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# LATE-QUATERNARY PALEOECOLOGY OF THE CUATRO CIÉNEGAS BASIN, COAHUILA, MÉXICO<sup>1</sup>

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**Abstract.** Two sediment cores drawn from springs in the Cuatro Ciénegas Basin, a small desert valley in central Coahuila, yielded fossil pollen chronologies transgressing more than 30,000 radiocarbon years. Comparisons of modern pollen spectra from the basin floor with the fossil records indicate that vegetation ecologically equivalent, if not identical, to that now present has occupied the floor of the basin since mid-Wisconsin time. A highly-endemic fauna and a lack of geological evidence for large Pleistocene lakes in the area afford strong support for this interpretation, and suggest that aquatic and terrestrial habitats of the valley lowlands remained stable environments throughout the Quaternary, regardless of fluctuations in regional climate. Fossil arboreal and Compositae pollen sequences provide a means for making stratigraphic correlations between the cores, and are the first late-Quaternary palynoclimatic chronologies available from northeastern México. Trends in those components of the fossil records indicate that regional climate was cooler and perhaps more moist during the last Pluvial than at present. It became progressively warmer and drier during late-Pluvial time, and approximated modern climate during the Holocene. Holocene Altitheirml or Hypsithermal intervals were undetected, but may be obscured by gaps in the fossil records.

## INTRODUCTION

The Cuatro Ciénegas Basin lies at approximately 27° N and 104° W on the northeastern edge of the Mesa del Norte of northern México (West 1964), immediately south of Cuatro Ciénegas de Carranza, Coahuila (Fig. 1). The floor of the basin averages 740 m above sea level, and is surrounded by mountains rising higher than 2,500 m. The mountains are formed of folded mid-Cretaceous limestones that overlie bedrock of Permian age (Minckley 1969). The valley lies within the Chihuahuan Desert and receives an average of less than 20 cm of precipitation per year (Shreve 1944), but has many springs, streams, ponds, and lakes. The biota of the area was brought to the attention of American scientists through collections made in 1939 by E. G. Marsh, Jr., and has been subjected to intensive study by many biologists from the United States and México since 1958. Minckley (1969) recently provided a physical and geological description of the basin, and summarized the status of biological research from the area.

To describe the diverse assemblage of animals known only from the Cuatro Ciénegas Basin as "remarkable" (Taylor 1966) is an understatement. Aquatic organisms endemic in the valley include at least nine kinds of fishes (Minckley 1969), three genera and four species of stenassellid and cirrolanid isopods (Cole and Minckley 1972), and more than 13 species of hydrobiid snails (Taylor 1966). Five species of scorpions of the genus *Vejovis* seem to be

unique to the area (Williams 1968). The herpetofauna of the basin also contains numerous endemic species (Hubbs and Miller 1965), a considerable portion of which are relicts (McCoy and Minckley, *personal communication*).

The degree of endemism exhibited by this fauna implies long-term isolation of the valley and its drainages. Taylor (1966) wrote that ancestral stocks common to the precinctive snails were isolated in early-Tertiary or late-Mesozoic time and Miller (1968) proposed a Miocene origin for one of the endemic fishes, suggesting that the special spring and pond habitats those organisms require existed in the basin throughout the Cenozoic. The surficial geology of the valley lends indirect support to these postulations of environmental stability. No evidence (e.g., shoreline carbonate deposits, strand lines, etc.) has been found in the area depicting past existence of large lakes as were present in many closed and currently arid basins of the Basin and Range physiographic province during more mesic periods of the Quaternary (Morrison 1965).

In August 1968 W. L. Minckley and two assistants collected two long sediment cores suitable for pollen analysis from springs in the Cuatro Ciénegas Basin. I received the cores in October 1968 and initiated analyses of pollen contained in the sediments at that time. The analyses were designed to shed as much light as possible on the vegetational and climatic histories of the valley over the time transgressed by the cored sediments, and, if possible, to provide a means by which to test the hypothesis of Cenozoic environmental stability in the study area. The pollen diagrams from the cores are also the first late-Qua-

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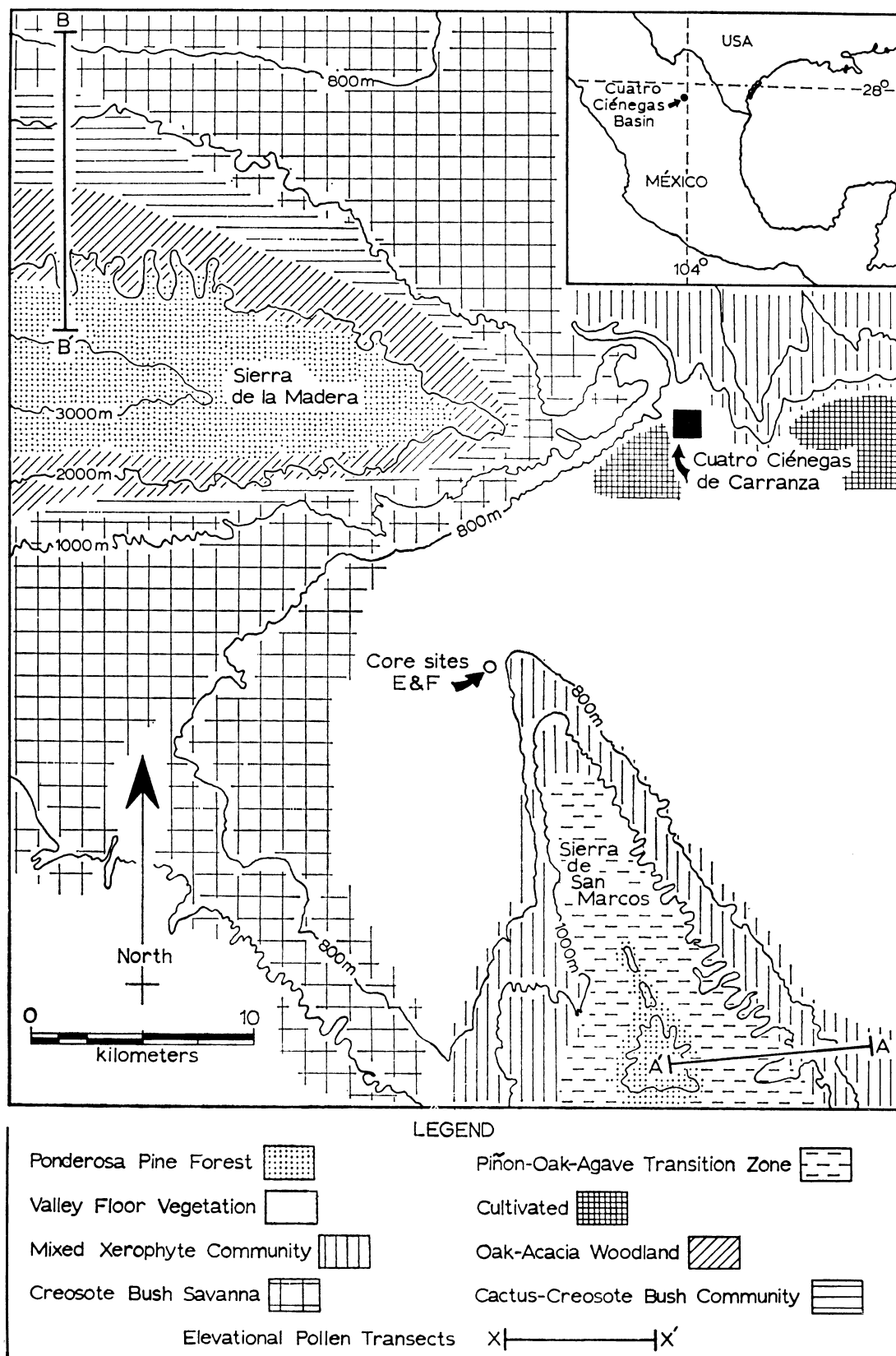


FIG. 1. Generalized vegetation map of the Cuatro Ciénegas Basin showing major topographic features of the area and location of the coring sites.

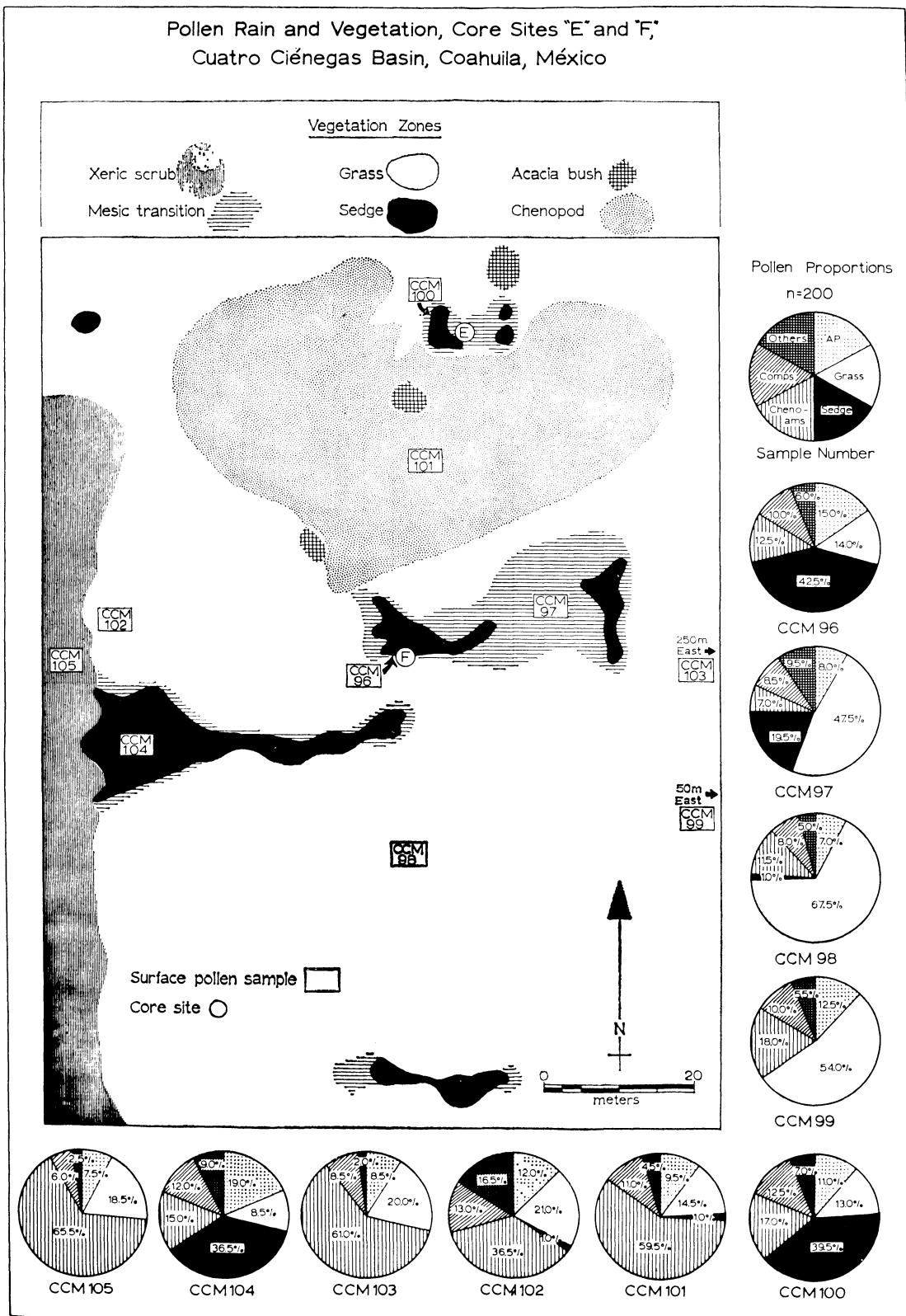


FIG. 2. Vegetation map of core sites E and F showing pollen spectra from surface samples gathered in that area of the valley floor.

ternary pollen records available from arid north-central México, between the Rio Grande to the north (Martin and Mehringer 1965) and the valley of México to the south (Clisby and Sears 1955, Sears and Clisby 1955). The survey included below of modern vegetation and pollen rain in the basin was designed to provide control information on which to base interpretations of the fossil records, and also constitutes a palynological reconnaissance of an area not previously described on that basis.

#### METHODS

##### *The core sites and cores*

The cores, designated cores E and F by the collectors, were drawn manually by means of automobile jacks and a 5-cm  $\times$  100-cm piston corer from small marshy springs located ca 500 m west from the north-west tip of Sierra de San Marcos (Fig. 1), a range that dissects the basin on a north-south axis. The springs (Fig. 2) appear to be extinct feeders of an ancient lake, a remnant of which may be a small playa located ca 300 m west from the coring sites. Core E was 6.2 m long, and core F was 13.9 m long. Core E was terminated by a travertine lens that could not be penetrated by the coring device. The deepest segment of core F was not in contact with bedrock, but coring was terminated by mechanical failure of the coring equipment. Core sections were sealed in cellophane wrap in the field and returned to the laboratory for stratigraphic description and pollen sample removal.

Both cores consisted of extremely complex series of clay, peat, and mixed clay and peat horizons, often containing granular travertine. Their stratigraphies are too lengthy and complex to present here, but are available elsewhere (Meyer 1972). Although data presented below indicate equivalent sedimentation rates at the two springs during the time in which core E and the uppermost 6 m of core F were deposited, stratigraphic correlations between the cores using sediment types and colors were unsuccessful. This suggests that the springs have quite different hydrological histories, even though they are located close together and are similar in size and general appearance.

##### *Radiocarbon dates*

Peat strata were wide enough to provide sediment samples for radiocarbon dating at five different places in the cores, and a sediment sample from each of those horizons was submitted to Gakushuin University, Tokyo, Japan, for analysis. The results are presented on following pollen diagrams.

Radiocarbon chronologies from springs, however, should be interpreted with caution. Ancient carbon

may enter solution in water passing through deep spring sediments and be accumulated by plants growing at the spring, ultimately being redeposited in forming peats. In recognition of this possibility, I submitted a collection of sedges from the spring that yielded core F to the University of Arizona for dating to establish a modern control value for the radiocarbon dates from the cores. The result,  $160 \pm 2.4$  BP (A-1191), represents atmospheric equilibrium and is the same value the University of Arizona laboratory obtained in 1968 from fresh mulberry leaves grown in Tucson (Austin Long, *personal communication*). Based on that figure, the  $> 31,400$  BP and  $> 26,800$  BP dates from deeper sections in core F are interpreted here as indication that the basal sediments of the core transgress mid-Wisconsin time.

##### *Pollen samples*

Sediment samples ca 1 cm<sup>3</sup> in volume were initially removed from the cores at roughly 20-cm intervals for analysis of fossil pollen. Later in the study I removed 0.3–0.5 cm<sup>3</sup> samples at 1–5 cm intervals from a clay stratum in core F, from a peat stratum in core E, and from narrow, varve-like, alternating clay and peat horizons in core F in order to measure close-interval variations in fossil pollen contained in those sediment types.

Forty-eight modern surface sediment samples containing sufficient pollen for analysis were accumulated. The samples fell into two major assemblages: those from the valley floor, and those from transects up mountains surrounding the basin. Nine of the samples comprised a transect up the east slope of Sierra de San Marcos, from the base of the mountain at ca 775 m to its summit at ca 2,400 m (Transect A-A' in Fig. 1). Seven samples formed a transect up the north slope of Sierra de la Madera, the range forming the northwest boundary of the basin. That transect extends from the base of the mountain at ca 800 m to near its summit (ca 3,000 m) at 2,600 m (Transect B-B' in Fig. 1). The remaining 32 samples came from various vegetation formations on the valley floor. Exact geographic locations in the basin at which surface samples were collected are specified elsewhere (Meyer 1972). The elevational transects illustrate the nature of pollen rain on local montane environments where areal extent and species composition of vegetation communities are controlled for the most part by physiographic factors such as slope exposure, and meteorological parameters such as temperature and precipitation. The transects were designed to provide a basis for interpreting fossil profiles of pollen types produced by upland vegetation. The surface samples from the basin floor supply modern pollen spectra from an area where distributions and compositions of vegetation assemblages are deter-

mined mainly by edaphic factors such as soil moisture and soil salinity. These spectra are used as a basis for interpreting fossil profiles of pollen types produced by lowland vegetation.

Surface pollen samples were gathered in multiple subsamples as described by Mehringer (1967). Collection site elevations for Sierra de San Marcos were read from a 50-m contour interval topographic quadrangle of the central portion of the valley provided by Petroleos Mexicanos, México, D. F., and site elevations on Sierra de la Madera were estimated from an air navigation chart of northern México published by the U.S. Air Force. I determined locations on the basin floor from a drainage map of the study area prepared by Minckley (1969).

Mehringer's (1967) extraction procedure was used for all pollen samples, and samples containing organic debris in noticeable amounts were also subjected to a 1.5-min acetolysis (Gray 1965). Preparations for counting were suspended in glycerol and stained with basic fuchsin, and counting was done under a Leitz "Ortholux" microscope at 540 $\times$ .

Two fixed-sum counts were performed. In the first I attempted to tally at least 200 grains from each sample. During the second, including only Compositae and arboreal pollen types, I attempted to establish a sum of at least 100 grains for each fossil sample and for each sample from the valley floor.

## RESULTS

### *Modern vegetation*

Botanical nomenclature follows Kearney & Peebles (1964). Plant identifications were confirmed by D. J. Pinkava, Department of Botany, Arizona State University.

Müller (1947) provided a regional survey of Coahuilan vegetation and climates, and Gilmore (1947), Baker (1956), and Minckley (1969) presented preliminary botanical descriptions of the Cuatro Ciénegas area. The present study required a relatively detailed description of vegetation characterizing different habitats in the valley and on surrounding mountains. During compilation of that information names were applied to discernible vegetation formations. The names are purely descriptive, and are used here only to facilitate interpreting modern and fossil pollen records.

*Montane vegetation.*—Vegetation zones on Sierra de San Marcos and Sierra de la Madera are summarized in Fig. 1. An extensive pine forest persists above 2,000 m on Sierra de la Madera, a high, massive range. Ponderosa pine (*Pinus ponderosa*) dominates the landscape, and a few true fir (*Abies*). Douglas fir (*Pseudotsuga*), and Arizona cypress (*Cupressus arizonica*) are also present. Pine forests on

Sierra de San Marcos, a lower and more precipitous range, are restricted to localized groves of ponderosa pine with a few Arizona cypress on higher ridges. The understory in this association on both mountains is a complex array of scrub oak (*Quercus*), prickly-pear (*Opuntia*), agave (*Agave*), barrel cactus (*Ferocactus*), grass, piñon (*Pinus cembroides*), and acacia (*Acacia*). A dense, low, chaparral-like woodland dominated by scrub oak and acacia grows on Sierra de la Madera between the pine forest and the upper margin of a well-developed bajada that extends northward from that range. Piñon, grass, prickly-pear, agave, palm (*Brahea bella*), and hackberry (*Celtis pallida*) are also present in that zone. At the upper margin of the bajada scrubby woodland is abruptly replaced by more xerothermic desert formations. Two zones are apparent on this bajada—a lush higher formation and a less diverse lower assemblage. The upper formation is a cactus-creosote bush community that includes creosote bush (*Larrea divaricata*), ocotillo (*Fouquieria splendens*), candelilla (*Euphorbia antisiphilitica*), prickly-pear, hedgehog cactus (*Echinocactus*), tree yucca (*Yucca*), agave, club cholla (*Opuntia*), barrel cactus, limebush (*Jatropha dioica*), and mesquite (*Prosopis glandulosa*). The lower sections of the bajada are occupied by a creosote bush savanna with an occasional tree yucca and prickly-pear.

The slopes of Sierra de San Marcos are steep and extensively dissected by canyons. Vegetation there does not form well-defined zones, but grades from mesic pine forests at high elevations to desert assemblages on bajadas. Piñon and Arizona cypress occupy ridges between canyons, and canyon floors support scrub oak thickets. Dense stands of *Agave lechihuilla* cover intermediate slopes. Grass, tree yucca, barrel cactus, ocotillo, acacia, candelilla, and hackberry are present throughout this area. Bajadas on Sierra de San Marcos are smaller and less developed than are those on Sierra de la Madera. At different areas within the same elevational range on the former vegetation varies from creosote bush savannas, structurally equivalent to those on Sierra de la Madera, to more diverse desert assemblages, similar to the cactus-creosote bush community on Sierra de la Madera. The same xerophytes grow on the bajadas of both ranges, but are not zoned into recognizable elevational subunits on Sierra de San Marcos.

*Valley floor vegetation.*—The floor, or "barrial" (West 1964) of the Cuatro Ciénegas Basin supports a complex mosaic of distinctive vegetative formations. Areal extent and species composition of the communities are controlled by available surface and subterranean water, and to a considerable extent by variations in soil salinity, which is generally high throughout the basin.

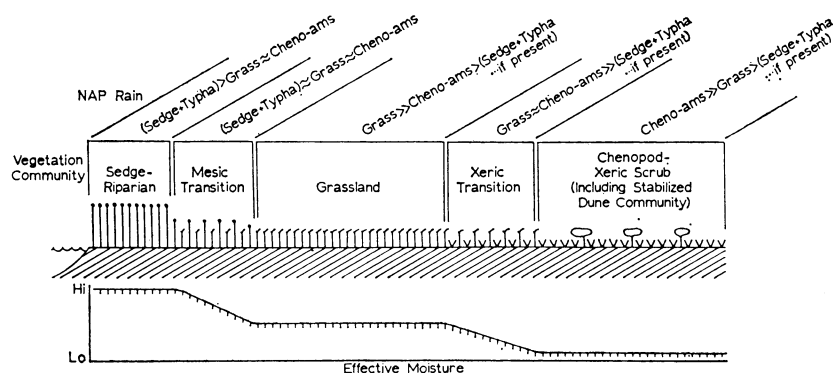


FIG. 3. Generalized pattern of vegetation on the floor of the Cuatro Ciénegas Basin.

A dense riparian association exists in springs and adjacent to ponds and streams. It includes at least nine kinds of sedges (Cyperaceae), cattail (*Typha domingensis*), and rarely ash (*Fraxinus*), willow (*Salix*), and seep-willow (*Baccharis glutinosa*). More mesic sections of the barrial support an extensive grassland community. Effective soil moisture is lower and soil salinity is higher in such areas than at riparian sites, and three salt-tolerant grasses—dropseed (*Sporobolus spiciformis*), bunchgrass (*S. airoides*), and saltgrass (*Distichlis stricta*)—are the dominant taxa. Other obvious members of this association are mesquite, prickly-pear, yucca, beargrass (*Nolina cespitosa*), sotol (*Dasylirion cedrosanum*), catclaw-acacia (*Acacia greggii*), and several kinds of succulent composites. Transitions between grassland and riparian habitats are usually abrupt, but intermediate situations are present in some places. Transitional vegetation varies considerably in composition, but always includes grasses and sedges. Extremely dry sections in the basin support a scrubby xeric flora. With the exception of several active dune fields in the valley, all such areas are characterized by saline crusts and presence of the halophytic chenopods iodine bush (*Allenroelfea occidentalis*) and seepweed (*Suaeda fruticosa* and *S. palmeri*). The xeric scrub community includes mesquite, catclaw acacia, ocotillo, herbaceous euphorbs, a variety of cacti, several succulent composites, sotol, and beargrass. This community occupies stabilized dunes and permanent playas. Playas subjected to periodic flooding are barren or support only iodine bush and seepweed. Formations transitional between grassland and xeric scrub also exist at certain locations; these are characterized by iodine bush, seepweed, and grasses growing together.

Fig. 3 summarizes the pattern of vegetation apparent on the basin floor; however the sequence is disjunct in many places. Riparian formations fail to develop at the margins of ephemeral or extremely

saline lakes, and xeric scrub assemblages often grow directly adjacent to sedge beds (e.g., Fig. 2). The water table beneath the barrial is high, and the valley floor is undermined by travertine-lined water tubes and channels, many of which form connections between ponds. Hundreds of small pits are present. These appear when the surface over a subterranean channel collapses. Sedge beds develop in the pits, eventually resealing the openings, and the new surfaces are occupied by surrounding mesic or xeric vegetation, depending on location. In areas where the surface crust is thin and subsurface water is particularly abundant, vegetation is transitional between the typically riparian and typically mesic formations.

#### Modern pollen rain; the first count

Grouped pollen types, or categories, proved more useful than single types alone in characterizing major sample assemblages. Arboreal pollen (AP) includes pine, oak, fir, spruce (*Picea*), and the cypress family (Cupressaceae). The GCA category contains pollen from grasses (Gramineae), cheno-ams (Chenopodiaceae + Amaranthaceae), and aquatic plants (sedge and cattail pollen). The Compositae category contains pollen from the sunflower family. Echinate grains in that group were separated as either high- or low-spined types based on having supratectate projections either greater or less than  $2\ \mu$  long.

Pollen proportions from surface samples collected on Sierra de la Madera and on Sierra de San Marcos (Fig. 4) show that samples from montaine locations were characterized by AP and Compositae frequencies that collectively exceeded 50%, and GCA proportions less than 35%. On both mountains AP frequencies exceeded 74% in samples from the high-elevation ponderosa pine forests and decreased gradually, moving downhill, to ca 20% in samples from lower areas on bajadas. A reciprocal trend is apparent in the nonarboreal pollen (NAP) profiles. Pine and oak dominated the AP from both mountains,

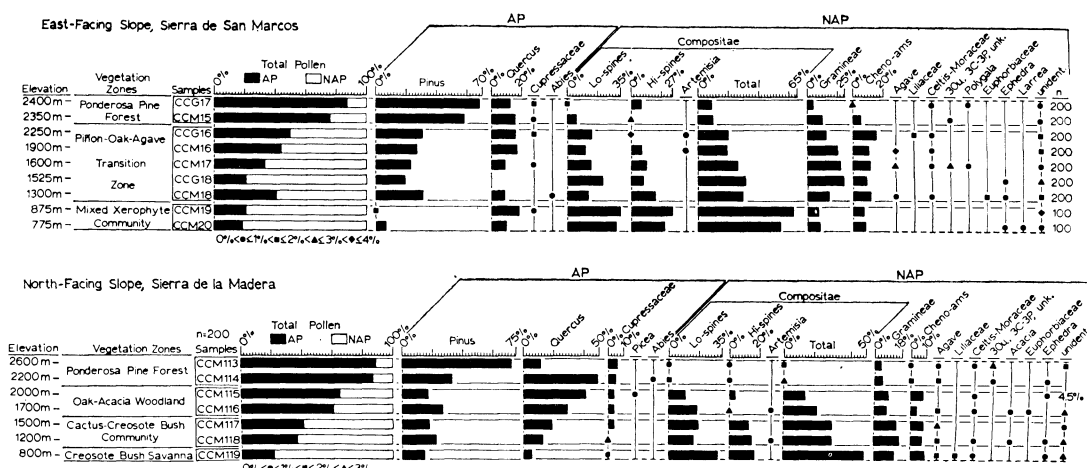


FIG. 4. Pollen spectra from surface samples gathered on mountains around the Cuatro Ciénegas Basin.

although Cupressaceae pollen was present in several samples from Sierra de San Marcos and comprised 2% to 6% of all counts from Sierra de la Madera. Spruce and fir appeared in three of these samples but did not exceed 1%. Grass pollen and cheno-ams were present in all montaine samples, but the Compositae, comprised mainly of high- and low-spined pollen types, dominated the NAP profiles from both transects. The high relative abundance of Compositae pollen at lower elevations apparently results from the short-term abundance of a variety of annual composites that appear in quantity on bajadas in the study area immediately following rains.

Fig. 2 and 5 present total pollen spectra from surface samples gathered on the floor of the Cuatro Ciénegas Basin. Arboreal pollen comprised 5% to 20% of each count, approximating AP values from samples taken on bajadas in the study area. Pollen rain on the valley floor was similar to that on surrounding mountains only on this basis. Compositae pollen, which dominated spectra from bajadas, was consistently present but did not exceed 22% in any sample. Pollen rain on the basin floor was dominated by grains from anemophilous plants that characterize vegetation formations growing there, and GCA pollen comprised at least 58% of each sample from the barrial.

Spectra from equivalent edaphic habitats at different locations were extremely similar. Aquatic pollen types exceeded 21% in all spectra from riparian situations, reflecting sedge and cattail abundances. All profiles from the grassland community were characterized by at least 54% grass pollen, reflecting saltgrass, dropseed, and bunchgrass abundances, and all spectra from xeric sites where seepweed and iodine bush were growing contained more than 55% cheno-ams. Profiles from transitional areas were more variable, reflecting cospatial existence of sedges, cheno-

pods, and grasses. Fig. 2 exemplifies the relationship. Sample CCM 98, gathered in the grassland zone at the core sites ca 15 m away from a spring where sedges were growing, contained 67.5% grass pollen and only 1% sedge pollen. Samples CCM 101 and CCM 105, collected in xeric formations 0.5–12 m away from sedge beds, each contained more than 59% cheno-ams and little or no sedge pollen. Samples from the springs contained at least 36% sedge pollen at the expense of grasses and cheno-ams.

The high degree of influence local vegetation has on the composition of pollen rain falling onto the barrial is further illustrated by the spectra from samples CCM 14 and CCM 39 (bottom, Fig. 5). Both samples were taken from a ca 0.5-km<sup>2</sup> section, located 8 km southwest from the village of Cuatro Ciénegas, that does not bear vegetation. The soil there is hard and calichified, a condition presumably prohibiting invasion by plants; pollen accumulating in the area is blown in from outside sources. The site is surrounded by grassland and xeric scrub formations. The pollen spectra from both samples were dominated by pollen from anemophilous components of the surrounding vegetation formations, and contained ca 40% cheno-ams and ca 30% grasses. Compositae proportions from these two samples approximated those of all other samples gathered on the barrial, even though several kinds of composites grow on the valley floor. This suggests that the amount of pollen contributed to local pollen rain by composites inhabiting the basin floor is minimal, and that most Compositae grains reaching the barrial are produced on surrounding bajadas.

#### *The fossil records; first count*

Fig. 6 and 7 present the preliminary fossil chronologies from cores E and F. The records include all pollen types I encountered during the first count,



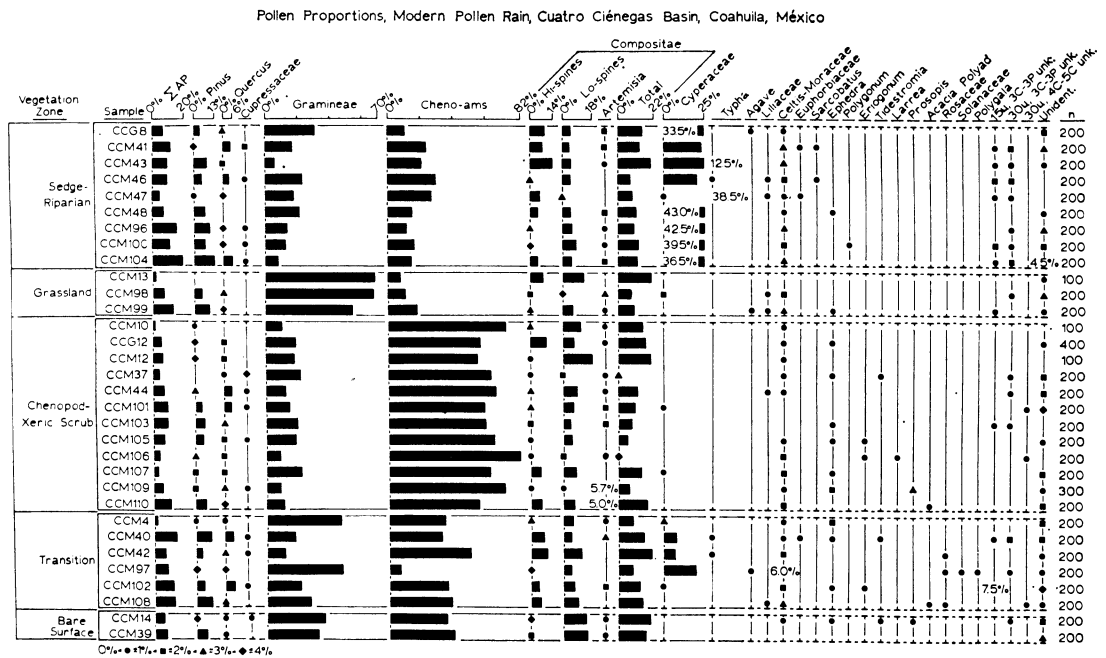


FIG. 5. Preliminary pollen spectra from surface samples gathered on the basin floor.

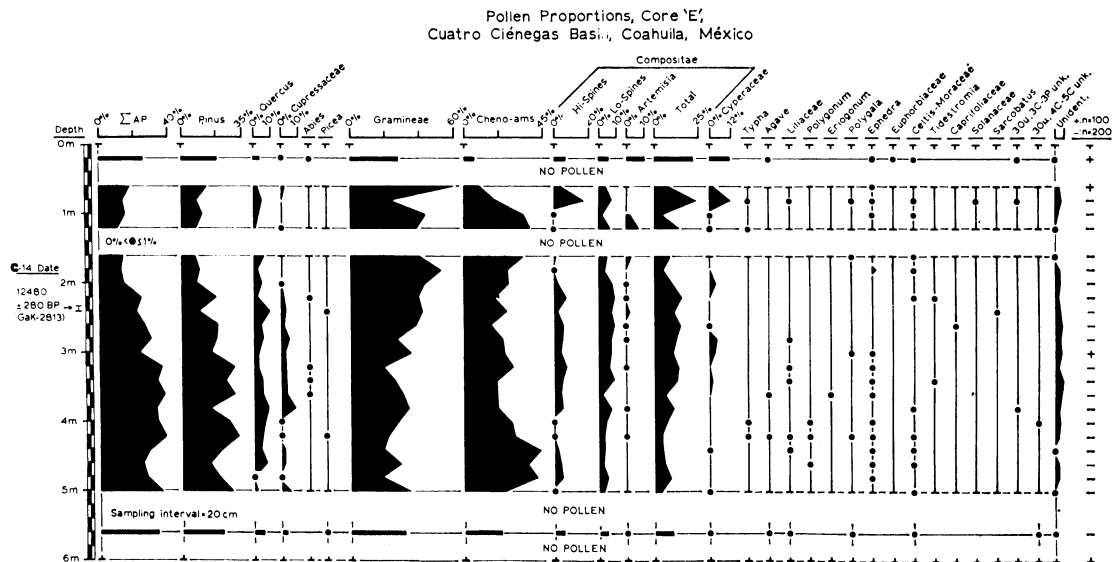


FIG. 6. Preliminary pollen diagram from core E.

using sediment samples removed from the cores at ca 20-cm intervals. Both records are dominated throughout by GCA pollen. Compositae pollen was present at all depths in both cores, but did not exceed 32% in either diagram and did not exhibit significant trends. The diagrams are similar on these bases and closely resemble the modern spectra from the basin floor. They do not resemble spectra from the montane transects.

The fossil GCA profiles were dominated by grass pollen and cheno-ams. Proportions of those pollen

types fluctuated considerably in both records, but did not provide a means for making stratigraphic correlations between the cores. *Typha* pollen appeared in a few samples but did not exceed 1% in either record. Sedge grains were present at most horizons, but sedge frequently did not exceed 12% in core E and surpassed 10% at only five places in core F. The fossil AP profiles were dominated by pine, with oak and the Cupressaceae playing lesser roles. A few fir and spruce grains were recovered from the cores, but had little effect on AP patterns. Arboreal pollen fre-

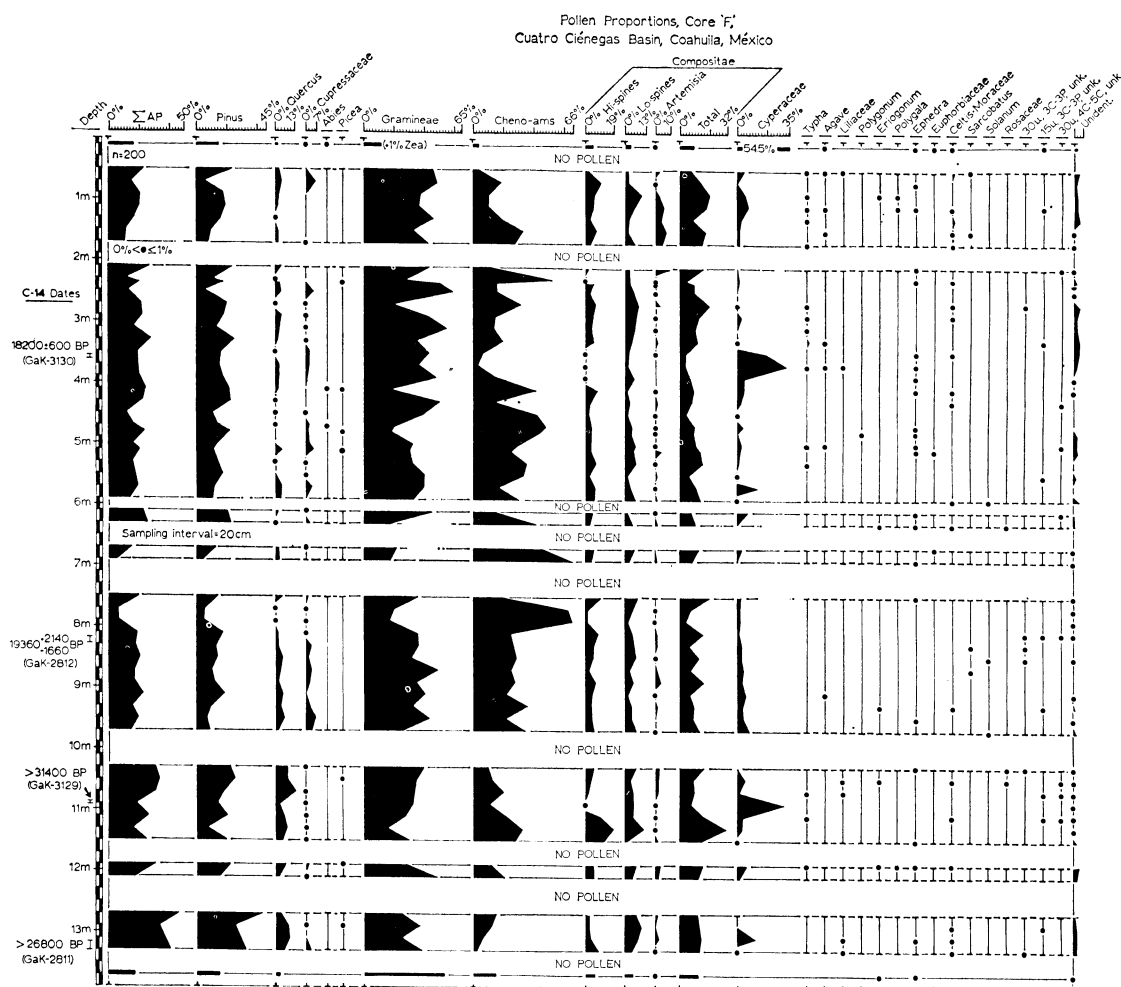


FIG. 7. Preliminary pollen diagram from core F.

quency increased gradually with increasing depth in core E; however, the trend appears artifactual when compared to AP proportions from the uppermost 6 m in core F. There are gaps in both diagrams representing pollen-sterile horizons. The gaps could not be correlated between the cores by means of sediment types.

The cores consisted of well-defined clay and peat horizons. Close-interval pollen profiles from those sediment types from three different levels in the cores are presented in Fig. 8–10. The diagrams are much like the 20-cm-interval records described above. The GCA group was again dominant, forming 55% to 83% of all close-interval counts. In the diagrams, relationships within that category are exaggerated by means of the adjusted sum technique (Mehringer 1967).

Grass and cheno-am curves from the clay stratum in core F (Fig. 8) were relatively stable compared to those from the peat stratum in core E (Fig. 9). A

pattern is apparent in the grass and cheno-am profiles from the alternating peat and clay horizons in core F (Fig. 10). Cheno-am proportions increased at the expense of grasses in clays, whereas the reverse was true in peats. Arboreal pollen curves were much more stable in these diagrams than in the wide-interval records, as were those for "other" pollen types (predominantly Compositae). These data indicate that the preliminary fossil diagrams are good indices of time-transgressive trends in AP, total GCA, composites, and rare pollen types, but give only a general picture of vicissitudes within the GCA group. Fluctuations within the GCA, in peats and between peats and clays, at any rate, are as pronounced at narrow sampling intervals as at wider ones.

The preliminary fossil chronologies provide a partial vegetation history since mid-Wisconsin time for the floor of the Cuatro Ciénegas Basin. First-count spectra from all levels of the cores were dominated by the same pollen types that are diagnostic of dif-

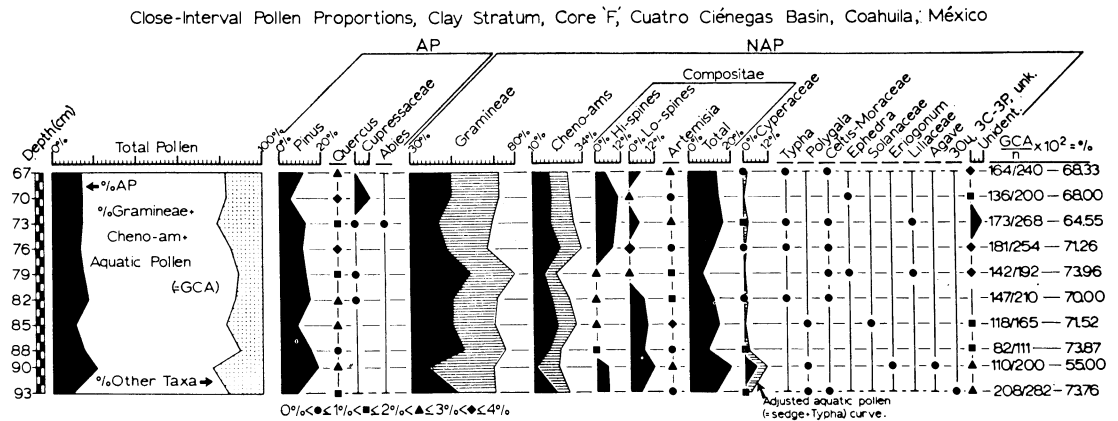


FIG. 8. Close-interval pollen proportions from a clay stratum in core F.

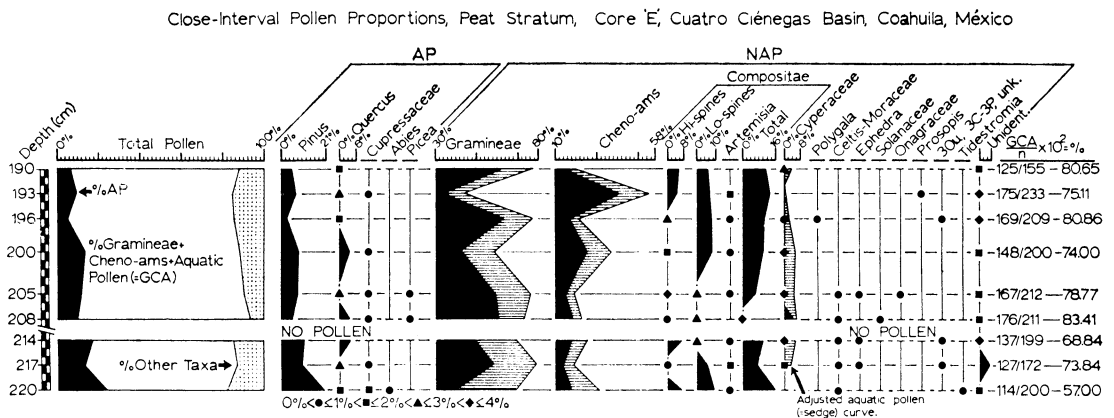


FIG. 9. Close-interval pollen proportions from a peat stratum in core E.

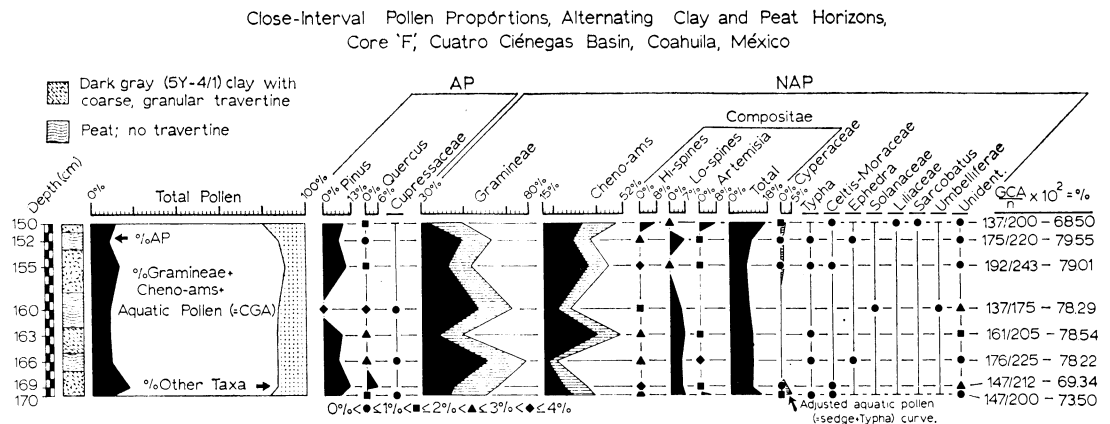


FIG. 10. Close-interval pollen proportions from alternating clay and peat horizons in core F.

ferent edaphic habitats that exist as a vegetational mosaic on the barrier. This suggests that the valley floor as a unit remained a stable local environment throughout the time transgressed by the fossil records, and lends considerable support to the hypothesis of Cenozoic environmental stability in the Cuatro Ciénegas Basin. Fluctuations within the GCA compo-

nents of these records indicate that the type of vegetation growing at and adjacent to the core sites changed repeatedly during late-Quaternary time, probably in response to changes in the controlling edaphic factors, namely soil moisture and soil salinity. The preliminary fossil records, being composed primarily of pollen from plants now growing

TABLE 1. Compositae and AP proportions, grouped counts from surface samples gathered on the floor of the Cuatro Ciénegas Basin

Sample assemblages	Number samples	n	AP		Compositae	
			number	percent	number	percent
Sedge-riparian	9	900	381	42.3	519	56.7
Grassland	3	237	94	39.7	143	60.3
Chenopod-xeric scrub	12	1,137	427	41.5	665	58.5
Transitions	6	600	250	41.7	350	58.3
Bare surface	2	200	68	34.0	132	66.0
Total: grouped	32	3,074	1,265	41.2	1,089	58.8

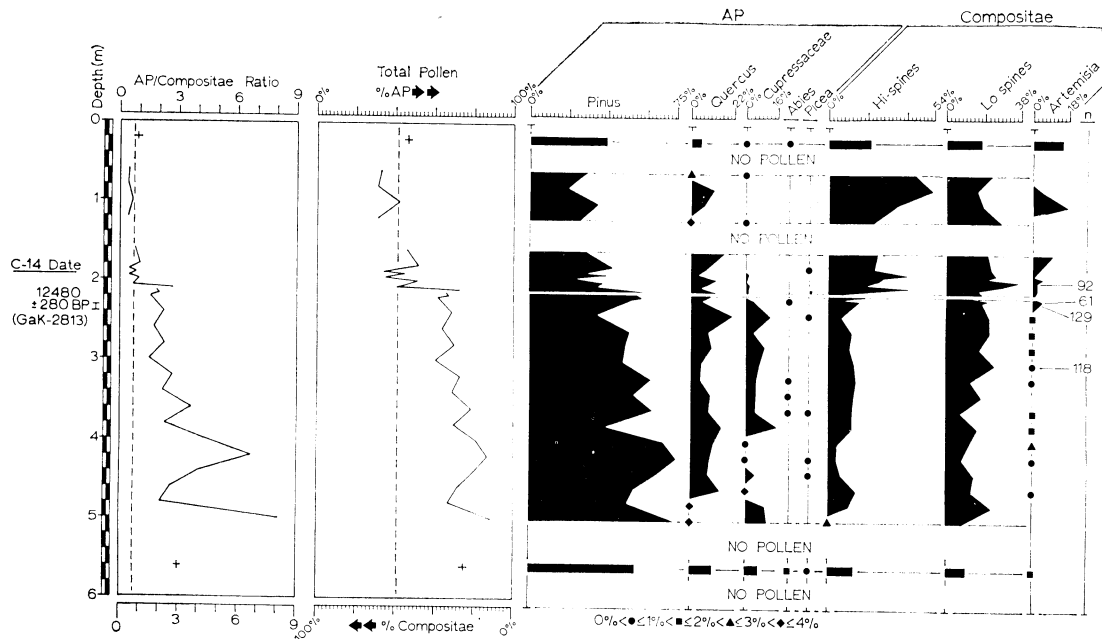


FIG. 11. Arboreal pollen and Compositae profiles from core E. Unless otherwise indicated,  $n = 100$ .

in vegetation formations whose distributions are controlled by edaphic rather than climatic factors, do not reflect past climatic conditions.

The second count

Downslope expansion during the Pluvial of mesic upland vegetation in montane regions of western North America is well documented, and shifts in montane pollen type curves in fossil records from lowland sites in the American Southwest are established indices of Quaternary climatic changes (Martin and Mehringer 1965). In the first-count fossil records from cores E and F and in all preliminary spectra from the floor of the Cuatro Ciénegas Basin, patterns exhibited by the AP and Compositae were masked by the abundant GCA. The second count removed that constraint, with modern spectra from the barrial again providing control for the fossil sequences. Since all AP and most Compositae grains reaching the basin floor appear to be blown or washed

in from surrounding mountains and bajadas, these data are indirect measures of gross paleoclimatic trends.

Counts from modern samples taken in the various edaphic habitats on the valley floor were grouped to estimate AP-Compositae rain on each habitat, and all counts were grouped to form a mean spectrum for the barrial as a unit. Results are presented in Table 1. A homogeneity Chi-squared value (Mosimann 1965) computed for the grouped counts (excluding the total spectrum) was not statistically significant ( $P > 0.2$ ), indicating that AP-Compositae rain is essentially the same in all areas of the basin.

Second-count profiles from the cores are diagrammed in Fig. 11 and 12. Pine again dominated the AP, and high- and low-spined pollen types again dominated the Compositae. Overall trends were most apparent when counts were separated as AP and total Compositae. The mean, modern valley surface spectrum is included in the total pollen section in

Fig. 11 and 12 as a broken vertical line, and the total fossil curves are also exaggerated exponentially in the diagrams by means of AP/Compositae ratios.

The AP-Compositae proportional curves from core E and from the uppermost 6 m in core F are similar. Both approximate the modern control value from surface to a depth of 1.6–2.0 m (with one exception, at the 30-cm level in core F). Below 2 m AP proportions fall between 48% and 85%, and are consistently higher than the modern value, roughly 41%.

at the expense of the Compositae. Below 6 m in core F, AP frequencies remain higher than the control value down to the 11.0–11.4 m depth, where fossil values shift back to ca modern. Arboreal pollen proportions are consistently higher than the modern value below 11.4 m in core F, except for the deepest sample, in which AP and Compositae frequencies again approximate the control spectrum.

The similarity between these chronologies is critically important to following paleoclimatic interpre-

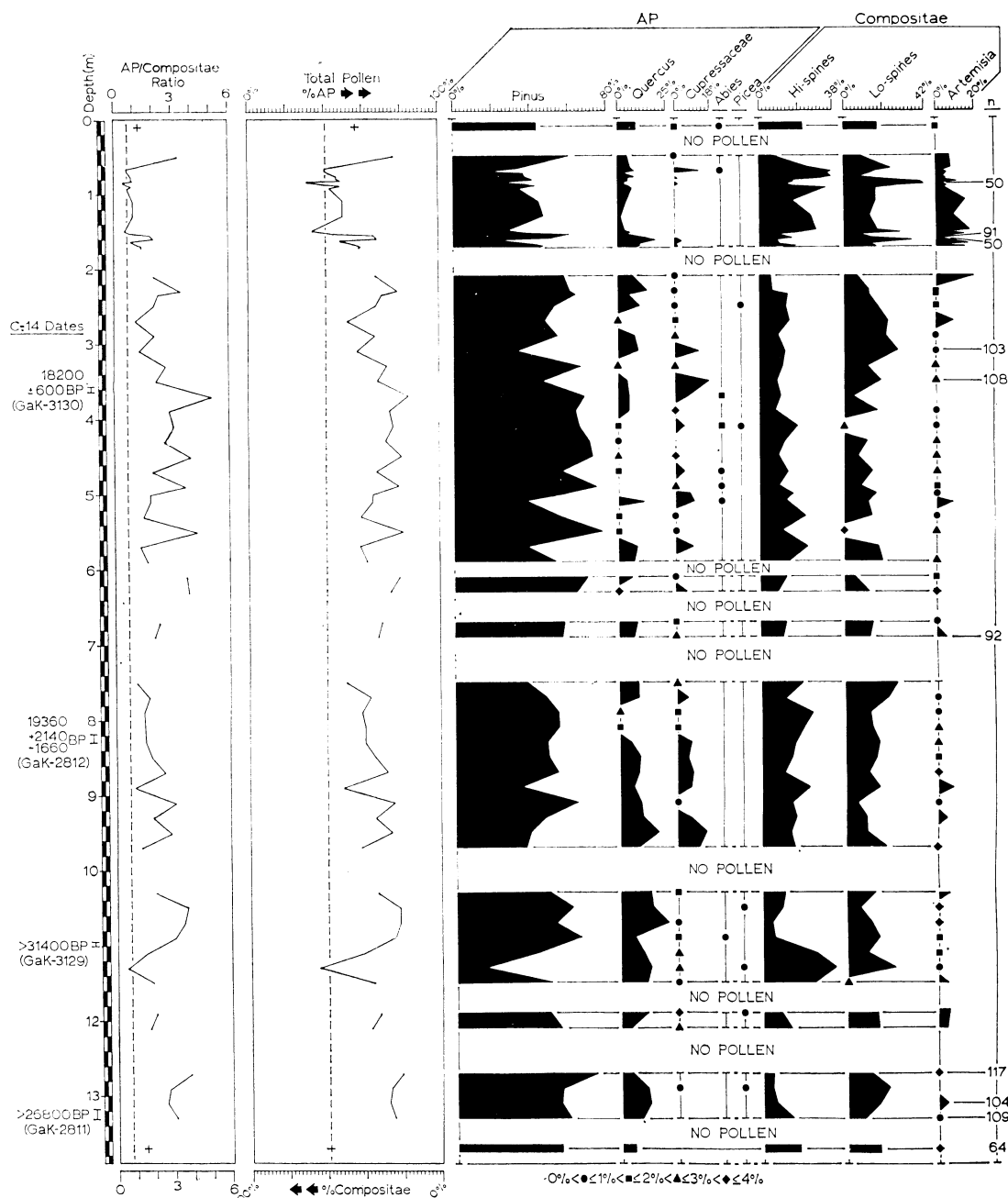


FIG. 12. Arboreal pollen and Compositae profiles from core F. Unless otherwise indicated,  $n = 100$ .

tations. The cores yielded equivalent but independent fossil records of pollen types produced by upland vegetation—the records reflect changes during late-Quaternary time in vertical distributions of vegetation formations on mountains surrounding the Cuatro Ciénegas Basin. The fossil AP-Compositae curves also provide a means for making stratigraphic correlations between the cores, independent both of sediment types and of pollen from plants growing on the valley floor, and indicate equal or nearly equal deposition rates during the late-Quaternary in the vicinity of the springs involved.

#### DISCUSSION AND CONCLUSIONS

Certain areas of North America have yielded Quaternary fossil pollen records that do not seem to have modern analogs, implying past existence of vegetational assemblages that do not have modern counterparts (Wright 1971). Since all first-count pollen spectra from the floor of the Cuatro Ciénegas Basin were quite similar to the preliminary fossil records in most respects, however, the analog approach to interpreting the preliminary diagrams from cores E and F appears to be justified.

Comparisons of the preliminary diagrams from the cores with the first-count profiles from surface samples gathered on the valley floor indicate that aquatic and terrestrial habitats ecologically equivalent to those now present on the barrier existed at and adjacent to the core sites throughout the time transgressed by the cored sediments—i.e., since at least mid-Wisconsin time. Levels in the fossil records where proportions of aquatic pollen types exceed 10% represent periods when sedge beds much like those now present at the core sites occupied the springs. Horizons dominated by grass pollen and chenopods represent periods when the springs were less active than at present, or had moved relative to their modern positions. During such intervals vegetation at the core sites probably resembled the modern mesic transitional assemblage and included grasses, chenopods, and a few sedges. The generally high values for grass pollen and chenopods in the fossil chronologies seem to indicate that the springs have been surrounded by grassland and xeric scrub formations throughout the late-Quaternary.

Modern hydrological properties of the basin floor support this interpretation. Water table beneath the valley surface is high and is in a state of constant local fluctuation. Water table changes in the study area have been under observation by biologists for 13 years (Minckley 1969). Local vegetation responds to variations in available soil moisture; hence the edaphic communities undergo constant changes in areal extent. Sedimentation at a given location in the basin may be continuous, but vegetation at the

site varies through time in response to changing soil moisture and salinity. This relationship explains both the gross similarity between total GCA profiles from the two fossil chronologies, and the differences within the GCA columns at equivalent depths in the cores.

Obvious parallelisms between the total modern pollen rain on the valley floor and the first-count fossil pollen records, together with the lack of geological evidence for large Pleistocene lakes in the study area, support the notion that local habitats on the basin floor were much like they are at present during the last 30,000–40,000 years. The diverse and highly-endemic aquatic fauna inhabiting this valley is also evidence for environmental antiquity and stability, implying that the stream and pond habitats it requires have existed since perhaps the Tertiary. The evidence collectively suggests that the floor of the Cuatro Ciénegas Basin remained a stable environment throughout Quaternary time, regardless of recurrent changes in climate.

The fossil AP-Compositae chronologies from cores E and F provide a partial climatic history for the Cuatro Ciénegas area, and are the first late-Quaternary palynoclimatic sequences available from arid north-central México. In Fig. 11 and 12 total AP proportions are higher than the modern control value at most horizons below 2 m, transitional between 1.6 m and 2 m, and approximate the control value above 1.6 m. Pollen from below 2 m was deposited during mid-Wisconsin time, when regional climate was cooler and perhaps more moist than it is now. Pine forests and woodlands on mountains surrounding the basin were more extensive than they are at present, and scrub oak-piñon-acacia woodland may have occupied the bajadas surrounding the valley floor that presently bear desert vegetation. The locally unique edaphic nature of the barrier, however, apparently prohibited expansion of woodland beyond the bajadas. Local AP production was higher during that period than at present, reflecting the greater source, and more AP reached the valley floor than does now. The 1.6 m–2 m intervals represent climatic amelioration during late-Pluvial time, and reflect elevational constriction of upland vegetation assemblages. The amount of AP falling onto the basin floor progressively decreased during that period. The uppermost 1.6 m in both records represents the Holocene, when AP-Compositae rain at the core sites and vegetation distributions on mountains study area were sub-modern to modern.

Since there were no significant increases in Compositae proportions below 2 m in the first-count fossil records, the total amount of Compositae pollen reaching the core sites appears to have been about the same during the Pluvial as at present. This negates the possibility that the high AP values below

2 m in the second-count fossil profiles are the result of a decrease in the amount of Compositae pollen reaching the core sites at an earlier time.

The paleoclimatic curves and radiocarbon dates from the cores are in general agreement with what is presently known about the late-Quaternary climatic histories of both temperate and arid regions of North America (Martin and Mehringer 1965, Wright 1971). The Holocene AP-Compositae records provide no evidence for Altithermal (Antevs 1955) or Hypsithermal (Deevey and Flint 1957) intervals, when continental climate is believed to have been warmer and in some cases drier than at present. Those and other climatic events, however, may be obscured by gaps in the fossil records.

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