicate that the glacial-age vegetation of the southern Great Plains was a grassland. The High Plains was a treeless *Artemisia* grassland and the Edwards Plateau, at the south edge of the Great Plains, was a grassland with pinyon pines and deciduous trees in canyons and riparian habitats. The glacial-age grasslands differ from modern shortgrass and tallgrass prairies and may have no modern analog. The dominance of prairie vegetation during the last glacial maximum is compatible with late Pleistocene mammalian faunas and late-glacial grassland pollen records from the region. Earlier interpretations of a pine-spruce forest on the High Plains were based on pollen assemblages that are here shown to have been altered by postdepositional deterioration, resulting in differential preservation of conifer pollen grains. Accordingly, the "Tahoka Pluvial" and other "climatic episodes" defined by High Plains pollen records are abandoned. ©1995 University of Washington.

INTRODUCTION

The late Quaternary biogeography of the southern Great Plains was an early topic of discussion concerning the extent of tree expansion westward from the eastern United States deciduous forest and eastward from the Rocky Mountains into the prairies, and the influence of the grasslands as a barrier to faunal migrations. Analysis of a core from Patschke Bog, Lee Co., Texas, the first pollen study of glacial-age deposits in the region, showed the presence of spruce and fir (Potzger and Tharp, 1947). Subsequently, the analysis of other Texas bogs failed to replicate the presence of fir but confirmed the presence of low percentages of spruce pollen (reviewed by Bryant and Holloway, 1985). Basal sediments at Patschke and nearby Boriack Bog contain glacial-age pollen assemblages with moderately high percentages of grass and composites and small amounts of oak and pine pollen, indicating a grassland with scattered or distant tree populations (Bryant, 1977; Camper, 1991).

Another series of early pollen studies focused on late Pleistocene lake beds in the Southern High Plains, where high percentages of pine and spruce pollen were interpreted as a late Wisconsin pine-spruce forest (Hafsten, 1961; Oldfield, 1975). These pollen records from Texas bogs and High Plains paleolakes suggested to many reviewers that the southern Great Plains was forested and that grassland vegetation was absent during the late Pleistocene. In contrast, fossil vertebrate records from the region are compatible with prairie vegetation (Graham, 1987). A reevaluation of the White Lake pollen record and development of the new Friesenhahn Cave record were undertaken to examine the issue of whether the southern Great Plains was dominated by forest or grassland during the late Wisconsin Glaciation.

STUDY SITES AND METHODS

Southern High Plains: White Lake and the "Tahoka Pluvial"

The modern vegetation of the Southern High Plains (Llano Estacado) of Texas and adjacent New Mexico is a shortgrass prairie dominated by blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchloe dactyloides*) with small patches of mesquite shrub (*Prosopis glandulosa*) in broken terrain (Frye *et al.*, 1984; McMahan *et al.*, 1984). Annual precipitation is generally 350 to 450 mm, much of it falling from convectional thunderstorms in the summer. Most of the shortgrass prairies in the Texas South Plains were destroyed by farming activity in this century, although some enclaves of native prairies are preserved, such as White Lake at Muleshoe National Wildlife Refuge in Bailey Co., Texas (Fig. 1).

During the Wisconsin Glaciation, a number of large lakes occupied deep basins on the Southern High Plains. Lacustrine clays that accumulated in the glacial-age lakes were named the Tahoka Formation (Evans and Meade, 1945). Pollen analysis of several localities of the Tahoka clays, begun in 1958 by U. Hafsten, revealed a zone of very high percentages of *Pinus* and some *Picea* pollen. The *Pinus-Picea* zone, Hafsten's pollen

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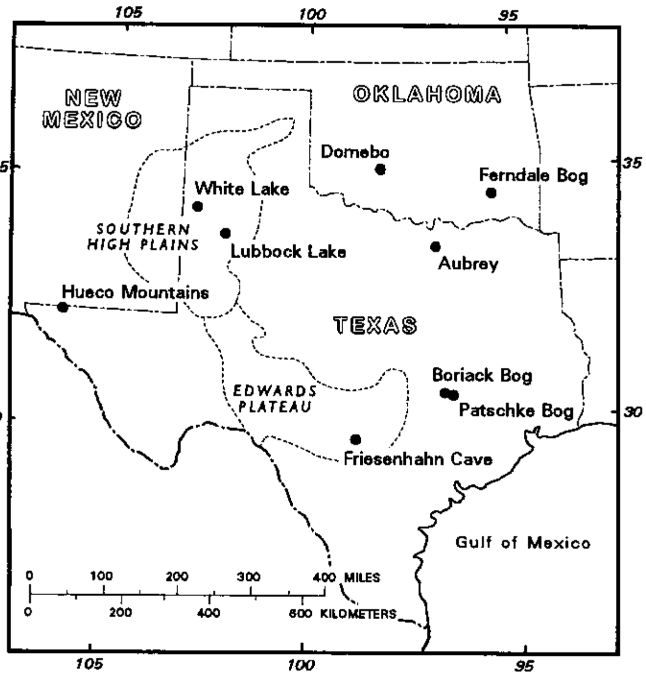

FIG. 1. Map showing glacial-age and late-glacial pollen sites in the southern Great Plains mentioned in text; the Southern High Plains and Edwards Plateau physiographic regions form the southwestern margin of the Great Plains Province.

Zone C, was interpreted as a pine-spruce forest which he called the "Wisconsin Pluvial" and correlated with the Wisconsin Glaciation (Hafsten, 1961, p. 90; Hafsten, 1964). The period of cool, moist climate represented by the *Pinus-Picea* zone in the upper part of the thick sequences of lacustrine clays was also called the "Tahoka Pluvial" (Wendorf, 1961a, p. 130). Further pollen studies of High Plains lake-basin deposits, including White Lake, extended the number of Tahoka Formation localities with zones of high percentages of *Pinus* pollen, leading Oldfield and Schoenwetter (1964, 1975) to conclude, as did Hafsten, that a pine or pine-spruce forest was present in the Southern High Plains during the last glacial maximum. At the time, however, Hafsten discussed problems with his interpretation of a pine forest on the High Plains, pointing out the small amount of pollen from herbaceous ground plants and the absence of a late Pleistocene soil characteristic of conifer forest vegetation (Hafsten, 1961, p. 84). The absence of a forest soil is discussed also by Holliday (1987) who concluded that the High Plains had not been forested.

In a reevaluation of the conifer forest and Tahoka Pluvial interval, new material for pollen analysis and radiocarbon dating was collected from lacustrine clays at White Lake. This section, including the eolian dunes above the lake beds, is the longest pollen record from the High Plains. The occasionally dry lake bed, with a diameter of about 1 km, is one of three remnants of a larger late Pleistocene lake that occupied a 32-km^2 basin, the floor of which extends to 60 m below the High Plains surface, cutting through the Blackwater Draw and Ogallala formations. The stratigraphy of late-Quaternary deposits exposed along the eastern shore of the lake consists of 7 m of calcareous, laminated, gypsiferous, silty lacustrine clay overlain by 6 m of eolian sandy, silty clay dunes (Harbour, 1975). In the earlier study, a 15.8-m section from the NE corner of White Lake was collected by F. Oldfield, who found a zone of high *Pinus* pollen percentages that he correlated with the Tahoka Pluvial (Oldfield, 1975, p. 124).

Samples of Tahoka clay were collected at White Lake for radiocarbon dating. In the field, about 10 to 15 kg of humus-bearing clays were excavated from the pollen section at White Lake, preceded by the removal of about 0.5 m of surface clay at the outcrop in order to exclude weathered material from the radiocarbon sample. The clays for dating were collected immediately below each of the two dolomite beds occurring in the lacustrine sequence. The two dolomites are also dated (Table 1).

Radiocarbon dates of humus are obtained through a labor-intense pretreatment procedure at the University of Texas Radiocarbon Laboratory. The humus-bearing clays are washed through a 100-mesh screen, and the fraction larger than 149 μm is discarded. The fine fraction is washed separately in HCl

TABLE 1
Radiocarbon Ages from White Lake and Friesenhahn Cave

Laboratory number	δ (^{13}C)	Age[a] (^{14}C yr B.P.)	Material dated	Stratigraphy
White Lake				
I-11,269	—	18,660 ± 340	Carbonate	995–1005 cm, upper dolomite
Tx-7055	−21.3	17,710 ± 410	Humus	1010–1020 cm, silty clay just below upper dolomite
I-11,515	—	24,060 ± 640	Carbonate	1210–1220 cm, lower dolomite
Tx-7056	−21.7	19,760 ± 860	Humus	1230–1240 cm, sandy clay beneath lower dolomite
Friesenhahn Cave[b]				
Tx-2395	—	19,600 ± 710	Mammoth bone apatite	Unit 3A
	—	14,020 ± 3010	Collagen	
Tx-2393	—	17,800 ± 880	Mammoth bone apatite	Unit 3B
	—	18,720 ± 4340	Collagen	

[a] Radiocarbon dates based on Libby half-life, 5570 ± 30 yr; dates from the University of Texas Radiocarbon Laboratory are corrected for ^{13}C fractionation.
[b] Selected radiocarbon dates from Graham (1987).

to remove carbonates and in NaOH to remove the soluble humic-acid fraction; the remaining organic residue is radiocarbon dated (White and Valastro, 1984). Palynologic analysis shows that pollen grains, algal colonies, and charcoal are 63,000 and 81,100 particles per gram of the younger and older radiocarbon-dated matrix, respectively, even though in both cases the organic-matter content is <1% (Table 2).

Edwards Plateau of Central Texas: Friesenhahn Cave

The Edwards Plateau is a broad upland surface formed by a thick sequence of Lower Cretaceous limestones with numerous caves, many with deposits containing Pleistocene vertebrates (Lundelius, 1967). The plateau today is characterized by thin, eroded, rocky soils. It receives more than 800 mm of annual rainfall in the east and less than 400 mm in the west. The modern vegetation is an evergreen live oak/ashe juniper (*Quercus virginiana/Juniperus ashei*) parkland with increased mesquite (*Prosopis glandulosa*) in the drier western half of the plateau, where oaks drop out and the vegetation becomes a mesquite-juniper shrubland. The southeastern edge of the plateau has been dissected by streams, with substantial arboreal riparian vegetation in deep limestone valleys and live oak/ashe juniper woodland in the uplands (Frye *et al.*, 1984; McMahan *et al.*, 1984; Van Auken *et al.*, 1979; Van Auken, 1988).

Friesenhahn Cave is located in northern Bexar Co., central Texas, on the southeastern edge of the Edwards Plateau, north of San Antonio (Fig. 1). Since its discovery and initial investigation, Friesenhahn has been regarded as having one of the most important late Pleistocene vertebrate faunas in the region (Evans, 1961). Sedimentation in the cave during the late Pleistocene and early Holocene resulted in extensive lacustrine, fluvial, and travertine deposits. Two lacustrine deposits, a gray clay and a red clay, accumulated during the late Wisconsin. Both contain numerous vertebrate remains, including more than 40 mammalian taxa, with reptiles, amphibians, and birds (Graham, 1976, 1987), and abundant pollen. Pollen samples were collected by R. W. Graham from the late Pleistocene lacustrine gray and red clays and the overlying early Holocene "red fill" and historic "black fill" units during excavations of the deposits for fossil vertebrates. Friesenhahn is the first glacial-age cave in the region to yield vertebrates and pollen.

PALYNOLOGY LABORATORY METHODS

The pollen samples from White Lake and Friesenhahn Cave were processed similarly. Each sample, about 25 to 45 g, was oven-dried at 50°C, weighed to the nearest 0.1 g and treated to a succession of acid washes; HCl, HF, and hot HCl. The remaining sediment was centrifuged for 8 min in heavy liquid ($ZnCl_2$) with a sg of 1.98; the floatant was acetolyzed for 4 min and stained with safranin O. At the initial HCl wash, 4 *Lycopodium* spore tablets (11,267 ± 370 spores per tablet; batch 201890) were added to each sample. *Lycopodium* spike grains were tabulated along with fossil pollen, algae, and charcoal.

CHRONOLOGY

White Lake

The previous chronology and correlation of the Tahoka Formation and the Tahoka Pluvial were based on radiocarbon dates of freshwater carbonates and on a presumed correspondence of the *Pinus-Picea* pollen zone to the late Wisconsin Glaciation (Wendorf, 1961a, 1975; Reeves, 1976). In the present study at White Lake, two radiocarbon dates for solid organic matter from silty and sandy laminated lacustrine clays, 17,710 ± 410 yr B.P. and 19,760 ± 860 yr B.P. (Table 1), are the first direct dates for organic carbon from the Tahoka Formation. While the radiocarbon dates from the upper dolomite and associated humus are similar, the lower dolomite date is 4300 yr older than the date for associated humus, illustrating the problem of obtaining reliable dates of inorganic carbon. The successful dating of lacustrine clays from White Lake opens new possibilities for expanded geochronologic investigations of other Wisconsinan paleolakes and has already produced stratigraphically consistent dates from late-Quaternary alluvium in the southern Great Plains (Blum and Valastro, 1989, 1992; Blum *et al.*, 1994).

Friesenhahn Cave

The chronology of the stratigraphic units at Friesenhahn Cave was derived by the radiocarbon dating of apatite and collagen from mammoth and rodent bone (Graham, 1976, 1987). The gray clay and red clay are the oldest units with pollen. Dates for mammoth bone from these sediments range from 19,600 ± 710 to 14,020 ± 3010 yr B.P. (Graham, 1987) (Table 1). While some younger bone dates are inconsistent, the older dates are from the lower stratigraphic units containing extinct taxa, placing the gray and red clays firmly in the late Pleistocene and correlative with the late Wisconsin Glaciation.

TABLE 2
Humus from Radiocarbon-Dated Clay at White Lake

Laboratory number	Total pollen concentration (per gram)	Algal colony concentration (per gram)	Charcoal concentration[a] (per gram)	Organic matter (%)
Tx-7055	51,400	6220	5390	0.75
Tx-7056	11,400	32,200	37,500	0.30

[a] Charcoal fragments, long axis >25 μm.

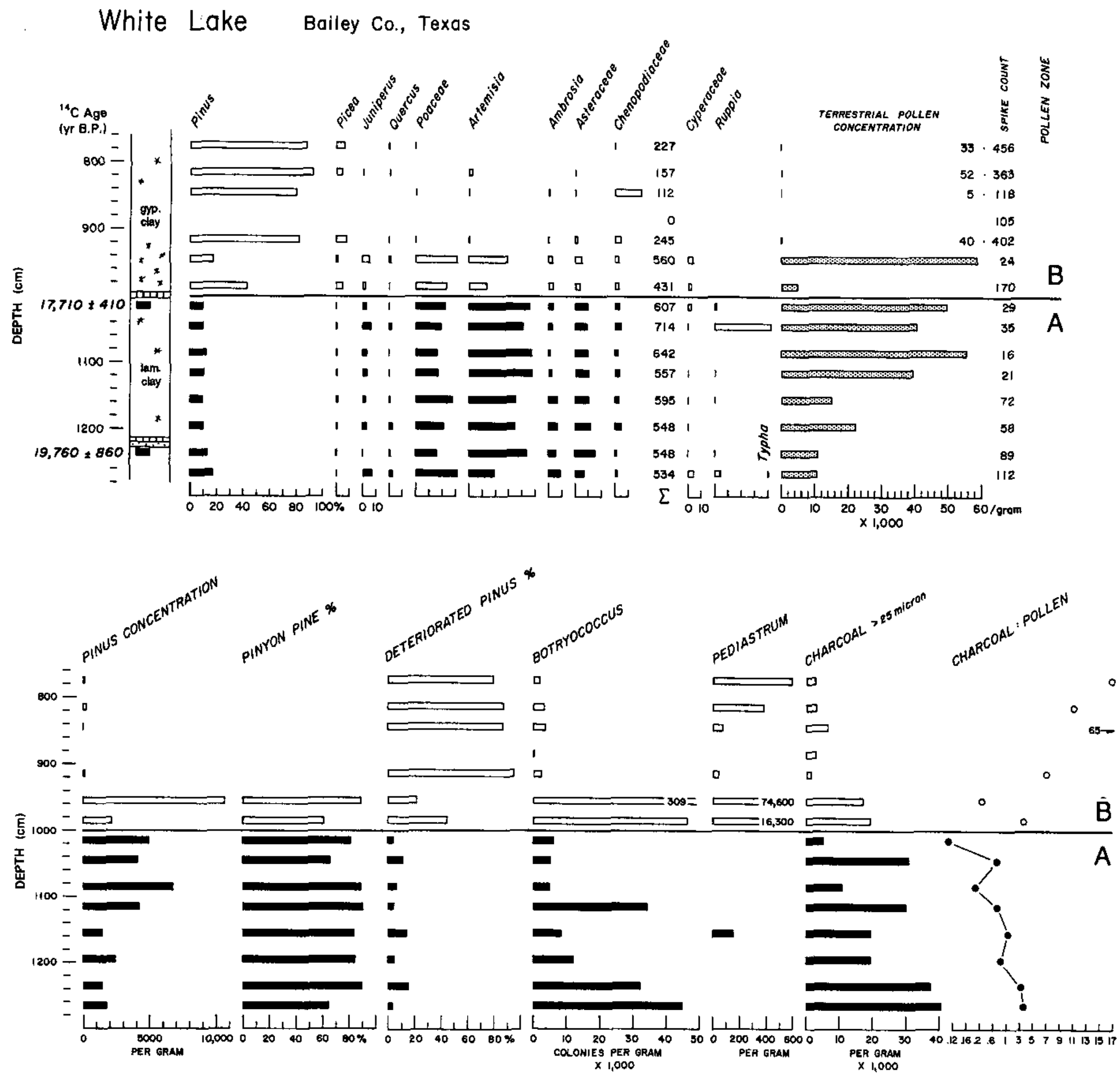

FIG. 2. Pollen diagram from White Lake. Pollen concentrations of upper five samples based on spike counts and pollen-count numbers to left of spike counts. Deteriorated *Pinus* pollen exines in the upper three samples of zone B are mostly corroded and in the lower three samples they are degraded with loss of cellulose. The small number of deteriorated *Pinus* grains in zone A are corroded. *Pinus* pollen differentiation above 920 cm was not attempted. Charcoal counts and concentration are based on particles >25 μm, long axis. The charcoal–pollen ratio is charcoal concentration/terrestrial pollen concentration.

RESULTS OF POLLEN ANALYSIS

White Lake

The White Lake pollen diagram is divided into pollen zones A and B. Zone A is characterized by 39% *Artemisia,* 21% Poaceae, 12% *Pinus,* 10% Asteraceae, 5% *Ambrosia,* 3% Chenopodiaceae, 4% *Juniperus,* 1% *Quercus,* and 1.7% *Picea.* Rare occurrences (<0.5%) of other pollen taxa include *Alnus, Populus, Fraximus, Corylus, Celtis, Cirsium, Franseria,* Liguliflorae, *Eriogonum,* Apiaceae, Brassicaceae, *Sarcobatus,* Amaranthaceae, Onagraceae, *Yucca,* Cactaceae, and Campanulaceae; "indeterminable" and "unknown" categories are each <1%. Pollen from wet-ground or aquatic plants include Cyperaceae, *Ruppia, Typha latifolia,* and colonies of freshwater algae, *Botryococcus* and *Pediastrum.* Pollen grain abundance and preservation in zone A are excellent (Fig. 2).

Although pollen percentages from this reanalysis at White

Lake match those reported by Oldfield, pollen-concentration and pollen-preservation determinations, not made previously, show that zone B, with high *Pinus* pollen percentages, is characterized by low total pollen concentrations, ranging from <19 to 265 grains per gram. Conversely, the underlying zone A of low *Pinus* percentages has high pollen concentrations, ranging from 10,600 to 56,000 grains per gram, excluding two transition spectra. The incidence of deteriorated *Pinus* pollen shows a similar dichotomy. The zone of high *Pinus* percentages is also characterized by high percentages of deteriorated *Pinus* pollen grains, ranging from 80 to 98%; in contrast, the deteriorated *Pinus* grains in the underlying interval range from only 2 to 16% (Fig. 2). Based on these findings, the White Lake pollen sequence is reinterpreted as a record of differential pollen preservation, in which *Pinus* pollen grains were preferentially preserved while nonconifer grains were preferentially destroyed, resulting in artificially high percentages of *Pinus* pollen.

Conifer pollen grains contain higher amounts of sporopollenin in their exines than do grains from other plant taxa; as a result, *Pinus* and *Picea* pollen are less susceptible to deterioration (Stanley and Linskens, 1974; Rowley and Prijanto, 1977). Criteria for evaluating the reliability of pollen assemblages have been suggested from other studies and include (a) pollen concentration per unit of sediment processed, (b) abundance of indeterminable grains, i.e., pollen that cannot be identified owing to poor preservation, (c) number of deteriorated grains (e.g., corroded, degraded) in an assemblage, and (d) number of pollen taxa present in an assemblage (Hall, 1981; Bryant and Hall, 1993).

Friesenhahn Cave

Pollen assemblages from the Pleistocene lacustrine units are dominated by 19% Asteraceae, 18% Poaceae, 16% *Pinus*, 15% *Ambrosia*, 7% *Juniperus*, 5% Chenopodiaceae, 4% Liguliflorae, 3% *Quercus*, 2% *Artemisia*, and 1% *Picea* (Fig. 3). Pollen preservation in the lacustrine clay is moderately good, and pollen concentration ranges from 2300 to 9700 grains per gram of dry sediment (Fig. 4). The 1% *Picea* pollen at Friesenhahn parallels other glacial-age and late-glacial records from the Southern Great Plains. The presence of Cyperaceae pollen and fern spores indicates a moist local habitat at the cave. The 30% *Quercus* in the two upper samples from the early Holocene "red fill" and modern "black fill" at Friesenhahn Cave suggests that oaks were established on the Edwards Plateau in the early Holocene (Shaw *et al.*, 1980).

DISCUSSION

Comparison of White Lake zone A spectra with pollen percentage data from the modern shortgrass and tallgrass prairies provides some insight into the character of the grassland vegetation on the High Plains at the last glacial maximum (Hall, 1990, 1992, 1994) (Fig. 5). Glacial-age zone A pollen assemblages have more *Artemisia* and Asteraceae and less *Ambrosia, Juniperus,* and *Quercus* than modern prairies. Although it may not have an exact counterpart today, the Southern High Plains vegetation during the last glacial maximum is interpreted as an *Artemisia* grassland.

At Friesenhahn Cave, the late Pleistocene pollen percentages of Poaceae, all Asteraceae (excluding *Artemisia*), and Chenopodiaceae together (PAC) average 64%. Regional pollen-trap data show that PAC average 47% from the modern shortgrass prairies and 38% from the modern tallgrass prairies (Hall, 1994). High percentages of PAC and low amounts of tree pollen indicate that the vegetation of the eastern Edwards Plateau was a grassland during the last glacial maximum. Although the glacial-age grassland of central Texas shares some pollen characteristics with shortgrass prairies (percentage of Poaceae and *Ambrosia*) and tallgrass prairies (percentage of Chenopodiaceae), the Edwards Plateau grassland was very different from modern prairies.

Pinus pollen from the glacial-age sites, ranging from 10 to 17% at White Lake and 7 to 34% at Friesenhahn Cave, is almost entirely pinyon pine (based on criteria in Hansen and Cushing, 1973). Today, the Texas papershell pinyon (*Pinus remota*) is the most abundant pine on the western Edwards Plateau and in Trans-Pecos Texas (Powell, 1988). Woodrat-midden studies show that the range of *P. remota* was expanded during the last glaciation into the Hueco Mountains and other ranges in the northern Chihuahuan Desert (Van Devender,

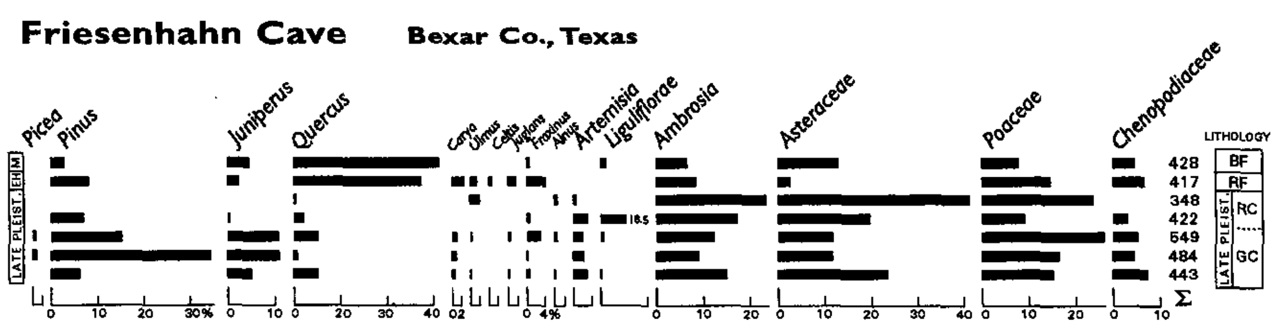

FIG. 3. Pollen diagram from Friesenhahn Cave, Bexar Co., Texas. The lower five samples are from late Pleistocene gray clay (GC) and red clay (RC); the next-to-uppermost sample is early Holocene red fill (RF), and the uppermost sample is modern black fill (BF).

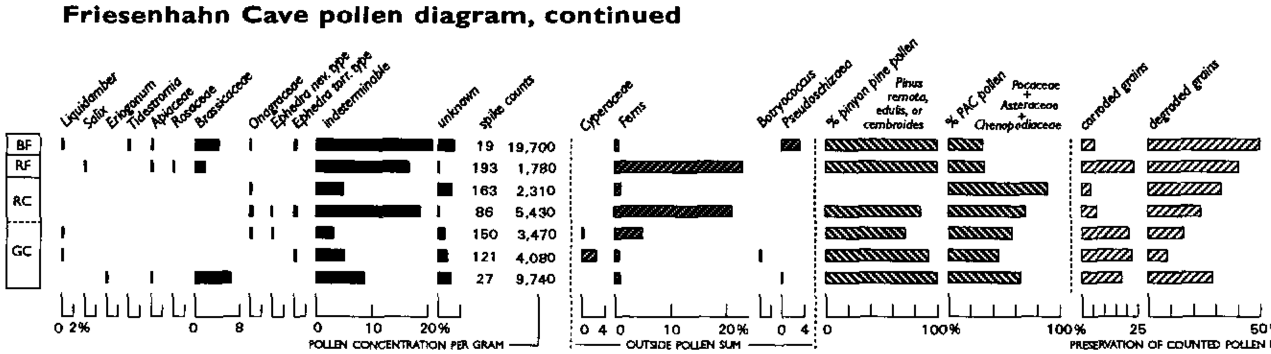

FIG. 4. Additional pollen data from Friesenhahn Cave. The "indeterminable" category refers to grains that cannot be identified because of poor preservation. *Pseudoschizaea* is a problematic organism, possibly soil algae. The percentages of pinyon pine are based on all identifiable pine grains. Percentages of corroded and degraded grains are based on all pollen grains inside the pollen sum (Σ), including the indeterminable grains.

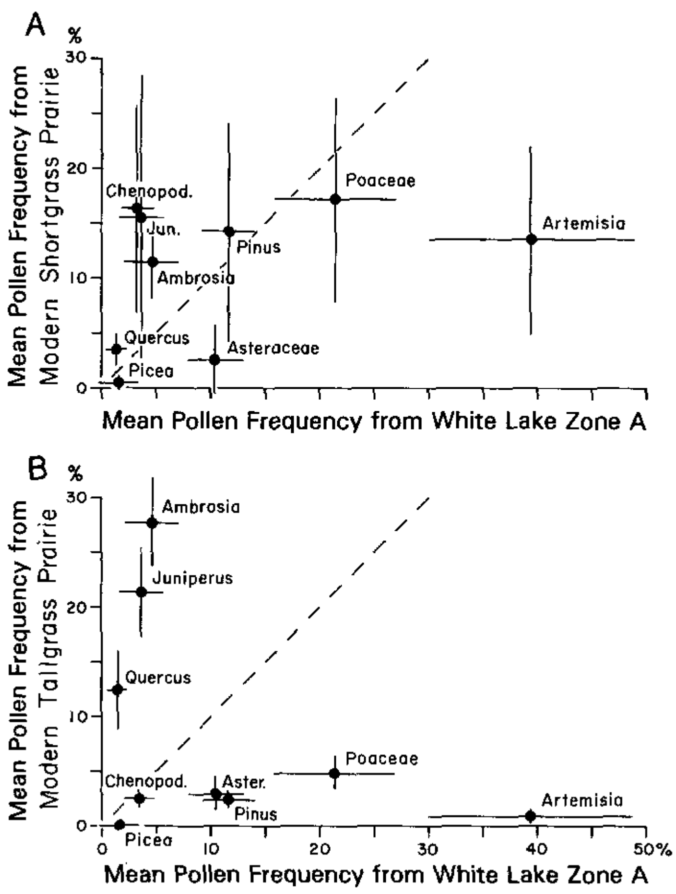

FIG. 5. Percentages of pollen from glacial-age pollen zone A, White Lake, compared with percentages of pollen from (A) modern shortgrass and (B) modern tallgrass prairies; bars = 1 SD. Averaged shortgrass prairie pollen data for 2 yr is from 10 Tauber trap stations (#4–13), northeastern New Mexico (Hall, 1990). Averaged tallgrass pollen data for 1 yr is from 9 Tauber traps, north-central Texas (Hall, 1992, 1994). Dashed line is 1:1 ratio of modern and glacial-age pollen percentages. *Artemisia* grassland pollen assemblages from the last glacial maximum (White Lake, pollen zone A) differ from both modern shortgrass and modern tallgrass prairie pollen assemblages.

1986). The pollen grains of different species of pinyon cannot be distinguished, and other pinyons (*P. edulis, P. cembroides*) could have expanded their populations as well; however, the 34% *Pinus* in one spectrum at Friesenhahn suggests some type of pinyon-pine component in the local grassland vegetation. The *Juniperus* and *Quercus* glacial-age pollen percentages, including *Pinus* at White Lake, are in the low range of these taxa in the modern shortgrass prairies where the tree-pollen grains originate by long-distance transport from montane forests or small isolated populations in the grasslands. At Friesenhahn, other tree taxa, *Carya, Fraximus, Ulmus, Juglans, Liquidamber,* and *Alnus,* together are no more than 6% of the glacial-age pollen assemblages and may represent nearby riparian vegetation in deeply eroded limestone valleys along the south and eastern escarpment of the Edwards Plateau.

Picea is a persistent component of White Lake, Friesenhahn, Aubrey, Domebo, and other late Pleistocene pollen assemblages in the southern Great Plains and, because *Picea* pollen today is dispersed in only small amounts within short distances of spruce tree populations, the presence of *Picea* pollen was previously cited as evidence for spruce trees on the High Plains (Wendorf, 1961a, p. 126, 127). A resolution of the issue of whether or not spruce occupied the southern Great Plains is uncertain at this time. Even though spruce trees were present in the Rocky Mountains, Central Plains, and lower Mississippi River Valley, it is not known how far east, south, or west spruce trees may have migrated into the Texas plains. The low amounts of *Picea* pollen may be the result of spruce populations surrounding the southern Great Plains during a period of time when pollen-carrying winds were stronger than today; an alternative hypothesis, more difficult to justify, would be spruce trees producing more pollen during the late Pleistocene than they do today.

Both White Lake and Friesenhahn Cave are isolated sites with chronologically brief records. When other studies are complete, further details on vegetational history are likely. Even so, the High Plains pollen sequences at Rich Lake, Tahoka Lake, Crane Lake, Illusion Lake, and Vigo Park (Hafsten, 1961; Oldfield, 1975) mimic the sequence reported from

White Lake and are likely products of differential pollen preservation as well.

Late-Glacial Pollen Records

Owing to erosional unconformities, glacial-age and late-glacial records in the region are seldom continuous. As a result, late-glacial pollen records are often found at the base of thick sequences of sediments, the upper portions of the same sequences generally lacking pollen. Three late-glacial pollen records indicate prairie vegetation: Domebo Site, dated about 10,100 to 11,000 yr B.P. (Wilson, 1966); Aubrey Site spring deposits, dated 13,300 to 14,200 yr B.P. (Hall, 1991); Ferndale Bog, with a basal date of 11,800 yr B.P. (Bryant and Holloway, 1985) (Fig. 1).

Studies of late-glacial deposits at the Lubbock Lake Site have produced pollen, as well as differences of opinion on how to interpret it (Bryant and Schoenwetter, 1987). New data from both outcrop and core samples of Lubbock Lake diatomite dated 10,000 to 11,000 yr B.P. show the presence of poorly preserved pollen in very low concentrations (Fig. 6). The pollen percentages are regarded as unsuitable for use in interpreting past vegetation.

Late Pleistocene Vertebrate and Land Snail Faunas

The earlier view of a Tahoka Pluvial conifer forest vegetation conflicted with the fossil vertebrate evidence from the region. Glacial-age and late-glacial mammalian faunas from the southern Great Plains are composed of extinct as well as extant species found in grassland and riparian habitats (Harris, 1977, reevaluates the Clovis site tree squirrels and other fossil vertebrates reported by Slaughter, 1975; Graham, 1976, 1987; Dalquest and Schultz, 1992; Toomey, 1989, 1993; and Toomey *et al.*, 1993). Because many of the late Pleistocene species are today allopatric, it has been concluded that the glacial-age climate in the southern Great Plains was cooler and moister, with reduced seasonal temperature extremes, although it is not known from the faunal (or floral) record whether precipitation had an even or a strongly seasonal distribution (Hibbard, 1960; Graham, 1987; Graham and Mead, 1987; Graham and Lundelius, 1984).

Previous studies of Southern High Plains paleoenvironments included the analysis of several collections of late Pleistocene mollusks, with some species of land snails that occur commonly in the damp litter of wooded habitats cited as supporting evidence for a conifer forest vegetation (Wendorf, 1961b; Drake, 1975). The forest species reported from the glacial-age and late-glacial faunules are *Discus cronkhitei, Helicodiscus parallelus, Pupilla muscorum, P. blandi, Zonitoides arboreus,* and *Euconulus fulvus.* Subsequently, living populations of *H. parallelus* and *Z. arboreus* have been reported from the Texas Panhandle where mesic-adapted species of land snails occur both on treeless damp-soil floodplains and under litter in stands of plains cottonwood trees (Neck, 1990). Small populations of *D. cronkhitei* and *P. muscorum* have been discovered in the northwestern Oklahoma Panhandle (Metcalf, 1984). *P. blandi* has been reported from moist habitats along streams in the western Great Plains grassland of northeastern New Mexico (Ashbaugh and Metcalf, 1986). *E. fulvus* has not been found alive in the southern Great Plains although it persisted from the late Pleistocene to the middle Holocene, when it disappeared from the Texas grasslands (Neck, 1987). All of the above species occur in numerous glacial-age and late-glacial faunules in the southern Great Plains (Miller, 1975), including the Domebo site where pollen data indicate grassland vegetation (Wilson, 1966). Given the new modern grassland records of these land snails that traditionally were believed restricted to forest habitats, and the likelihood that late Pleistocene climates in the Great Plains were cooler and moister than today, the land snail record from Tahoka-correlated deposits cannot be regarded as evidence supporting the interpretation of a conifer forest vegetation.

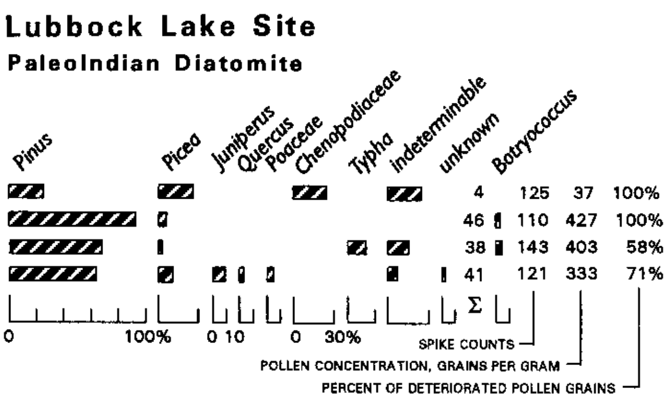

FIG. 6. Pollen from diatomite at Lubbock Lake Site, Lubbock Cty., Texas. Diatomite designated unit 2A and radiocarbon dated about 11,000 to 10,000 yr B.P. was reported in Holliday (1985). The upper two samples are from outcrops (collected by S. Hall and V. Holliday), the lower two samples are from a core (provided by V. Holliday). The high percentages of *Pinus* and *Picea* are a result of differential preservation of conifer pollen grains and loss of non-conifer pollen. The samples here are processed in the same manner as described for White Lake and Friesenhahn Cave.

SUMMARY AND CONCLUSIONS

The glacial-age pollen records from White Lake and Friesenhahn Cave indicate a grassland vegetation in the southern Great Plains. The High Plains region of West Texas was an *Artemisia* grassland with comparatively high amounts of composites; the Edwards Plateau of central Texas was also a grassland with high amounts of composites, but without *Artemisia.* Both the High Plains and Edwards Plateau had less tree pollen (*Pinus, Juniperus, Quercus*) than modern shortgrass and tallgrass prairies, although the Edwards Plateau may have had small populations of pinyon pine and deciduous taxa (hickory, ash, elm, walnut, alder, liquidamber) in riparian and canyon habitats. The new pollen information and its interpretation are compatible with the paleoecology of late Pleistocene mammalian faunas and match regional late-glacial grassland pollen records. However, the glacial-age pollen assemblages do not correspond exactly to those of modern shortgrass or tallgrass prairies, suggesting that the Late Wisconsin prairies may have been a mixture of grass and herb species that do not have a modern analog.

The interpretation of a climate supporting pine-spruce boreal forest on the High Plains, formerly called the "Tahoka Pluvial," was based on pollen assemblages that had been altered by post-depositional deterioration, resulting in differential preservation of conifer pollen and destruction of nonconifer pollen grains. Other lesser known "pollen analytical episodes" or "climatic episodes" described from the High Plains were also based on pollen spectra that may have undergone various degrees of postdepositional alteration and, consequently, require reexamination. Holliday (1987) reached a similar conclusion based on the absence of conifer-forest soils in the High Plains.

The nature of the glacial-age *Artemisia* grassland in the southern High Plains and the treeless prairie in the Edwards Plateau, whether shortgrass, mixed grass, or tallgrass prairie, is undetermined. Given a more equable but cooler and moister climate, as indicated by mammalian faunas in the southern Great Plains, the glacial-age herbaceous prairie communities may have been composed of some assortment of species that differ from present-day prairie floras. Because the glacial-age pollen records diverge from the modern grasslands, there is a strong possibility that the Late Wisconsinan prairies of the southern Great Plains may not have a modern analog. The cool, wet Great Plains grassland, along with its mammalian communities, may represent a unique grassland biome during the last glacial maximum, complementing the drier and colder Mammoth Steppe of the far north (Guthrie, 1990).

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