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PALEOENVIRONMENTAL REASSESSMENT OF THE 1.6-MILLION-YEAR-OLD RECORD FROM SAN AGUSTIN BASIN, NEW MEXICO

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INTRODUCTION

Early recognition of potential Pleistocene paleoenvironmental records from the arid Southwest came from dry basins and playas in the Basin and Range and Colorado Plateau provinces (Meinzer, 1922). Fossil beach ridges, wave-cut cliffs, and thick sedimentary sequences provided evidence of extensive ancient lakes in these basins during past pluvial periods that were tentatively correlated with the glacial ages.

The San Agustin Basin in western New Mexico (Lat. 34°N, Long. 108°W) and its fossil-lake features have been described in detail by Bryan (1926) and Powers (1939). In the years 1955 and 1958-59, two cores, Oberlin 1 (200 m depth) and Oberlin 2 (600 m depth) were taken near the deepest part of the basin (fig. 1). Sediment texture and pollen were analyzed and yielded a continuous record down to about 300 m (Clisby and Sears, 1956; Clisby and Foreman, 1957; Foreman and others, 1959; Sears, 1961). However, the detailed data were never published. A radiocarbon date of 27,000 yr from the upper 10 m of the section and the appearance of Tertiary pollen below 280 m suggested a long record that extended to the Pliocene. With the exception of the last glacial/interglacial cycle (Wisconsin-Holocene), the paleoenvironmental analysis failed to define the anticipated earlier cycles of alternating glacial and interglacial environments. The last cycle was characterized by pine/spruce woodland during glacial times which changed to saltbush/grassland by about 10,000 yrs ago. Below 40 m pine/sagebrush/grassland dominates the record, but gradually sagebrush/grassland becomes dominant below 100 m; spruce pollen was always sparse and sporadic. The lack of apparent environmental change was interpreted as documenting regional uplift of the San Agustin Basin to woodland elevations only during the late Pleistocene (Foreman and others, 1959). Although this interpretation seems unlikely, it cannot be rejected because few comparative early Pleistocene paleoenvironmental data are known in this region. On the other hand, the static pollen record could be the result of variable sampling density, poor pollen preservation, and the extreme extraction techniques applied at that time.

Given the importance of such a long continental record and refined dating and preparation techniques, it becomes appropriate to reassess the San Agustin Plains record as follows:

(1) Determine the age of the record by paleomagnetic analysis (inclination) of the available original core samples.

(2) Determine the continuity of sedimentation in the basin by calculating sedimentation rates of the section using different dating techniques such as radiocarbon, amino-acid racemization, and paleomagnetic data.

(3) Determine the paleoenvironment region as recorded in the pollen assemblages and the paleolimnology as recorded by ostracods and algal assemblages (diatoms, *Pediastrum,* and *Botryococcus).* For this purpose we collected and analyzed a third sediment section (auger, fig. 1) extending back to about 20,000 years ago. This interval encompasses the two extreme climate modes (the glacial and interglacial modes), whose paleontologic character should provide a standard for interpreting the earlier record. Comparison of the new paleoenvironmental data with the original results should also provide some insight into the problems of the earlier study.

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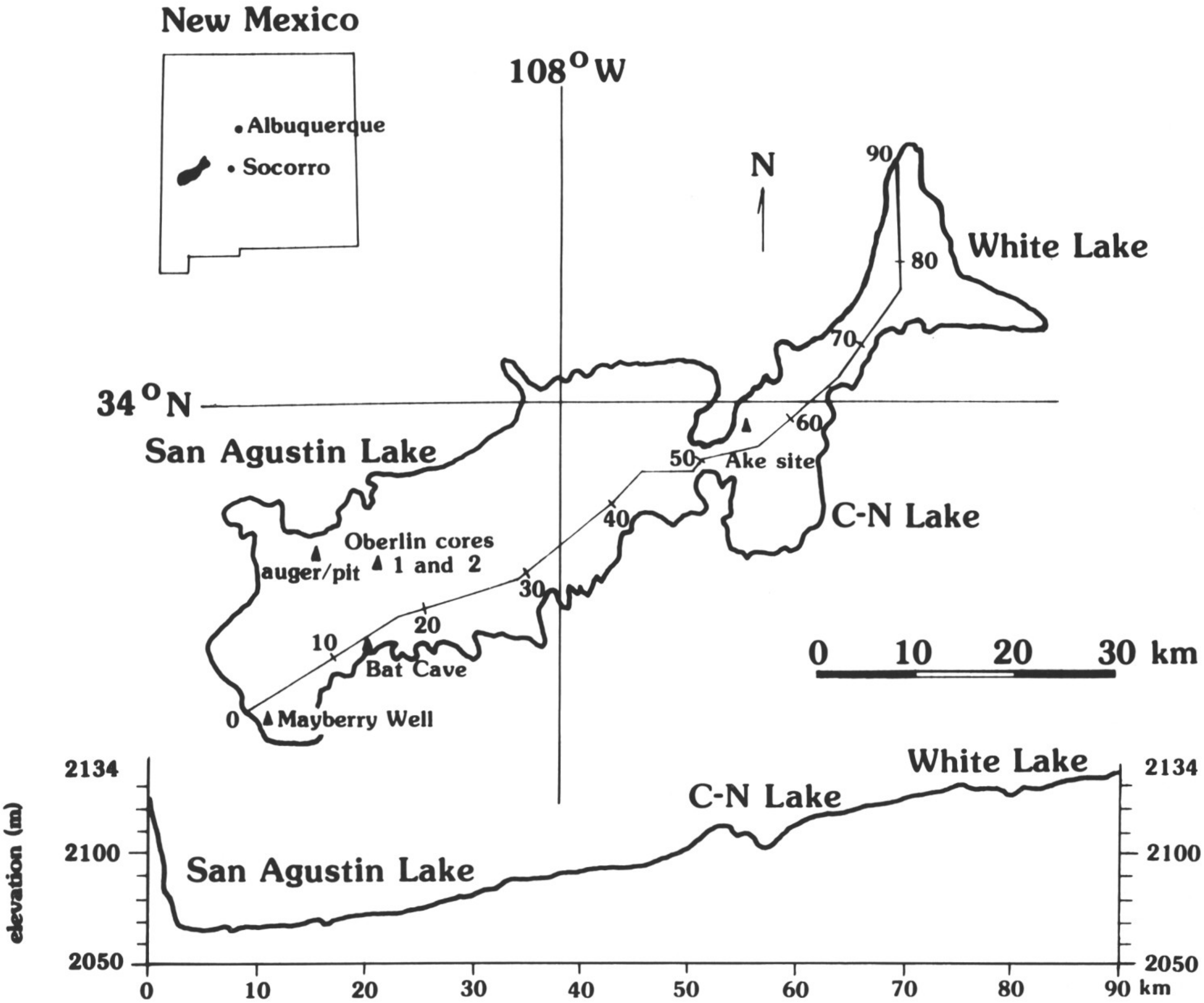

Figure 1. Longitudinal and elevational profile of San Agustin Plains, New Mexico. Profile follows lowest general surface elevations in San Agustin Basin. Vertical exaggeration = 200 ×.

ENVIRONMENTAL SETTING

The San Agustin Basin is located about 90 km west of Socorro, New Mexico, in the Mogollon-Datil volcanic plateau (fig. 1). The surrounding mountains, with elevations up to 3,000 m, are composed of Tertiary rhyolites and basalts (Stearns, 1956, 1962). The basin is a graben with three subbasins: White Lake (2,119-m floor elevation), C-N Lake (2,101m floor elevation), and San Agustin Lake (2,065-m floor elevation) that are interconnected by channel ways. Intermittent streams from a 5000 km^2 watershed (Weber, 1980) separately feed the two upper basins and the lower basin. Ancient beach ridges are found from 2134- to 2082m elevations (Weber, 1980; Powers, 1939), and suggest a lake that at one time connected all three basins. Later lowering of the lake level led to separation of the basins and ultimate desiccation of San Agustin Lake. At the maximum lake level, the lake had a total area of 1200 km^2 (Weber, 1980) and was about 70 m deep in its deepest part. The lowest part of the drainage divide of the basin lies 2,150 m east of the easternmost branch of White Lake (fig. 1). Although no dating is as yet available for the beach levels in the three basins, a tentative cor relation is proposed on the basis of characteristic ostracod and diatom assemblages obtained from lacustrine outcrops and from the core material.

The modern vegetation of the basins and their surroundings has been studied in detail (Potter, 1957; Potter and Rowley, 1960) and is summarized in Table 1. The modern climate of the San Agustin Plains is semiarid with less than 350 mm of annual precipitation that falls predominantly during the summer months. The mean annual temperature is 8.5°C, with extremes between — 30° and 41°C.

CHRONOLOGY OF THE CORE

Paleomagnetic Polarity Stratigraphy

The 600-m Oberlin core of (Foreman and others, 1959) had originally been cut into 1-ft sections and wrapped in wax paper and stored in glass jars. The deeper part of the core remained in 10-ft-long segments wrapped in wax paper in the original core boxes. In both cases the material slowly desiccated during storage, and the hard material had to be sawed to collect paleomagnetic samples from the center of the core.

Table 1. Plant taxa, vegetation and elevation in San Agustin Plains, New Mexico.

Elevation	Vegetation	Plant Taxa
2,700 m	Douglas Fir forest	*Pseudotsuga menziesii* *Abies concolor* *Pinus flexilis/Strobiformis* *Picea engelmanni* (locally)
2,100–2,700 m (shady)	Ponderosa Pine forest	*Pinus ponderosa* *Pinus edulis* *Juniperus deppeana* *Quercus gambelii* *Quercus grisea* *Pseudotsuga menziesii* *Pinus flexilis/Strobiformis*
2,100–2,700 m (sunny)	Pinyon and Juniper forest	*Pinus edulis* *Juniperus deppeana* *Quercus grisea* herbs and grasses
2,100 m (higher flats)	Saltbrush grassland	*Atriplex canescens* *Bouteloua gracilis* *Sporobolus airoides*
Less than 2,100 m (alkaline flats)	Greasewood grassland	*Sarcobatus vermiculatus* *Sporobolus airoides* *Distichlis* sp. *Muhlenbergia* sp. *Suaeda suffrutescens*

Three samples were collected at each of 27 horizons, ranging in depth from 164 m to 327 m. All horizons were sampled through vertical distances of 5 cm or less and were relatively oriented (top versus bottom) so Fisher (1953) statistics could be used to calculate site averages and precisions. The core segments were not azimuthally oriented, and magnetic polarity was inferred solely from the inclination.

Progressive alternating-field demagnetization was carried out on one sample from each horizon. After initial removal of viscous remanence, the magnetization was fairly stable. A spurious (presumably rotational) remanence was often imparted for peak fields above 500 oersted. On the basis of the pilot demagnetization for each horizon, two steps were chosen at which to demagnetize the other samples. The optimal demagnetization step was then selected as the one that produced the least dispersion among the samples. Field strengths for this step ranged from 50 to 400 oersted. The undemagnetized natural remanent magnetization (NRM) was not used, even when it yielded the best precision. Horizon results were accepted if the sample directions were nonrandom at the 5 percent significance level. Out of the 27 horizons, 23 met this requirement. One additional horizon was rejected because the magnetization was unstable.

Two problems arise in the interpretation of the paleomagnetic data (fig. 2). First, the polarities must be correctly interpreted. This is hampered by the poor record of paleomagnetic direction that often shows shallow inclinations compared to the geocentric axial dipole value of 53.3° for this latitude. Also, the a95's (cones of 95 percent confidence) were large for some samples. These results may relate to the acquisition of viscous magnetic remanence during the core's 20-year storage period. Second, the reversal sequence must be correctly matched to the reversal time scale. This study concentrated on levels of the core below 164 m, and the lack of higher samples coupled with a large sample interval makes a definitive interpretation impossible. A reasonable interpretation, however, suggests that the Brunhes/Matuyama boundary (0.73 m.y. ago) lies at a depth of about 252 m, and that the normally magnetized zones within the Matuyama (268-270 m and below 305 m) are the Jaramillo (0.97 m.y.) and Olduvai (1.67-1.87 m.y.) paleomagnetic events, respectively (fig. 2A).

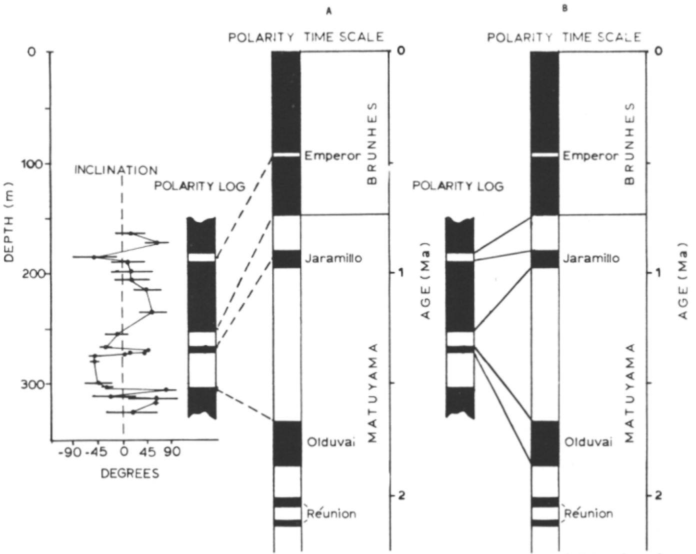

Figure 2. Results and two possible interpretations (A and B) of paleomagnetic analyses of the Oberlin core 2 (Foreman and others, 1959).

Two horizons in the core may record brief reversal events. The site at 313 m depth shows a shallow negative inclination, but the a95 is high and therefore the site is not considered to be truly reversed. On the other hand, the single reversed horizon at 186 m depth has a negative inclination and is tentatively correlated with the Emperor event (0.46 m.y.) (Champion and others, 1981). This interpretation gains support from sedimentation rates in the upper part of the core as determined by radiocarbon analysis. Although somewhat variable, these sedimentation rates (fig. 3) generally fall between 0.3 and 0.4 mm per year, and if extrapolated downward in the core would place an age of 730,000 yrs at a depth of about 250 m. However, such extrapolation may be unwarranted, and little certainty can be ascribed to this interpretation.

An alternate interpretation (fig. 2B) in which the Brunhes/Matuyama boundary is placed at about 180 m, where the first sediments with reversed polarity occur, is possible; however, it relies on variable sedimentation rates within the Matuyama to account for the Jaramillo and Olduvai paleomagnetic events. The discovery of Tertiary pollen at a depth of 289 m (Foreman and others, 1959) may suggest ages for that part of the core that are consistent with a pre-Olduvai age (Gauss), when Pliocene climates finally gave way to the glacial environments of the Pleistocene.

Clearly, the paleomagnetic data gathered thus far are insufficient to decide which of these or other interpretations are most logical. The important result of this study is that the Oberlin core 2 contains sediments showing reversed polarity that implies substantial age for these deposits and that indicates their potential for dating by detailed paleomagnetic analysis.

Sedimentation Rates

Radiocarbon dates have been determined for material in the upper part of the San Agustin Basin section from the two Oberlin cores studied by Clisby and Foreman (1957) and Foreman and others (1959), and a 2-m augered section about 7 km west-northwest of the Oberlin core site. These provide an opportunity to evaluate the continuity of the upper part of the San Agustin Basin record and to gain insights into the depositional and erosional processes of this system that are required for its successful paleoenvironmental interpretation. Assuming the radiocarbon dates are accurate, the derived sedimentation rates (fig. 3A) indicate that net sediment accumulation and/or sediment preservation

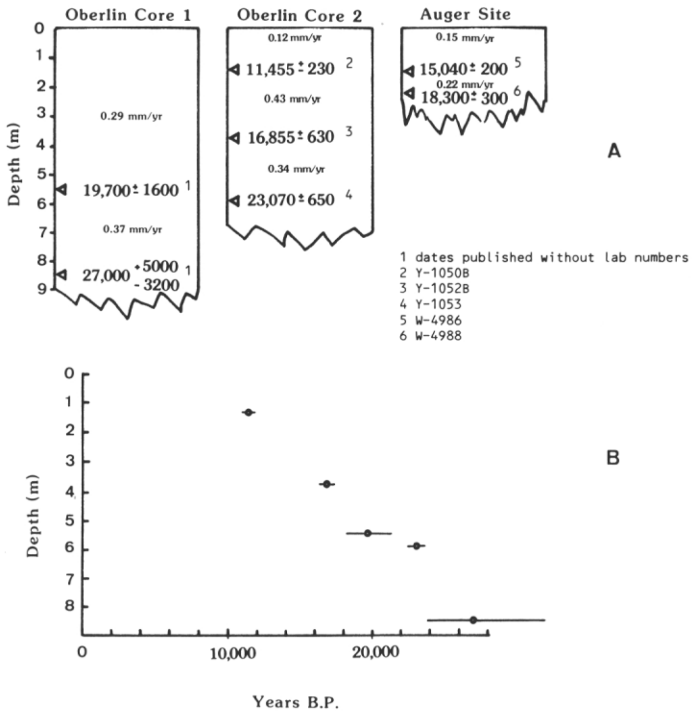

Figure 3. **A.** *Radiocarbon dates and derived sedimentation rates for three sediment profiles from the San Agustin Basin. Data for Oberlin core 1 from Clisby and Sears, 1956; data for Oberlin core 2 from unpublished documents of K. H. Clisby; data for auger site courtesy of Meyer Rubin, U.S. Geological Survey.* **B.** *Plot of radiocarbon dates (one standard deviation) from Oberlin core 1 (200 m long) and core 2 (600 m long) against depth.*

at these three sites is somewhat variable. The uppermost parts of each section show consistently lower sedimentation rates that presumably reflect post-depositional removal of sediment by middle or late Holocene erosion. At other sites in the southwestern part of San Agustin Basin, such as the Bat Cave area (fig. 1), upper Pleistocene sediment is exposed at the surface and is presently being removed by ephemeral stream erosion. The location of Oberlin core 2, the 600-m core that was never completely analyzed and published, was reported to be within a few feet of the Oberlin core 1 site (Foreman and others, 1959), and the radiocarbon dates from the two sites, despite some rather large statistical margins of error in the earlier dates, plot in a reasonably linear fashion with depth (fig. 3B). Lower sedimentation rates at the auger site presumably reflect its more marginal location with respect to the edge of the basin (fig. 1), where sedimentation rates are generally slower under natural conditions. The fact that the auger site is known to be somewhat topographically lower than the Oberlin core sites brings the dates of this sequence into reasonable stratigraphic agreement with the Oberlin core-sites data.

On longer time scales, amino-acid racemization analyses can be useful in determining the relative age of lacustrine deposits and can provide some insights into the magnitude of time-separating samples in stratigraphic sequences. In the San Agustin Basin, amino-acid racemization data are based on alloisoleucine/isoleucine ratios (total acid hydrolysate) in the ostracod *Limnocythere ceriotuberosa.* About 40 valves of this species were isolated for each sample from the Oberlin 2 core at the depths of 307 cm (ca. 15,200 yrs ago), 1,360 cm (ca. 45,000 yrs ago) and 2,385 cm (ca. 70,000 yrs ago), in addition to one Holocene sample from the re-collected material at 120 cm depth (ca. 9,500 yrs ago). The alloisoleucine/isoleucine ratios increase uniformly with depth from 0.051 to 0.23 (fig. 4). If it is assumed that the effective temperature did not change significantly between 10,000 and 70,000 yrs ago, then the uniform increase in the extent of isoleucine epimerization suggests a uniform late Pleistocene sedimentation rate. The increase in epimerization rate during the last 10,000 yrs could reflect a higher effective temperature experienced during the Holocene. Despite the limited kinetic data available for the isoleucine epimerization reaction in *Limnocythere,* the obtained ratios imply a constant diagenetic temperature that is consistent with data obtained elsewhere (McCoy, 1981).

Using the time frame tentatively established by the paleomagnetic stratigraphy (fig. 2A), a hypothetical accumulation rate for the deposits in the San Agustin Basin is about 0.34 mm per year, if calculated between the core top and the Brunhes/Matuyama boundary (730,000 yrs ago at 252 m depth). The similarity of this figure with that derived from the radiocarbon dates and the uniformity of sediment accumulation suggested by the amino-acid racemization analysis is curious because the great variability in sediment texture and lithology (Foreman and others, 1959) implies that natural sedimentation rates were anything but constant. It is possible that the similarity of accumulation rates is circumstantial, for it is clear that many variabiles exist that must be accounted for, and that the preliminary chronological information for this thick sedimentary sequence is inadequate for developing a firm explanation.

Nevertheless, the presence of carbonate-coated ostracod valves at depths down to about 150 m (Foreman and others, 1959) indicates that shallow, alkaline-water conditions characterized earlier periods of lacustrine deposition in the basin. It is thus unlikely that the San Agustin Basin began, as a deep graben that slowly filled with lacustrine and alluvial sediment because paleontologic and sedimentologic evidence for deep-water conditions is rare and sporadic. It seems more likely that the constancy of accumulation rates in the basin is a reflection of tectonic subsidence, the consequence of which is to preserve deposited sediments at a more or less equal rate for long periods of Quaternary time. This notion cannot be taken seriously until more detailed analyses are undertaken, but the implications of this preliminary reassessment may provide important information about the tectonic evolution of this part of the Rio Grande rift.

PALEOENVIRONMENTAL DATA AND INTERPRETATION

In order to expand and reevaluate the original paleoenvironmental interpretations, a duplicate record for the last 18,000 yrs was collected in 1981-82 seven km west-northwest of the Oberlin 1 and 2 core site (elev. 2,069 m, fig. 1). This record allows a reevaluation of both Pleistocene and Holocene environments. The recollected record came from a 145-cm pit that yielded a ^{14}C date of 8,735 ±260 yrs B.P. (GX-7813) at a depth of 90-95 cm, and from a set of nearby auger samples that extended to a depth of 220 cm. A ^{14}C date of 18,300 ± 300 yrs B.P. (W-4988) was obtained at the 220-cm depth. Pollen, ostracods, and algae (including diatoms) were analyzed to provide paleoenvironmental information (fig. 5).

The pollen data are given in percent of total pollen (200-300 grains per level, excluding the dominant pine) and in pollen concentration based on the number of pollen grains per gram of sediment. Low pollen diversity, especially during the early Holocene, makes the pollen percentages somewhat unrealistic, and consequently the paleoenvironmental interpretation of the pollen record is mostly based on pollen concentration values. The algae *Pediastrum* and *Botryococcus* are given in percent of total pollen, whereas diatoms and ostracods are given in percentages of their respective sums.

During the last 18,000 yrs, four major paleoenvironmental phases can be distinguished in the region as reflected by pollen analysis. First,

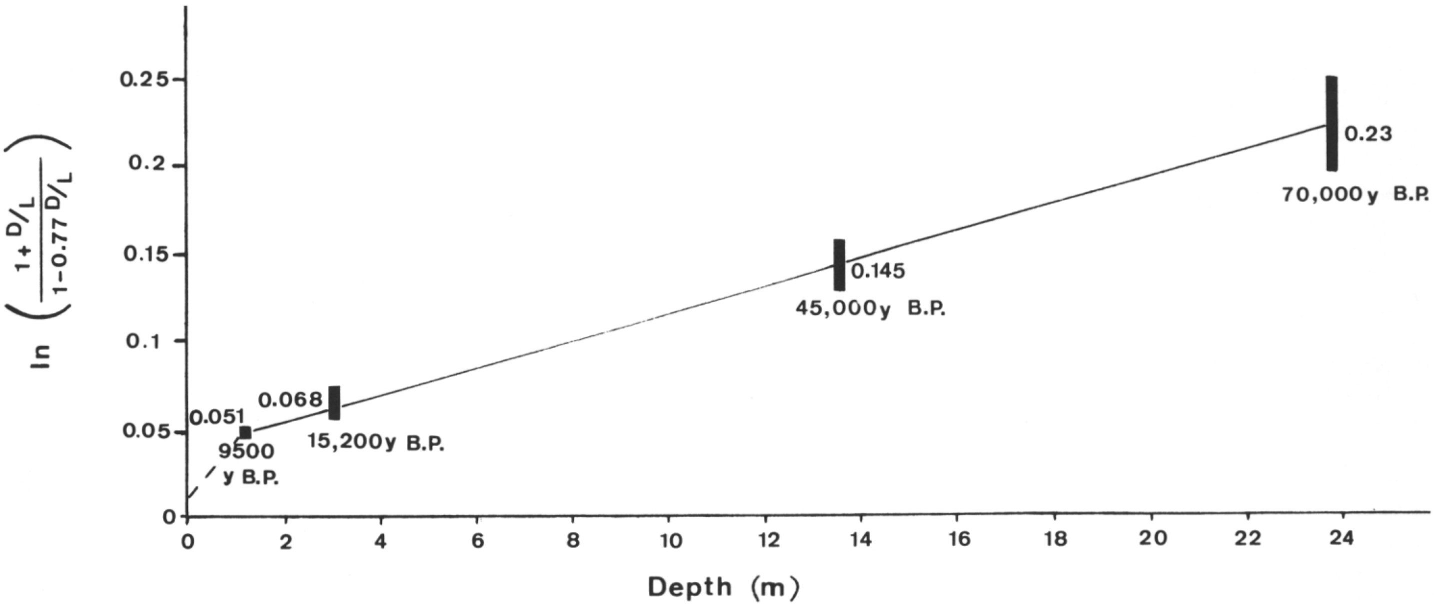

Figure 4. Extent of isoleucine epimerization (total acid hydrolysate) in valves of Limnocythere ceriotuberosa *vs. depth in Oberlin core 2 (Foreman and others, 1959). D/L is the alloisoleucine/isoleucine ratio. Ages are extrapolated from radiocarbon dates listed in the text and on Figure 3.*

an open pine/spruce woodland with some juniper, abundant sagebrush, and grasses, composites, and some saltbush occurred between 18,000 and 15,000 yrs ago (auger, 220-140 cm). Second, between 15,000 and about 10,000 yrs ago this was replaced by a pine/spruce/juniper woodland with a similar herbaceous vegetation but with somewhat less sagebrush (auger, 140-95 cm). Third, between 10,000 and about 5,000 yrs ago the woodland was dominated by only pine and juniper (pit, 145-55 cm). Other arboreal taxa such as fir and spruce had low concentrations, and the herbaceous vegetation consisted mostly of grasses. Fourth, the modern saltbush/greasewood playa vegetation with pine and juniper on the surrounding slopes appeared about 5,000 yrs ago and persists to the present (pit, 55-0 cm).

Pollen-concentration values for all taxa during this 18,000-yr period are consistent with this interpretation except for pine values that show extreme fluctuations, especially during the Holocene. This may reflect changes in pine species in the intervals under discussion, but more likely it results from variable sedimentation processes. Erratic sedimentation is suggested in at least one level (pit, 95 cm) where pine- and spruce-pollen concentration increases tenfold. The reappearance of significant values of spruce and grasses at this level indicates that this change may be due to the redeposition of older sediment.

The paleolimnologic sequence as reconstructed from ostracods and algae *(Botryococcus, Pediastrum* and diatoms) shows a more variable paleoenvironmental picture than that derived from pollen analysis. The deepest auger samples were deposited about 18,000 yrs ago. They are distinctly laminated and contain abundant *Pediastrum* sp. cf. *P. duplex, Botryococcus* sp., and the diatom *Stephanodiscus niagarae.* This algal assemblage is typical of temperate freshwater lakes. All the species are planktonic and the nearly complete lack of benthic diatoms implies that an extensive, open-water environment occurred at the auger site at that time.

The dominant ostracod in this interval is a new species of *Limnocythere* whose present-day distribution is in the highlands of central Mexico (Forester, 1983). *Limnocythere ceriotuberosa,* an ostracod of semiarid areas of the northern United States and central Canada, is subdominant, along with a small representation of species of *Candona.*

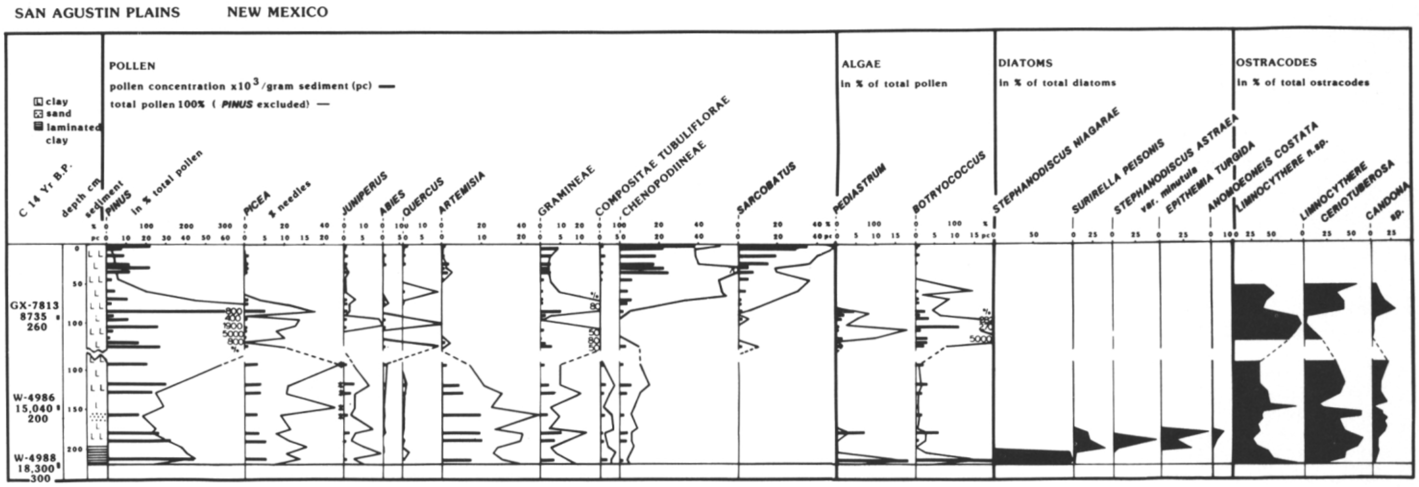

Figure 5. Paleoenvironmental data including pollen, algae, diatoms, and ostracods from a sediment section (auger, fig. 1) in the southwestern portion of San Agustin Basin. Pollen and algae data are given in percent of total pollen excluding pine (open silhouettes), and in concentration/gram sediment (histograms). Diatoms and ostracods are given in percent of total of each respective group.

Both species of *Limnocythere* live in lakes with a sodium-bicarbonate water chemistry, and both tolerate a wide range of salinity (200 to 7,000 ppm for *Limnocythere* n. sp., and 200 to 25,000 ppm for *L. ceriotuberosa)*. The ostracods do not coexist today, possibly because the new species of *Limnocythere* cannot tolerate the excessively low winter temperatures that characterize much of the western United States today, or because the lakes that existed in the San Agustin Basin during those times do not have modern analogs.

The dominance of *Stephanodiscus niagarae* rapidly changes after 18,000 yrs ago to a diatom flora characterized by *Surirella peisonis, Anomoeoneis costata, Stephanodiscus astraea v. minutula,* and *Epithemia turgida.* With the exception of *S. astraea v. minutula,* these diatoms are generally benthic forms, living attached to plants or on the bottom sediments, and they are commonly found in slightly to moderately saline aquatic environments. At this level in the section (180 cm), *Limnocythere ceriotuberosa* becomes the dominant ostracod, perhaps consistently with its preference for more saline waters. The suggestion of increased salinity and appearance of large numbers of benthic diatoms implies that the lake became shallower about 17,000 yrs ago. The brief appearance of significant numbers of *S. astraea v. minutula* during this interval indicates that the lake was periodically fresh enough to support this planktonic diatom.

Just above this level, the algae disappear except for *Botryococcus,* which continues in low values. The lack of diatoms in the upper part of the section appears to relate to their dissolution after deposition by turbulent, alkaline water in the shallow lake. Both *Limnocythere* species codominate in the record with fluctuation in individual dominance that possibly suggests changes in salinity or critical-temperature regimes without affecting its general chemical composition. The paleoenvironmental importance of *Candona* sp. is not known, although it is common in some of the marginal deposits of the basin. Its abundance may be related to the proximity and flow of streams entering the lake.

Between 17,000 and 10,000 yrs ago, *Artemisia* pollen values remain high, and the occurrence of spruce implies the persistence of somewhat cool climates after 18,000 yrs ago. During this interval, *Limnocythere* n. sp. and *L. ceriotuberosa* continue their codominance, indicating the existence of a permanent body of water in the basin. After 10,000 yrs ago, *Pediastrum* and *Botryococcus* reappear, and *Limnocythere* n. sp. becomes dominant, probably indicating a period of fresher water conditions. However, *Limnocythere ceriotuberosa* regains dominance by 8,000 yrs ago, implying more saline conditions and possibly signaling the beginning trend to drier climates. The continued representation of *Candona* probably relates to the appearance of freshwater marshes that formed at the mouths of drainages that fed the drying lake. This limnological environment persisted until about 5,000 yrs ago.

After 5,000 yrs ago, the pollen assemblage is dominated by Chenopodiineae and particularly *Sarcobatus* (greasewood). These salt-tolerant herbs and shrubs prefer fine-grained playa soils and indicate low and rapidly fluctuating lake levels. Ostracods and even *Botryococcus* disappear from the record at that point. Cladoceran ephippia and branchiopod eggs, presumably of the orders Notostraca, Anostraca, and Conchostraca, are the only aquatic microfossils that remain, and indicate that essentially modern limnologic conditions of ephemeral ponds began at this time.

This playa environment represents a very different sedimentary system from the one characterized by permanent water. Processes of active erosion, deflation, redeposition, and sediment cracking become effective in destroying or modifying the paleoenvironmental record. The highly variable pollen-concentration values in this part of the section (fig. 5) probably reflect such processes, as does the variable amount of upper Holocene sediment at different sites in the San Agustin Basin. Undoubtedly, the preservation of diatoms, pollen, and even ostracods is affected by these processes, and the implications of the existence of these harsh depositional environments for the interpretation of interglacial periods is apparent.

From the vegetational and limnologic data, it is evident that the interval between 18,000 and 15,000 yrs ago was generally cooler and had a higher effective moisture than is characteristic of the modern climate. Spruce and sagebrush indicate the existence of a cool, continental climate with a predominance of winter precipitation. The lake was presumably deep enough to provide equitable temperatures for the persistence of *Limnocythere* n. sp., an ostracod of Mexican distribution that lives today where average winter temperatures for the coldest month are seldom below 5°C, in conjunction with *L. ceriotuberosa* which today has a predominantly northern distribution.

The diatom stratigraphy indicates that only between 18,000 and 17,000 yrs ago did runoff suffice to maintain a large, fresh lake in the basin. The presence of *Stephanodiscus niagarae* in pine- and spruce-pollen-dominated sediments in the C-N Basin, to the northeast (fig. 1), suggests that the lake may have been at least 40 m deep during this period. By 17,000 yrs ago, the diatom flora reflects increased salinity; the presence of a stromatolitic, tufa-coated shoreline at approximately 2,082 m that may correlate with this alkaline-lake interval suggests that the lake stabilized at this level for a longer period. Variations in the ostracod fauna imply that the lake may have freshened briefly about 15,000 yrs ago, but generally the system remained shallow and turbid between 17,000 and 5,000 yrs ago. Abundant spruce needles *(Picea engelmanni)* in the sediments at the auger site indicate the proximity of the shoreline, which may have been less than 2 km distant at that time. The maximum water depth during this time was probably not much over 10 m. Evaporite minerals have not been found in the sediments of the San Agustin Basin, and maintenance of this somewhat saline, shallow lake over an interval of at least 10,000 yrs was apparently accomplished by a delicate balance of precipitation, evaporation, and removal of the water from this nominally closed basin by leakage through fractures to the groundwater system (Blodgett and Titus, 1973).

Increased salinity levels after 8,000 yrs ago, as suggested by the predominance of *L. ceriotuberosa* and the large decrease in *Limnocythere* n.sp., presumably reflect decreased precipitation in the winter and/or generally warmer temperatures and higher evaporation rates. Continuation of these trends resulted in the complete desiccation of the lake by 5,000 yrs ago. Lower values of pine-pollen concentration may indicate a reduction of pine forests in the surroundings, although the late Holocene depositional environments are unfavorable for pollen preservation in general.

DISCUSSION

Few other records exist in the Southwest for comparison with the paleoclimatic record of the San Agustin Basin. The pollen records from the Chuska Mountains, New Mexico (Wright and others, 1973), Potatoe Lake, Arizona (Whiteside, 1965), Lake Estancia, New Mexico (Bachhuber, 1970), and a wealth of packrat-midden data (summarized in Spaulding and others, 1983) document a pine/spruce/Rocky Mountain juniper woodland with sagebrush during the late Pleistocene in the Southwest at elevations above 1,500 m. According to the packrat-midden data, the dominant pine in these assemblages is limber pine *(Pinus flexilis/Pinus strobiformis),* a subalpine species, whereas pinyon pine *(Pinus edulis)* and ponderosa pine appear to be absent from the region until the early Holocene (Betancourt and Van Devender, 1981). The dominant spruce in San Agustin Basin was identified as *P. engelmanni.* The co-occurrence of subalpine forest taxa with Great Basin xerophytes, such as sagebrush north of latitude 33°N, and woodland taxa with a desert flora south of 33°N (Van Devender and Spaulding, 1979) seems to be a peculiar late glacial environmental feature, suggesting paleoclimatic conditions unknown in the Southwest today. Such mixed assemblages have also been documented for small vertebrates

(Van Devender and Mead, 1980) and in the present study for ostracods. The paleoclimatic implication for the San Agustin Basin area, thus, can be explained only by a climate with cool summers and predominantly winter precipitation, as discussed in detail by Spaulding and others (1983).

In comparing the character and timing of the lacustrine phases recorded in the Southwest, the main problem is the poor dating control of the high-lake phases. In Lake Estancia, Bachhuber (1970) recorded a freshwater lacustrine phase about 12,000 years ago that is preceded by an undated saline phase. The data from the San Agustin Basin suggest that a high, fresh-lake level occurred about 18,000 years ago, but was of short duration and possibly consisted of several intervals. If additional radiocarbon dates support the lack of synchroneity of high-lake stands in nearby systems, the interpretation of paleolimnological records in terms of paleoclimate may require a more extensive integration of specific hydrologic and climatic data from individual basins to explain such apparent differences.

The timing of the younger environmental phases seen in the San Agustin Basin agrees with other records from the Southwest. The major change from a pine/spruce/juniper woodland to a pine/juniper woodland, interpolated as 10,000 yrs ago in the San Agustin record, could well correspond to the drastic change in the woodland vegetation south of latitude 33°N documented in the packrat-midden data at 11,000 yrs ago (Spaulding and others, 1983). In most of the pollen records from the area, this change is difficult to date because it occurs at a level of a major sedimentary break. The paleoenvironmental difference seen in the San Agustin Basin between the early and late Holocene is equally well documented in the packrat-midden record. The suggested paleoclimatic interpretation is that the early Holocene between 10,000 and 8,500 yrs ago may have been more mesic than the late Pleistocene prior to 10,000 yrs ago and the late Holocene after 8,500 yrs ago. This interpretation is based on the existence of a fresher lake in the San Agustin Basin and the distribution of Douglas fir, limber pine, and Rocky Mountain juniper in Chaco Canyon below their modern limits (Betancourt and Van Devender, 1981). The onset of drier conditions at 8,000 yrs ago ultimately led to desiccation of Lake San Agustin by about 5,000 yrs ago and is synchronous with the replacement of Douglas fir, limber pine, and Rocky Mountain juniper by ponderosa pine, pinyon pine, and one-seed juniper at Chaco Canyon (Betancourt and Van Devender, 1981).

CONCLUSION

The variety of sensitive paleoenvironmental indicators and the apparent continuity and great length of the San Agustin Basin record set it apart from many other paleoclimatic records in the Southwest. When compared to the original study (Clisby and Foreman, 1957), the paleoenvironmental resolution of the last 20,000 yrs is considerably greater in the reassessed record. This is partly due to the additional analysis of ostracods and diatoms and pollen-concentration data, and also to the greater diversity of the pollen assemblages that may result from differing circumstances of pollen preservation and extraction. The techniques for pollen extraction used by Clisby (unpub. laboratory records) are now considered harsh for Quaternary lacustrine sediments, and it is possible that inadequate curatorial procedures for the core before analysis may have adversely affected pollen preservation. If the apparent lack of paleoenvironmental sensitivity of the earlier record is partly an artifact of the extraction techniques of the time, and if a substantially amplified and detailed history can result from additional analyses of diatoms and ostracods, it is imperative to restudy this long and informative paleoenvironmental record.

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Gustav and Henriette Billing, ca. 1880. As a young man growing up in Germany during the 1850's, Gustav along with a friend is said to have flipped a coin to decide whether to seek his fortune in America or Greece. Lady Luck directed him first to New York and Cincinnati, Ohio (where he met Henriette) and then on to Salt Lake City, Utah, Leadville, Colorado, and Socorro, New Mexico, where in each case he established tremendously successful smelting works. The above portrait was probably taken in Denver during their Leadville days (when the Billing's owned the famous Tabor mansion in Denver). Within five years they would become Socorro's, and among the territory's, most prominent citizens. Photographer unknown; courtesy Helene Billing Wurtlitzer Foundation, Taos, New Mexico.