LATE-QUATERNARY PALEOECOLOGY OF THE CUATRO CIÉNEGAS BASIN, COAHUILA, MÉXICO

by

Edward Raymond Meyer

A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

ARIZONA STATE UNIVERSITY

June 1972

LATE-QUATERNARY PALEOECOLOGY OF THE
CUATRO CIÉNEGAS BASIN, COAHUILA, MÉXICO

by

Edward Raymond Meyer

has been approved

May 1972

APPROVED:

, Chairman
Gerald A. Cole
Neil Hadley
Donald J. Pinkava
James Schoenwetter

Supervisory Committee

ACCEPTED:

Department Chairman

Frederick C. Giffin
for Dean, Graduate College

LATE-QUATERNARY PALEOECOLOGY OF THE CUATRO CIÉNEGAS BASIN, COAHUILA, MÉXICO

by

Edward Raymond Meyer

An Abstract of a Dissertation Presented in
Partial Fulfillment of the Requirements
for the Degree
Doctor of Philosophy

ARIZONA STATE UNIVERSITY

June 1972

ABSTRACT

The Cuatro Ciénegas Basin is a small, intermontane valley in the Sierra Madre Oriental of northern México, located ca. 270 km SSE from the Big Bend of the Río Grande. Climatically and vegetationally, the area lies within the Chihuahuan Desert. The valley floor, averaging 740 m above sea level, has many streams, springs, and large, shallow, saline lakes, and supports a diverse and highly-endemic fauna. Surrounding mountains are higher than 2,500 m. Two sediment cores drawn from small, marshy, springs in the basin yielded fossil pollen records transgressing more than 30,000 radiocarbon years.

At present, the basin floor bears a complex mosaic of edaphically-controlled, successional, vegetational communities. Modern pollen rains on the valley floor are dominated by grass, cheno-am, and aquatic pollen types. Comparison of those components of local pollen rains to the nonarboreal fossil profiles indicates that vegetational assemblages ecologically equivalent, if not identical to those now present have existed on the basin floor since mid-Wisconsin time. The highly-endemic fauna, together with a lack of geological evidence for large, deep, Pleistocene lakes in the area afford strong support for this interpretation, and suggest that aquatic and terrestrial habitats of the valley lowlands were stable environments throughout the Quaternary, regardless of fluctuations in regional climate.

Vegetation on mountains adjacent to the basin varies from mesic, ponderosa pine forests at high elevations, to xeric, creosote bush savannas on bajadas. Modern pollen rains at high elevations are dominated by arboreal pollen types, mainly pine, while those on sites at lower elevations are dominated by Compositae pollen. All arboreal pollen and most composite grains reaching the valley floor are blown or washed in from surrounding mountains and bajadas. The 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 arid, north-central México. Trends in the fossil arboreal-Compositae pollen records indicate that regional climate was cooler and perhaps moister than at present during the last Pluvial. It became progressively warmer and drier during late-Pluvial time, and approximated modern climate during the Holocene. Holocene Altithermal, or Hypsithermal intervals were undetected, and may be obscured by gaps in the fossil profiles.

God's mercy

On the wild

Ginger man.

J. P. Donleavy

The Ginger Man (1955)

ACKNOWLEDGEMENTS

I thank Drs. W. L. Minckley and G. A. Cole for serving as co-chairmen of my graduate committee, and am grateful to Drs. N. Hadley, D. J. Pinkava, and James Schoenwetter for time and assistance as committee members. Special appreciation is proffered to Dr. G. L. Batchelder, San Francisco State College, for assistance in the laboratory, to J. J. Landye for assistance in the field, and to Drs. P. S. Martin, University of Arizona, and P. J. Mehringer, Jr., Washington State University, for stimulating conversations and suggestions.

I am particularly indebted to Dr. James Schoenwetter for teaching me the fundamentals of Quaternary palynology, for the use of his laboratory and equipment, and for many profitable conversations and suggestions concerning this entire project. Thanks are also expressed to Dr. D. J. Pinkava for plant identifications.

Funds for laboratory reagents and for three radiocarbon dates were provided by the Graduate Research Fund, Department of Zoology, Arizona State University. All other expenses were defrayed by National Science Foundation Grant GB-6477X, to W. L. Minckley.

TABLE OF CONTENTS

Page

ABSTRACT iii

ACKNOWLEDGEMENTS vi

LIST OF TABLES ix

LIST OF ILLUSTRATIONS x

INTRODUCTION 1

THE STUDY AREA AND ITS BIOTA 5

METHODS 9

Site Locations and Names 9

The Core Sites and Cores 9

Radiocarbon Dates 12

Fossil Pollen Sample Removal 15

Surface Samples 15

Pollen Extraction and Counting 18

Statistical Methods 18

RESULTS 20

Extraction Efficiency and the Pollen Flora 20

Pollen Categories 23

Duplicate Extractions and Counts 25

Modern Vegetation and Pollen Rain 26

Montane Vegetation 27

Valley Floor Vegetation 30

Modern Pollen Rain 34

The Fossil Records; First Count 49

Page

The Second Count 57

DISCUSSION AND CONCLUSIONS 64

LITERATURE CITED 70

APPENDICES 76

LIST OF TABLES

Table Page

1. Radiocarbon dates from cores E and F 13
2. Total pollen data accumulated 21
3. First count summarized by major pollen categories and sample assemblages 24
4. Chi-square analyses, north-facing slope surface pollen transect, Sierra de la Madera 37
5. Chi-square analyses, east-facing slope surface pollen transect, Sierra de San Marcos 38
6. Pollen proportions, grouped counts from surface samples gathered in habitats on the floor of the Cuatro Ciénegas Basin 44
7. Adjusted pollen proportions, grouped GCA counts from surface samples gathered on the floor of the Cuatro Ciénegas Basin 46
8. Compositae and AP proportions, grouped counts from surface samples gathered on the floor of the Cuatro Ciénegas Basin 59
9. Numbers and proportions of fragmented pine grains in modern and fossil samples 68

LIST OF ILLUSTRATIONS

Figure Page

1. Map of Coahuila, México, showing the location of the Cuatro Ciénegas Basin 6
2. Map of the Cuatro Ciénegas Basin 7
3. Vegetational map of core sites E and F 11
4. Pollen types encountered during the first count 22
5. Vegetation zones on Sierra de San Marcos and Sierra de la Madera 28
6. Generalized diagram of the valley floor successional patterns 33
7. Elevational pollen transects, Sierra de San Marcos and Sierra de la Madera 35
8. Pollen profiles from surface samples gathered on the floor of the Cuatro Ciénegas Basin 41
9. Adjusted grass, cheno-am, and aquatic pollen type proportions from surface samples gathered on the basin floor 47
10. Total pollen proportions, Core E 50
11. Total pollen proportions, Core F 51
12. Close-interval pollen proportions from a peat stratum in Core E 53
13. Close-interval pollen proportions from alternating clay and peat horizons in Core F 54
14. Close-interval pollen proportions from a clay stratum in Core F 55

LIST OF ILLUSTRATIONS (cont'd.)

Figure Page

15. Compositae and AP proportions from Core E 60

16. Compositae and AP proportions from Core F 61

INTRODUCTION

Fossil pollen is abundant in many kinds of Quaternary sediments, and provides a record of past vegetational assemblages. Analyses of fossil pollen floras may be presented in pollen diagrams that show percentages of pollen types counted in sediment samples from different stratigraphic levels. In regions where modern vegetation is in a completely natural condition, or has been modified only slightly by human activities, such as in the present study area, interpretations of late-Quaternary fossil pollen records may be controlled with pollen spectra that characterize modern plant communities—i.e., interpretations are based on comparing fossil diagrams with profiles of pollen rains typical of extant plant formations. The approach is both uniformitarian and synecological, and is based on the assumption that there are modern analogs for vegetational units reflected by fossil pollen profiles. Although that is not always the case (Wright, 1971), this method has been used successfully in studies from many different areas of North America. Since climate is a major factor determining the type of vegetation that can exist within a given area, Quaternary fossil pollen diagrams can also provide an indirect measure of past climatic conditions, on a gross basis. The rational underlying control of fossil pollen records with modern profiles from natural vegetational communities, as well as problems and weaknesses inherent in the method, are discussed in detail by Wright (1971).

Analyses of fossil pollen floras to answer questions concerning Quaternary climatic fluctuations were first reported in 1916 by

Lennart von Post (1967) in a lecture presented at a scientific meeting in Sweden. The approach was new at that time, and its potential value as a key to past environments was immediately obvious to European scientists. Quaternary pollen analysis is presently used by paleoecologists, zoogeographers, geologists, and anthropologists from many countries, to reconstruct past climates and vegetational assemblages, and as a technique for making stratigraphic correlations. It has proven applicable with varying degrees of success on local and regional levels. Von Post's original profiles were from bogs, and many fossil pollen chronologies developed since then are from lacustrine sediments. Alluvial, marine, spring, marsh, and fluvial sediments, as well as cave fills and human middens, however, have also yielded valuable records. Some workers have even produced fossil pollen spectra from materials as diverse as packrat middens (van Devender and King, 1971), dung of giant ground sloths now extinct (Martin, Sables, and Schutler, 1961), and human coprolites (Martin and Sharrock, 1964). Theoretical and practical considerations underlying Quaternary palynology are reviewed by Martin and Gray (1962), Davis (1963, 1969), Martin (1963), Faegri and Iversen (1964), Mehringer (1967), Bryant and Holz (1968), Erdtman (1969), and Wright (1971).

Pollen studies using Quaternary deposits from arid regions in western North America were shown to be profitable by Sears (1937), and Clisby and Sears (1956) demonstrated the feasibility of pollen analysis of lacustrine sediments cored from xeric, lowland sites in the southwestern United States with their chronology from the San Augustin Plains, New Mexico. Numerous late-Quaternary pollen records have appeared from the American Southwest since 1956, collectively documenting a generally cooler-moister, to warmer-drier regional Pluvial/post-Pluvial climatic sequence, concurrent with uphill displacement of mesic vegetation in areas having exaggerated topographic relief. That information, representing many local investigations from eastern California, southern Nevada, Arizona, New Mexico, northwestern Chihuahua, and Texas, is summarized by Martin (1963), Oldfield and Schoenwetter (1964), and Martin and Mehringer (1965). Later reports from Texas archaeological sites (Bryant, 1966; Bryant and Larson, 1968), from marsh and spring deposits in the Great Basin and Mojave deserts (Mehringer, 1967 and personal communication), and from the central Sierra Nevada (Adam, 1967; Batchelder, 1970) add to the story. Late-Pleistocene and Holocene pollen records are also available from southern Mexico and Central America (Clisby and Sears, 1955; Sears and Clisby, 1955; Tsukada, 1966; Tsukada and Deevey, 1967; Schoenwetter, personal communication), but none currently exist from arid, north-central México, between the Río Grande to the north, and the Valley of México to the south.

In August, 1968, W. L. Minckley and two assistants drew four long sediment cores from springs in the Cuatro Ciénegas Basin, a small, desert valley in central Coahuila. I received the cores in October, 1968—two appeared suitable for pollen analysis, and proved so by yielding the fossil chronologies reported here. The purpose of this investigation at its inception was to reconstruct in as much detail as possible the vegetational and climatic histories of the basin for the time transgressed by the cored sediments. Since vegetation in the Cuatro Ciénegas area has been modified only slightly by man, I controlled the fossil records with pollen spectra from modern soil samples gathered in natural vegetation formations on the valley floor and on surrounding mountains. The fossil nonarboreal pollen records (excluding the Compositae) presented here provide a history of local vegetational successions on the floor of the Cuatro Ciénegas Basin since mid-Pluvial time. The arboreal and Compositae components of the fossil records are the first, late-Cenozoic, palynoclimatic sequences available from arid, northeastern México.

THE STUDY AREA AND ITS BIOTA

The Cuatro Ciénegas Basin lies at approximately 27° N latitude and 104° W longitude on the northeastern edge of the Mesa del Norte of northern Mexico (West, 1964), immediately south of Cuatro Ciénegas de Carranza, Coahuila (Fig. 1). Its floor (Fig. 2) 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 is unique in having many springs, streams, ponds, and large, shallow, lakes. Its biota was brought to the attention of American biologists through collections made in 1939 by E. G. Marsh, Jr., and has been subjected to intensive study by W. L. Minckley and associates since 1958, when Minckley first visited the area. Minckley (1969) recently provided a physical and geological description of the basin, and summarized the status of biological research from the area.

Deeming the diverse assemblage of animals known only from the Cuatro Ciénegas Basin "remarkable" (Taylor, 1966) approaches an understatement. Aquatic organisms endemic in the valley include at least nine kinds of fishes (Minckley, 1969), three genera and four species of stenasellid and cirolanid isopods (Cole and Minckley, 1972), and at least 13 species of hydrobiid snails, which are also autochthonous to the area (Taylor, 1966). Five species of scorpions of the genus Vejovis (Williams, 1968) and certain other terrestrial arthropods may

Figure 1. Map of Coahuila, México, showing the location of the Cuatro Ciénegas Basin.

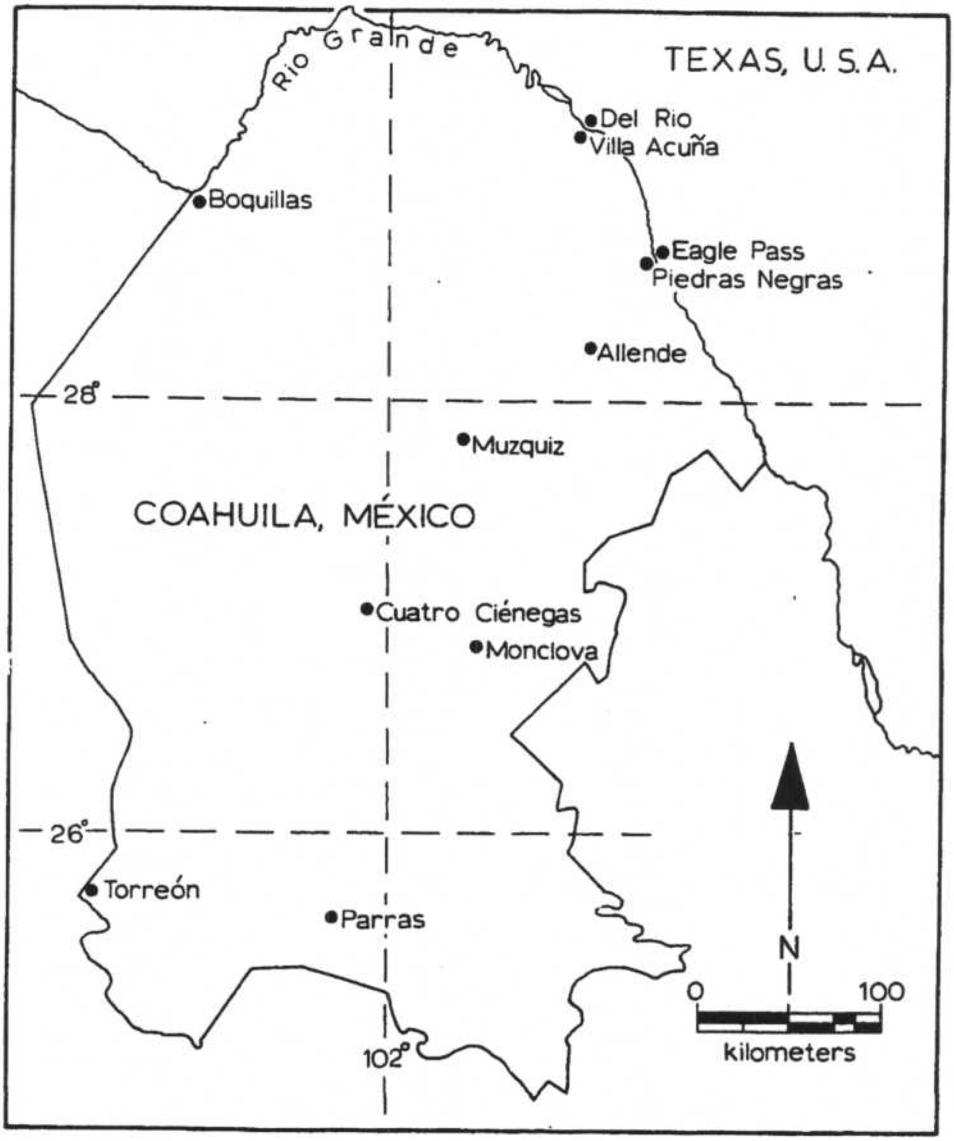
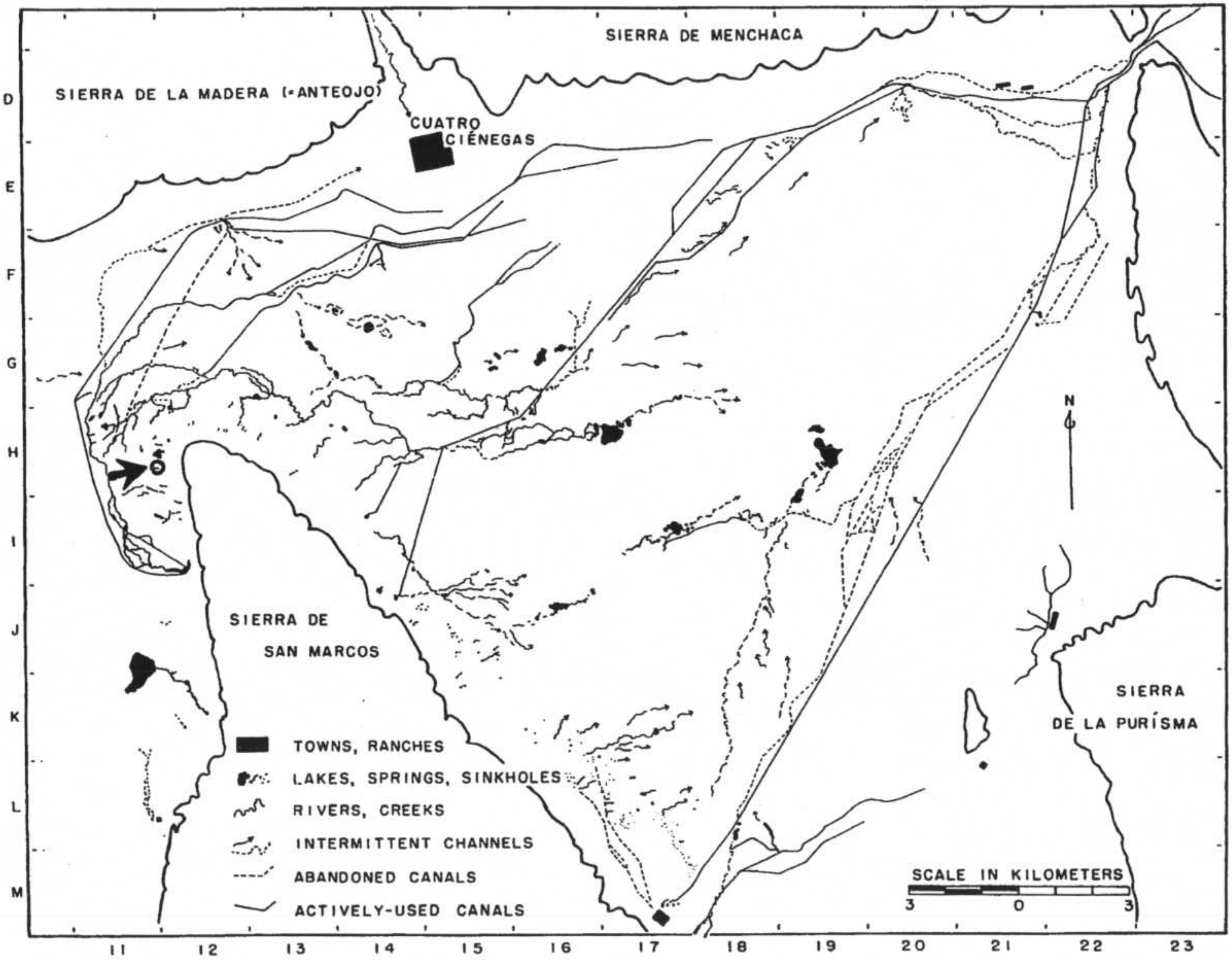

Rio Grande
TEXAS, U.S.A.
Del Rio
Villa Acuña
Boquillas
Eagle Pass
Piedras Negras
Allende
28°
Muzquiz
COAHUILA, MÉXICO
Cuatro Ciénegas
Monclova
26°
Torreón
Parras
N
0
100
kilometers
102°

Figure 2. Map of the Cuatro Ciénegas Basin. Location of the springs from which cores E and F were drawn is indicated by an open circle and an arrow.


SIERRA DE LA MADERA (=ANTEOJO)
SIERRA DE MENCHACA
CUATRO CIÉNEGAS
SIERRA DE SAN MARCOS
SIERRA DE LA PURÍSMA
N
TOWNS, RANCHES
LAKES, SPRINGS, SINKHOLES
RIVERS, CREEKS
INTERMITTENT CHANNELS
ABANDONED CANALS
ACTIVELY-USED CANALS
SCALE IN KILOMETERS
3
0
3
D
E
F
G
H
I
J
K
L
M
11
12
13
14
15
16
17
18
19
20
21
22
23

be comparable (Mont A. Cazier, personal communication). The herpetofauna of the basin also contains numerous endemic species (Hubbs and Miller, 1965), a considerable portion of which are relicts (McCoy and Minckley, 1972). Descriptions of new fishes, snails, and other organisms are in progress (W. L. Minckley and J. J. Landye, personal communication), and new species continue to be discovered as field work in the area progresses.

The degree of endemism exhibited by this fauna implies long-term isolation of the Cuatro Ciénegas Basin 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, which suggests that the special spring and pond habitats those organisms require existed in the valley throughout the Cenozoic. No geological evidence (e.g., shoreline carbonate deposits, strand lines, etc.) has been found in the area depicting past existence of large, deep, lakes, as were present in many closed and presently arid basins of the Basin and Range physiographic province to the northwest during more mesic periods of the Quaternary (Morrison, 1965). Minckley (1969) and Lytle (1972) believe such lakes did not form in the study area because of persistent drainage through deep, antecedent channels. Pollen data presented below support these postulations of Cenozoic environmental stability by indicating that aquatic habitats and terrestrial vegetation formations similar, if not identical to those now present have existed on the valley floor since at least mid-Wisconsin time.

METHODS

Site Locations and Names

Fig. 2, an outline map of the Cuatro Ciénegas Basin and its drainages prepared by Minckley (1969), is framed by a 2.5 km^2 grid in which vertical (north-south) sections are designated numerically, and horizontal (east-west) sections are designated alphabetically. Localities in the valley discussed below are coded parenthetically by this system to facilitate finding them on the map, and compass subdivisions of grid squares are included for increased precision. Most of the town of Cuatro Ciénegas, for example, lies within NW$\frac{1}{4}$, E15. Place names applied along with grid coordinates for certain sites follow Minckley (1969) and local terminology. In the local Spanish dialect, ponds, large, flowing springs, and shallow lakes are called "lagunas," while small springs and open pits containing water are called "posos."

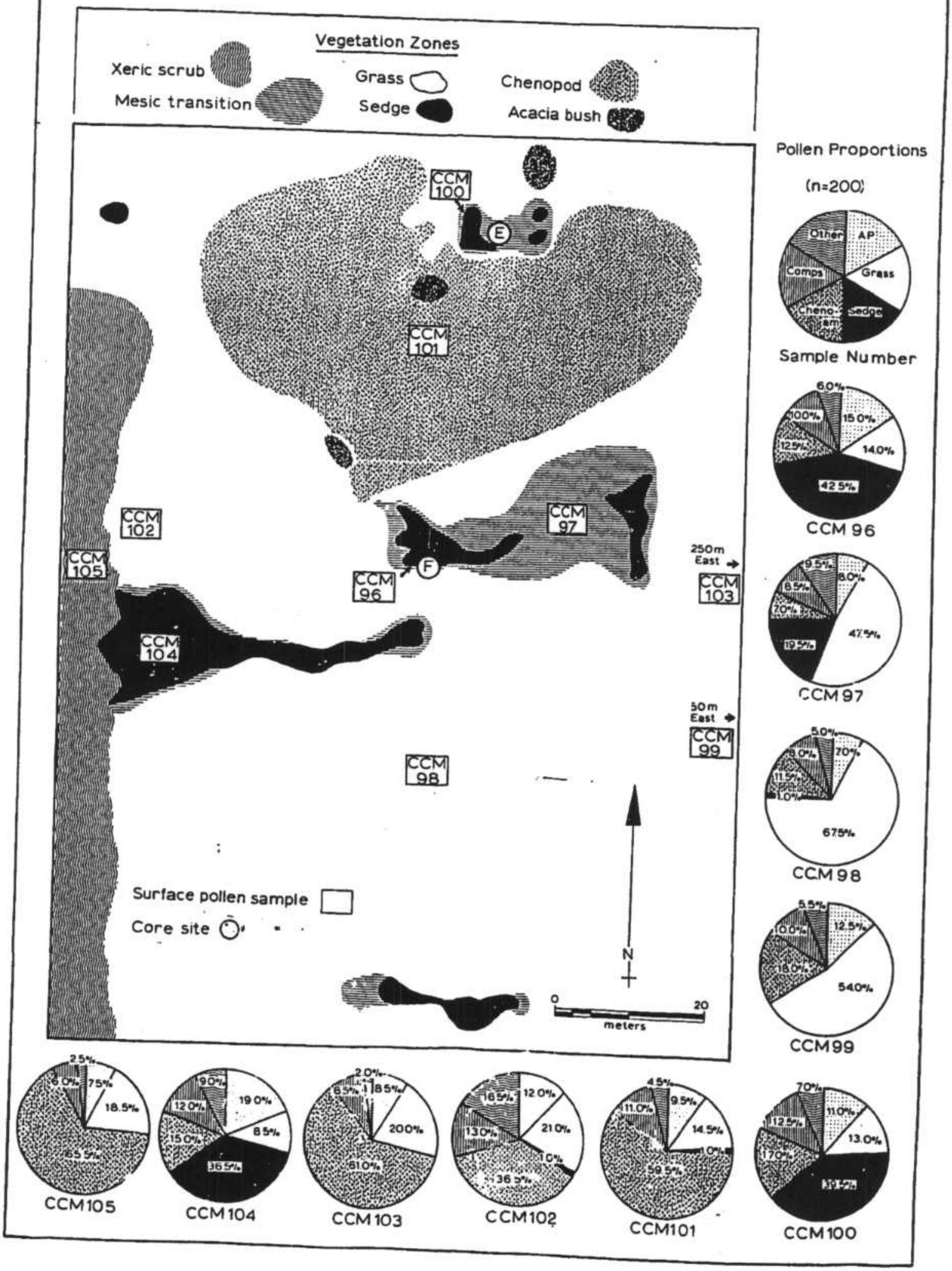
The Core Sites and Cores

The flanks of Sierra de San Marcos, which bisects the basin on a generally north-south axis (Fig. 2), are covered by a continuous apron of small, coalescing, alluvial fans that collectively form a weakly-developed bajada. The bajada slopes gently outward from the mountain, and overlies sediments of the valley floor. A perimeter of springs closely surrounds the outer margins of this bajada; many are perennial limnocrenes, supplying water to surficial drainages, while others are less active, with discharge limited to a slow, persistent, percolation. All kinds support dense beds of sedges, hence are easily located visually among the usually lower, more xeric, terrestrial vegetation. Sediments cored from two springs of the last type yielded the fossil pollen records reported here.

The cores, designated Cores E and F by the collectors, were drawn manually, using automobile jacks and a 5-cm x 100-cm, cylindrical, piston corer~~,~~ from small, marshy, helocrenes located ca. 300 m west from the outer margin of a bajada that extends from the northwest tip of Sierra de San Marcos (NW$\frac{1}{4}$, SW$\frac{1}{4}$, H12; Figs. 2 and 3). The springs are 45 m apart on a north-south axis, and appear to be extinct feeders of an ancient lake, a remnant of which may be Laguna Juan Santos (center, W border, H12). Core E, consisting of 9, 20-cm to 98-cm segments (Appendix 1 a), produced a hole measuring 8 m deep. Core F, composed of 18, 25-cm to 100-cm sections (Appendix 2 a), produced a hole 16 m deep. 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 at the 16-m depth by mechanical failure of the coring equipment. Core sections were sealed in cellophane wrap when extruded in the field, and returned to the laboratory for stratigraphic description and pollen sample removal. In the laboratory, Core E measured 6.18 m long, and Core F measured 13.86 m long. The discrepancies between these lengths, and depth measurements made in the field, may have resulted from compression of sediments during the coring operation, or perhaps from shrinkage due to desiccation during transport and storage of the segments.

Figure 3. Vegetational map of core sites E and F.

Pollen Rain and Vegetation, Cores 'E' and 'F' Sites, Cuatro Ciénegas Basin, Coahuila, México



Both cores consisted of extremely complex series of clay, peat, and mixed clay and peat horizons, often containing granular travertine. Their stratigraphies are presented in Appendices 1 b and 2 b. When describing the cores, I coded colors exhibited by clay strata following a Munsell soil color chart. Peats were uniformly black, and comprised approximately 21% of the total length of Core E, and roughly 8.5% of the total length of Core F. Although data presented below indicate that sedimentation rates were equivalent 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, and peat-clay sequences and depth relationships were unsuccessful. This suggests that the springs have quite different hydrological and depositional 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 I submitted a sample from each of those horizons to Gakushuin University, Tokyo, Japan, for dating. The results, presented in Table 1 and on following pollen diagrams, provide a measure of absolute temporal control for the fossil records. Radiocarbon chronologies from springs, however, should be interpreted with caution. Ancient carbon may enter solution in water passing through deep spring sediments, become available in carbon dioxide or other compounds to plants growing at the

TABLE 1. Radiocarbon dates from cores E and F.

Laboratory code	Core depth	C^{14} years BP (before 1950)
	Core E	
GaK-2813	2.36-2.41 m	12,480 ± 280
	Core F	
GaK-3130	3.57-3.62 m	18,200 ± 600
GaK-2812	8.17-8.28 m	$19{,}360 \begin{smallmatrix}+ 2140 \\ - 1660\end{smallmatrix}$
GaK-3129	10.95-11.00 m	> 31,400
GaK-2811	13.17-13.31 m	> 26,800

springs, and ultimately be redeposited in forming peats. Damon, Haynes, and Cole (1964) reported 17,000-25,000 BP radiocarbon dates from modern aquatic plants collected in Montezuma Well, Yavapai County, Arizona, and attributed the anomaly to ancient, reworked carbon accumulated metabolically by the plants tested. Recognizing the possibility that carbon in sediments at the core sites could also have been reworked by groundwater activity, I submitted a collection of sedges from the spring that deposited 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 ± 2.4 BP (A-1191), represents atmospheric equilibrium, and is the same value the University of Arizona laboratory obtained in 1968 from fresh mulberry (Morus sp.) leaves grown in Tucson (Austin Long, personal communication). Based on that datum, I interpret the >31,400 BP and >26,800 BP dates from deeper sections in Core F as indication that its basal sediments transgress mid-Wisconsin time.

Hubbs, Bien, and Suess (1965) reported a 2,070 ± 250 BP radiocarbon date from a peat sample removed from the 2.25-m to 2.35-m depth in a core collected at Posos de la Becerra (SW½, I12). Comparison of that value with the 12,480 ± 280 BP date from between 2.35-m and 2.41-m in Core E indicates that sedimentation rates are markedly unequal in different parts of the valley. Additional radiocarbon dates from the Cuatro Ciénegas area were published by Taylor (1956), but those are from cave archaeological sites, and do not apply to this investigation.

Fossil Pollen Sample Removal

Sediment samples ca. 1 cm^3 in size were initially removed from the cores at roughly 20-cm intervals for pollen analysis. Later in the study, 0.3 cm^3 to 0.5 cm^3 samples were removed at 1-cm to 5-cm intervals from a clay stratum in Core F, a peat stratum in Core E, and from narrow, varve-like, alternating clay and peat horizons in Core F, to measure close-interval variations in fossil pollen contained in those sediment types. Before removing a sample, I scraped the core surface to a depth of 0.5 cm with a clean spatula to avoid contaminating the sample with foreign pollen that may have accumulated on the outer surface. Samples were stored in tape-sealed plastic bags. To limit contamination by airborn pollen grains as much as possible, the bags were opened and samples handled only under a fume hood.

Surface Samples

Depending on the nature of the fossil record to be interpreted, modern pollen samples may be collected in sediment traps of various types, or may be obtained from natural sedimentation surfaces. Pollen preservation _in situ_, moreover, depends on physical and chemical properties of the depositional situation (Faegri and Iversen, 1964). Since the complex stratigraphies of cores E and F implied a variety of depositional environments, I controlled the fossil pollen profiles from the Cuatro Ciénegas Basin with spectra from modern sediment samples gathered on soil surfaces in terrestrial habitats, and from the mud/water interface in aquatic habitats, to account for possible dissimilarities in pollen preservation between different levels in the cores. Surface samples were gathered in multiple subsamples as described by Hevly and Martin (1961), Bent and Wright (1963), Hevly, Mehringer, and Yocum (1965), and Mehringer (1967), and stored in tape-sealed plastic bags. At each collection site detailed notes were taken concerning plants present, surficial extent of the vegetational unit, and the general edaphic nature of the area, and photographs were taken of most collection sites for future reference. In the laboratory, modern pollen samples were handled in the same manner as were fossil samples. The surface samples I accumulated fell into two major assemblages; those from elevational transects up mountains surrounding the basin, and those from the valley floor. Pollen profiles from the elevational transects illustrate the nature of pollen rains on local montane environments, where areal extent and species composition of vegetational communities are controlled by physiographic factors such as slope exposure, and altitudinal variations in meteorological parameters such as temperature and rainfall. The transects were designed to provide data to control fossil profiles of pollen types produced by upland vegetation. The samples from the basin floor supply modern pollen spectra from an area where distributions and compositions of vegetational assemblages are determined mainly by edaphic factors such as soil moisture and salinity. Those spectra are used to control fossil profiles of pollen types produced by lowland vegetation.

I accumulated 61 modern sediment samples. Nine of them comprised a transect up the east slope of Sierra de San Marcos, from the mountain's base at Ejido Santa Tecla (SE$\frac{1}{4}$, M17; 775 m), to near its summit at 2,400 m. David Greegor and J. J. Landye collected three samples for that series during August, 1968, and I gathered six in April,

1969. Seven samples I collected in August, 1970, are used as a transect up the north slope of Sierra de la Madera, a range forming the basin's northwest boundary (D11-D14). That series extends from the base of the mountain at 800 m, to near its summit (ca. 3,000 m) at 2,600 m. One additional sample was obtained in a montane situation, on a south-facing bajada that extends from Sierra de Menchaca (NW¼, SW¼, D16). The remaining 44 samples were taken in various plant formations on the valley floor. I collected 42 of those during January and June, 1969, and August, 1970, and D. Greegor acquired two in August, 1968. Collection site elevations for the samples from Sierra de San Marcos were read from a 50-m contour interval topographic quadrangle of the southwest portion of the basin provided by Petroleos México, D. F. Site elevations on Sierra de la Madera were estimated from an air navigation chart (500-m contour intervals) published by the U. S. Air Force Aeronautical Chart and Information Center, St. Louis, Missouri. More precise elevational control would be desirable for the samples from Sierra de la Madera, but topographic charts more detailed than the one used are presently unavailable in both the United States and México, and an altimeter was not available when I collected there. Forty-nine of the surface samples contained sufficient pollen for analyses; sites at which those were collected are specified in Appendix 3. The degree of control those samples provided for the fossil records could have been increased by analyses of additional modern samples, but further collections were not possible due to limitations on time available for field work. The data available, however, were sufficient to satisfy the initial objectives of the investigation.

Pollen Extraction and Counting

I used Mehringer's (1967) extraction procedure, and also subjected samples containing organic debris in noticeable amounts to a 1.5 min, hot, acetolysis (Gray, 1965). Residues were stored in 5-dr shell vials. Preparations for counting were suspended in glycerol, stained with basic fuchsin, and mounted under 20 x 60-mm, no. 0, glass cover slips. Counting was done under a Leitz "Ortholux" binocular microscope at 540 X. I performed two, fixed-sum counts (Mehringer and Haynes, 1965; Mehringer, 1967). In the first, which included all pollen types, I attempted to tally at least 200 grains from all modern and fossil samples. In the second, including only Compositae and arboreal pollen types, I tried to establish a sum of at least 100 grains for all fossil samples, and for all surface samples from the valley floor. During the first count, all grains too eroded or battered to be identified, and all unknown pollen types, were grouped as unidentifiables. Unidentifiables that appeared repeatedly were categorized by morphological descriptions. Raw data from the first count are tabulated in Appendix 4, and second count data are given in Appendix 5.

Statistical Methods

Statistical procedures useful in pollen analysis are presented by Barkley (1934), Faegri and Iversen (1964); Mosimann (1962, 1963, 1965), Martin and Mosimann (1965), and Adam (1970). I calculated Chi-square values from contingency tables, following Mosimann (1965), and read probability values from a table of Chi-square, using (n - 1)(k - 1) degrees of freedom (n samples, and k pollen types, or categories). The Yates correction for continuity of the Chi-square distribution was applied in cases having only one degree of freedom.

RESULTS

Extraction Efficiency and the Pollen Flora

One hundred fifty-eight, or roughly 84% of 188 surface and cored sediment samples contained sufficient pollen for analysis (Table 2). During the first count (n = 31,268), 144 samples yielded 200 or more grains, and 14 yielded 100 to 199 grains each. In the second count (n = 15,833), 138 samples afforded 100 or more grains, 18 produced 50 to 99 grains, and two yielded 25 to 49 grains each. Pollen was rare and poorly-preserved in most samples. Thirty-five pollen types, including the unidentifiable group, appeared in the first count; Fig. 4 presents their distributions among sample assemblages that developed during the investigation. The Gramineae column in Fig. 4 includes two corn (Zea) grains present in a sample removed 10 cm below ground surface in Core F. No pollen type was consistently diagnostic of samples from any one of the assemblages, although grains from aquatic plants were absent from all samples taken at montane locations. No additional types appeared during the second count, but I observed a grain from alder (Alnus) on an extra slide made from a sample removed 50 cm below ground surface in Core F. Alder is not known from the Cuatro Ciénegas area, but two kinds, thinleaf alder (A. tenuifolia Nutt.) and Arizona alder (A. oblongifolia Torr.) grow at high elevations on mountains in northern México (Preston, 1966). The grain I found could have been transported to the valley from a distant source, perhaps by wind, or it could indicate that alders grew in or near the basin at an earlier time.

Table 2. Total pollen data accumulated.

Sample assemblages	Samples extracted	Samples counted	% return	First count n	Second count n
		Modern Control Samples			
Valley floor	44	32	72.73	6,400	3,074
Altitudinal transects	17	17	100.00	3,175	2,371
Total modern	61	49	80.33	9,575	5,554
		Fossil Samples			
Core E	39	33	84.62	6,291	3,100
Core F	88	76	86.36	15,042	7,288
Total fossil	127	109	85.83	21,693	10,388
Grand total	188	158	84.04	31,268	15,833

Figure 4. Pollen types encountered during the first count.

POLLEN TYPES

SAMPLE ASSEMBLAGES		Gramineae.	Cheno-ams	Pinus	Lo-spine Compositae	Hi-spine Compositae	Quercus	Cyperaceae	Cupressaceae	Artemisia	Celtis-Moraceae	Typha	Ephedra	Agave	30u, 3C-3P, unk.	15u, 3C 3P, unk.	Liliaceae	30u, 4C-5C, unk.	Polygala
Altitudinal Transects		☒	☒	☒	☒	☒	☒	☒	☒	☒	☒		☒	☒	☒		☒		☒
Total Valley Surface		☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
Vegetation Zones	Sedge-Riparian	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒		
	Chenopod	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒		☒		☒		☒	☒	
	Grassland	☒	☒	☒	☒	☒	☒	☒		☒	☒		☒	☒	☒	☒	☒		
	Transition	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
	Bare Surface	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒		☒		☒				
Core E		☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
Core F		☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
TOTAL GRAINS PER POLLEN TYPE		10130	8046	4544	2103	1546	1404	1375	408	399	174	150	93	50	59	41	38	19	16
PERCENT TOTAL POLLEN		32.399	25.732	14.532	6.726	4.944	4.490	4.398	1.305	1.276	0.557	0.480	0.297	0.160	0.189	0.131	0.122	0.061	0.051

SAMPLE ASSEMBLAGES		Picea	Abies	Eriogonum	Euphorbiaceae	Solanaceae	Prosopis	Acacia	Sarcobatus	Rosaceae	Polygonum	Tidestromia	Caprifoliaceae	Larrea	Onagraceae	Opuntia	Umbelliferae	Unidentified	TOTAL TYPES
Altitudinal Transects		☒	☒		☒			☒						☒		☒		☒	21
Total Valley Surface				☒	☒	☒	☒	☒	☒	☒	☒	☒		☒				☒	29
Vegetation Zones	Sedge-Riparian				☒				☒		☒	☒						☒	20
	Chenopod			☒			☒	☒				☒		☒				☒	20
	Grassland																	☒	15
	Transition			☒	☒	☒		☒		☒		☒						☒	25
	Bare Surface						☒					☒						☒	15
Core E		☒	☒	☒	☒	☒	☒		☒		☒	☒	☒		☒			☒	30
Core F		☒	☒	☒	☒	☒	☒		☒	☒	☒		☒				☒	☒	28
TOTAL GRAINS PER POLLEN TYPE		15	13	12	11	11	10	6	7	6	5	5	3	2	1	1	1	564	
PERCENT TOTAL POLLEN		0.048	0.041	0.038	0.035	0.035	0.032	0.019	0.022	0.019	0.016	0.016	0.010	0.006	0.003	0.003	0.003	1.804	

Pollen Categories

First count data are summarized in Table 3. Grouped pollen types, or categories, proved more useful than single types in characterizing major sample assemblages. Arboreal pollen (= AP) includes pine (Pinus), oak (Quercus), fir (Abies), spruce (Picea), and the cypress family, Cupressaceae. With the possible exception of spruce, trees or shrubs of all taxa included in the AP grow in montane environments in the study area. Since cypress (Cupressus) and juniper (Juniperus) pollens are indistinguishable under a light microscope, and Arizona cypress (C. arizonica Greene) grows in the Cuatro Ciénegas area while juniper is not known from the vicinity, I assume all or most grains tallied as Cupressaceae were the former. The "GCA" category contains pollen from grasses (Gramineae), cheno-ams, and aquatic plants. Cheno-ams, an artificial group proposed by Martin (1963), includes male gametophytes from the goosefoot family (Chenopodiaceae) and from the genus Amaranthus (Amaranthaceae); in arid regions these taxa require similar habitats, and their pollens are indistinguishable. McAndrews (1967) feels that Chenopodiineae is a more suitable title for this assemblage of palynomorphs. The aquatic category refers to pollen from sedges (Cyperaceae) and cattail (Typha). A cattail, T. domingensis Pers., and at least nine kinds of sedges now grow in the basin. Modern pollen spectra from the basin floor as a unit were characterized by high GCA frequencies, and differences between pollen profiles from different habitats on the valley floor were diagnosed by fluctuations of proportions within the GCA. The Compositae category contains

TABLE 3. First count summarized by major pollen categories and sample assemblages.

	AP		GCA		Compositae		Others		
Sample assemblages	number	percent	number	percent	number	percent	number	percent	n
Valley floor	518	8.09	4,776	74.63	793	12.39	313	4.89	6,400
Altitudinal transects	1,549	48.79	643	20.25	822	25.89	161	5.07	3,175
Core E	1,395	22.17	4,026	64.00	624	9.92	246	3.91	6,291
Core F	2,922	18.97	10,256	66.59	1,809	11.75	415	2.69	15,402
Total fossil	4,317	19.90	14,828	65.83	2,433	11.22	661	3.05	21,693

pollen from the sunflower family. Following convention, I separated echinate grains in this group as high- and low-spines, based on having supratectate projections either greater than, or less than 2 µ long. The distinctive pollen from the composite Artemisia was enumerated separately. The "others" category contains 1,135 grains, or 3.63% of the first count. Five hundred sixty-four, or 49.69% of these and 1.80% of the first count, were unidentifiables. Five hundred seventy-one, or 50.31% of the "others", and 1.83% of the first count, include 22 rare pollen types that appeared sporadically in my samples. The "others" were of little interpretive value. The AP, GCA, and Compositae categories, containing 12 pollen types, comprised 95% to 97% of the first count. Samples from montane localities were characterized by AP and Compositae frequencies that collectively exceeded 50%, GCA proportions less than 35%, and absence of pollen from aquatic plants. Profiles from the valley floor were typified by less than 20% AP, less than 22% Compositae, and more than 58% GCA. Fossil spectra closely resembled those from modern samples collected on the basin floor.

Duplicate Extractions and Counts

To test methodological consistency, I performed duplicate extractions and counts of at least 100 grains, including all pollen types, on peat samples removed 2.4 m below ground surface in Core E and 3.1 m below surface in Core F, and on clay samples from 3.5 m below surface in Core F. The peats received acetolysis, the clays did not. Grains observed were grouped by the four major pollen categories defined above, and each set of data was subjected to a Chi-square test for homogeneity. I included the "others" with the Compositae for these computations so that all expected class values would exceed five, as required by the Chi-square method. All three results were insignificant ($P > 0.05$), indicating the two counts forming each data set to be statistically similar. Duplicate counts were also performed on two samples taken from a clay horizon 3 m below surface of Core E. In this case both samples received Mehringer's (1967) extraction sequence, but only one was acetolyzed. The Chi-square value calculated using these data was again insignificant ($P > 0.2$). These analyses document procedural consistency.

Modern Vegetation and Pollen Rain

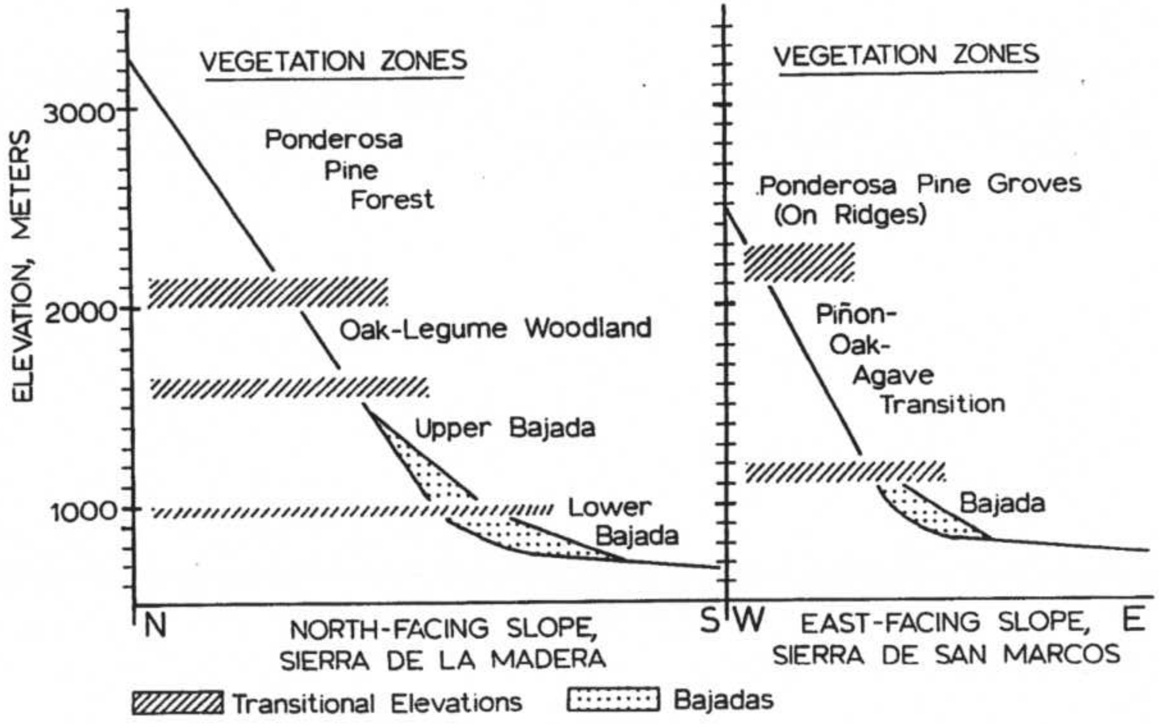
Müller (1947) provided a regional survey of Coahuilan vegetation and climates, and Gilmore (1947), Minckley (1969), and Pinkava (1969) presented preliminary botanical descriptions of the Cuatro Ciénegas Basin. A general description of vegetation on the north slope of Sierra de la Madera, including a diagram similar to Fig. 5 of vegetational zones on that range, was published by Baker (1956). My study required a relatively detailed account of plants characterizing different habitats in the valley and on surrounding mountains. While compiling that information, I applied names to discernible vegetational formations. The names are purely descriptive, and are proposed only to facilitate interpreting modern and fossil pollen spectra.

Montane Vegetation

Biotic and abiotic factors controlling vertical plant distributions in montane desert regions in North America are reviewed by Shreve (1922, 1942) and many other authors. Vegetation zones on Sierra de San Marcos and Sierra de la Madera are summarized in Fig. 5. An extensive, pine forest persists above 2,000 m on the north-facing slope of Sierra de la Madera, a high, massive, range. Ponderosa pine (*Pinus ponderosa* Laws. var. *arizonica* [Englm.] Shaw) dominates the landscape, and a few true firs (*Abies* sp.), Douglas firs (*Pseudotsuga* sp.), and Arizona cypress are present. Pine forests on Sierra de San Marcos, a lower, 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 oaks (several species), prickly-pears (*Opuntia* spp.), agaves (*Agave* spp.), barrel cacti (*Ferocactus* sp.), grasses, piñons, (*Pinus cembroides* Zucc. var. *romata* Little), and acacias (*Acacia* spp.). A dense, low, chaparral-like woodland, dominated by scrub oaks and acacias (several kinds of each) grows on Sierra de la Madera between the pine forest, and a well-developed bajada that extends northward from the mountain. Piñons, grasses, prickly-pears, agaves, palms (*Brahea bella* Bailey), and hackberry bushes (*Celtis pallida* Torr.) are also present in this 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 community, and a less diverse, lower assemblage. The upper bajada community includes creosote bushes (*Larrea divaricata* Cav.), ocotillos (*Foquieria*

Figure 5. Vegetation zones on Sierra de San Marcos and Sierra de la Madera.

Vegetation Zones, Sierra de la Madera &
Sierra de San Marcos, Cuatro Ciénegas Basin,
Coahuila, México



splendens [Roem. and Schult.] Nash), candelillas (*Euphorbia antisyphilitica* Zucc.), prickly-pears, hedgehog cacti (*Echinocactus* spp.), tree yuccas (*Yucca* sp.), agaves, club cholla (*Opuntia* sp.), barrel cacti, limebushes (*Jatropha dioica* Seese), and mesquite (*Prosopis glandulosa* Torr. var. *torreyana* [L. Benson] M. C. Johnson). The lower bajada formation is a creosote bush savanna, with occasional tree yuccas and prickly-pears. The east slope of Sierra de San Marcos is steep, and extensively dissected by canyons. Vegetation there does not form well-defined zones, but grades from mesic, pine forests at high elevations, to xeric, desert assemblages on bajadas. Piñons and Arizona cypress occupy ridges between canyons, and canyon floors support scrub oak thickets. Dense stands of *Agave lechihuilla* Torr. cover intermediate slopes. Grasses, tree yuccas, barrel cacti, ocotillos, acacias, prickly-pears, candelillas, and hackberry bushes are present throughout this area. Geologically, bajadas on Sierra de San Marcos are smaller and less developed than are those of Sierra de la Madera. At different areas within the same elevational range on the former, vegetation varies from creosote bush savannas, structurally equivalent to the lower bajada community on Sierra de la Madera, to more diverse desert assemblages, similar to the upper bajada community on Sierra de la Madera. The same xerophytes grow on the bajadas of both mountains, but are not zoned into recognizable subunits on Sierra de San Marcos. A locally-abundant cactus, *Opuntia bradtiana* (Coulter) Brandagee, is common in the Sierra de San Marcos bajada community, but absent from Sierra de la Madera.

Valley Floor Vegetation

The floor, or "barrial" (West, 1964) of the Cuatro Ciénegas Basin supports a complex mosaic of vegetational communities that are coeval seres in a local, edaphic successional sequence. 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.

Plants restricted to open water comprise an aquatic association. In different parts of the valley, these include a water-lily (Nymphaea ampla DC.), a pondweed (Potamogeton nodosus Poir. in Lamarck), widgeongrass (Ruppia maritima L.), muskgrasses (Chara spp., Nitella spp.), bladderworts (Utricularia spp.), and horned pondweed (Zanichellia palustris L.). A riparian association exists adjacent to open waters. Stream banks, and rheocrenes and limnocrenes supplying streams are flanked by dense stands of sedges (Scirpus olneyi Gray, Eleocharis rostellata Torr., E. cellulosa Torr., Schoenus nigricans L., and Cladium jamaicense Crantz). Helocrenes, such as the small, marshy, springs that yielded Cores E and F, also support sedge beds (Carex prenglei L. H. Bailey, Dichromena colorata [L.] Hitchc., Eleocharis rostellata, Fimbristylis spadicea [L.] Vahl., and Scirpus olneyi). Lagunas are surrounded by mixed sedge and cattail beds, rarely including ash (Fraxinus sp.), mesquite, willow (Salix sp.), and seepwillow (Baccharis glutinosa Pers.).

More mesic sections of the barrial support an extensive grassland community. In such areas, effective moisture, or soil moisture available to plants (Martin, 1963), is lower and soil salinity is higher than at riparian sites, and three salt-tolerant grasses, dropseed (*Sporobolus spiciformis* Swallen), bunchgrass (*S. airoides* [Torr.] Torr.), and saltgrass (*Distichlis stricta* [Torr.] Rybd.), are the dominant taxa. Other obvious members of this association are mesquite, prickly-pear, yucca, beargrass (*Nolina cespitifera* Trel.), sotol (*Dasylirion cedrosanum* Trel.), catclaw-acacia (*Acacia greggii* Gray), and several kinds of succulent composites. Transitions between grassland and riparian habitats are usually abrupt, but intermediate situations supporting ecotonal vegetation are present. The transitional assemblage varies considerably in composition at different localities. It includes, in addition to herbaceous plants common in both seral communities, a composite (*Flaveria chloraefolia* Gray), water pimpernal (*Samolus ebracteatus* H. B. K.), and a milkwort (*Polygala* sp.).

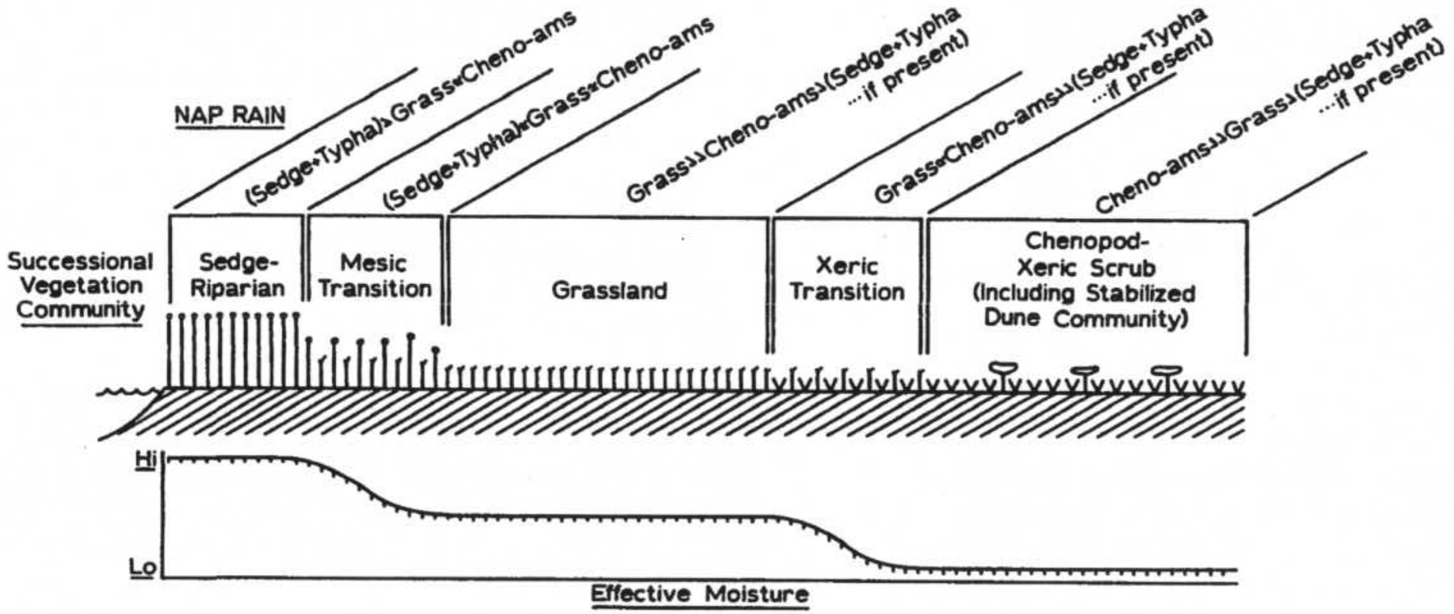
Extremely dry sections in the basin support a diverse, scrubby, xeric flora. With the exceptions of an extensive, active, gypsum dune field surrounding Laguna Grande (SE$\frac{1}{4}$, J11; NE$\frac{1}{4}$, K11) to the north and west, and a few smaller, active, dune fields at other places, all such areas are characterized by saline crusts and presence of the halophytic chenopods iodine bush (*Allenroelfea occidentalis* [Wats.] Kuntze) and seepweed (*Suadea fruticosa* Forsk. and *S. palmeri* [Standl.] Standl.). Vegetation on active dunes is similar to that on gypsum dunes in the Tularosa Basin, New Mexico (Shields, 1956), and consists of widely-spaced tree yuccas, catclaw-acacias, and occasional desert willows (*Chilopsis linearis* [Cav.] Sweet). The xeric scrub community occupies stabilized dunes (e.g., center, E14; G15) and playas, where effective soil moisture is low. Vegetation includes (in addition to iodine bush and seepweed) mesquite, catclaw-acacia, ocotillo, herbaceous euphorbs, a variety of cacti, several kinds of succulent composites, sotol, beargrass, and sea purselane (Sesuvium sp.). Playas subjected to periodic flooding are barren, or support only iodine bush and seepweed. In certain areas in the southeast lobe of the basin, the chenopods form an understory in a mesquite-acacia thorn forest. Formations transitional between grassland and xeric scrub also exist at certain locations; these are characterized by iodine bush, grasses, seepweed, and mesquite.

Fig. 6 summarizes the successional patterns apparent on the basin floor. The sequence is disjunct in many places. Riparian formations fail to develop at margins of ephemeral, or extremely saline lagunas, and xeric scrub assemblages often grow directly adjacent to sedge beds (e.g., Fig. 3). 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 lagunas. 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 reoccupied by surrounding mesic or xeric vegetation, depending on location (Minckley, 1969). In areas where the surface crust is thin, and subsurface water is particularly abundant (e.g., E$\frac{1}{2}$, H13), vegetation is transitional between typically riparian and typically mesic formations.

The village of Cuatro Ciénegas was established during or perhaps prior to the 17th Century by Spanish missionaries and colonists.

Figure 6. Generalized diagram of the valley floor successional pattern.

Generalized Terrestrial Succession, Cuatro Ciénegas Basin, Coahuila, México



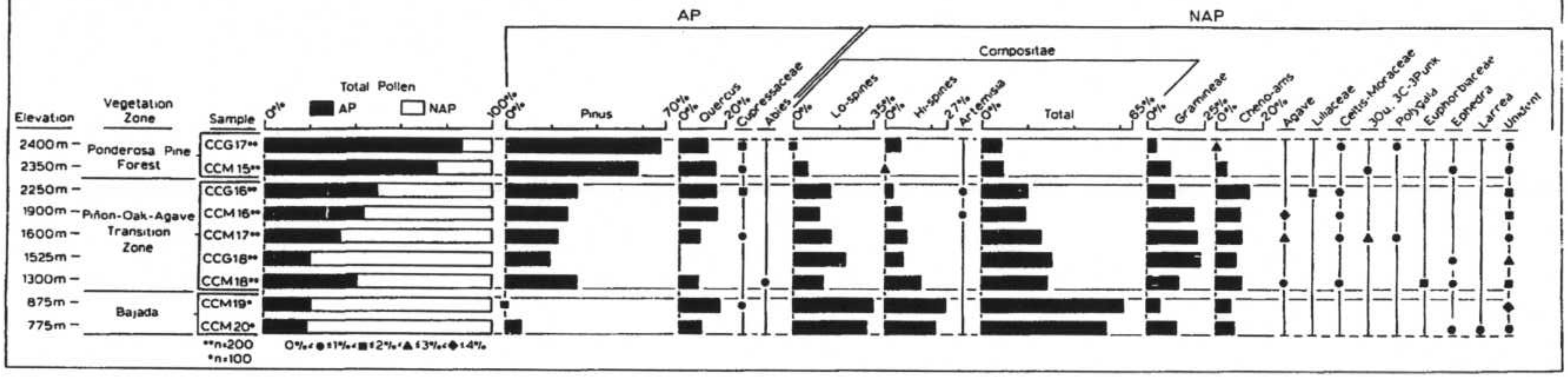
Since then, human endeavors have had noticeable effects on vegetation and drainage relationships at various places in the valley. Natural vegetation was cleared around the town in the course of agricultural development, and canals were constructed to carry water to the fields, and later out of the basin. In the process some lagunas were drained, and posos and lagunas supplying canals were decreased in size. Concrete canals built within the last 40 years have had little effect on successional patterns, but sedge and cattail beds have developed in and adjacent to older, earthen canals, many of which have fallen into disuse. Grassy areas grazed by feral and domestic livestock have been invaded by iodine bush and seepweed, and now bear vegetation assemblages transitional between the natural grassland and xeric scrub communities.

Modern Pollen Rain

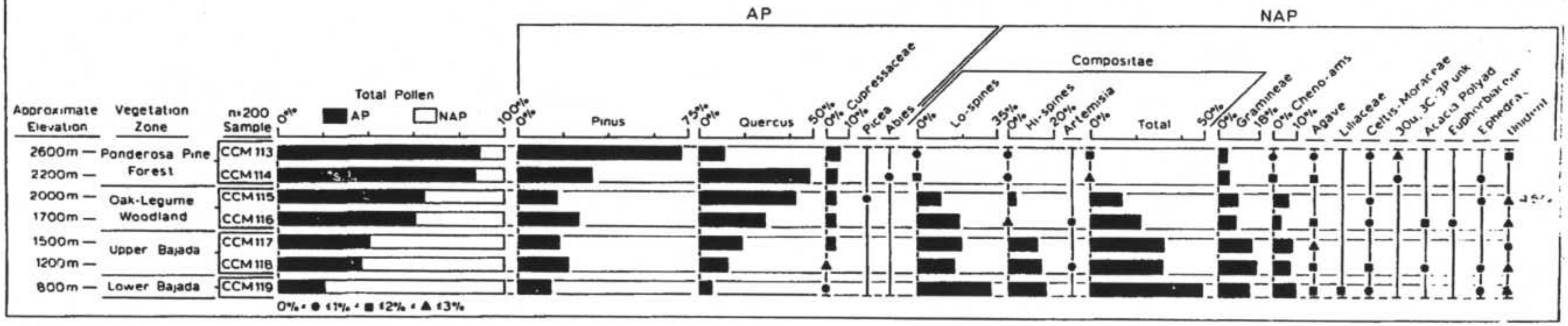
Total pollen spectra from surface samples collected on the north-facing slope of Sierra de la Madera and on the east-facing slope of Sierra de San Marcos are shown in Fig. 7. On both mountains, AP frequencies exceeded 74% in samples from the high-elevation ponderosa pine forests, and decreased gradually, moving downhill, to ca. 20% in samples from lower areas on bajadas. A reciprocal trend is apparent in the nonarboreal pollen (= NAP) proportions. Pine and oak dominated the AP on both mountains, 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 grains appeared in three montane samples, but did not exceed 1%. Grass pollen and

Figure 7. Elevational pollen transects, Sierra de San Marcos and Sierra de la Madera.

Pollen Proportions, East-Facing Slope Surface Pollen Transect, Sierra de San Marcos, Coahuila, México August, 1968, April, 1969



Pollen Proportions, North-Facing Slope Surface Pollen Transect, Sierra de la Madera, Coahuila, México. August, 1970.



cheno-ams were present in all montane samples, but the Compositae, comprised mainly of high- and low-spine pollen types, controlled elevational trends in the NAP. Artemisia pollen was present in four samples, but formed less than 2% in each—this relationship is interesting since Artemisia is an important pollen type in other elevational sequences from western North America (e.g., Maher, 1963; Martin, 1963; Whiteside, 1965; Batchelder, 1970). Pollen profiles from high elevations on mountains around the Cuatro Ciénegas Basin reflected local abundances of anemophilous (= wind-pollinated) pines and oaks, and high pollen production by those plants, particularly by the pines. At lower elevations they reflected distance from pine and oak forests, becoming a function of pollen transport and dispersal, by wind and perhaps by infrequent torrential runoffs from cyclonic rainstorms, and constraint imposed upon AP frequencies by Compositae proportions. Relative increases in Compositae frequencies with decreasing elevation 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.

I used the homogeneity Chi-square method (Mosimann, 1965) to measure similarities between pollen counts from samples taken at different elevations, but within the same montane vegetation zones. Since elevational trends were most apparent in montane profiles when grains observed were separated as AP and NAP, and since the NAP was predominantly composites, I performed two tests on counts from each vegetational formation. In the first, to show intrazonal similarities and differences in total pollen rain, I grouped data as AP and NAP. In

TABLE 4. Chi-square analyses, north-facing slope surface pollen transect, Sierra de la Madera.

			AP-NAP counts		AP-Compositae counts	
Vegetation zone	Samples	df	X^2	P	X^2	P
Ponderosa pine forest	CCM 113, CCM 114	1	0.3939	> 0.5	0.5385	> 0.3
Oak-legume woodland	CCM 115, CCM 116	1	0.6826	> 0.3	3.6194	> 0.05
Upper bajada	CCM 117, CCM 118	1	0.2058	> 0.5	0.0976	> 0.7

TABLE 5. Chi-square analyses, east-facing slope surface pollen transect, Sierra de San Marcos.

			AP-NAP counts		AP-Compositae counts	
Vegetation zone	Samples	df	X^2	P	X^2	P
Ponderosa pine forest	CCM 15, CCG 17	1	10.0518**	< 0.01	0.3568	> 0.5
Piñon-oak-agave transition	CCG 16, CCG 18, CCM 16-18	4	43.0879**	< 0.01	30.5214**	< 0.01
Bajada	CCM 19, CCM 20	1	0.1250	> 0.7	0.0066	> 0.9

**Chi-square values significant at the 0.01 probability point.

the second, to illustrate the control exerted by composite pollen over elevational NAP patterns, I used only AP and Compositae categories, excluding other pollen types. Tables 4 and 5 present the results. Counts from samples taken within discernible vegetation zones on Sierra de la Madera were consistently similar ($P > 0.05$; Table 4). This is attributable to the massiveness of that range, which permits extensive, structurally homogeneous plant formations to exist within particular elevational ranges. Counts from samples taken in the small pine forests and in the broad transitional zone on Sierra de San Marcos, the lower and steeper of the two ranges, were in most cases dissimilar ($P < 0.01$; Table 5). This reflects the disjunct nature of montane environments on Sierra de San Marcos. Extensive, well-defined vegetational habitats are more restricted there than on Sierra de la Madera, hence pollen rains within given elevational ranges are more variable.

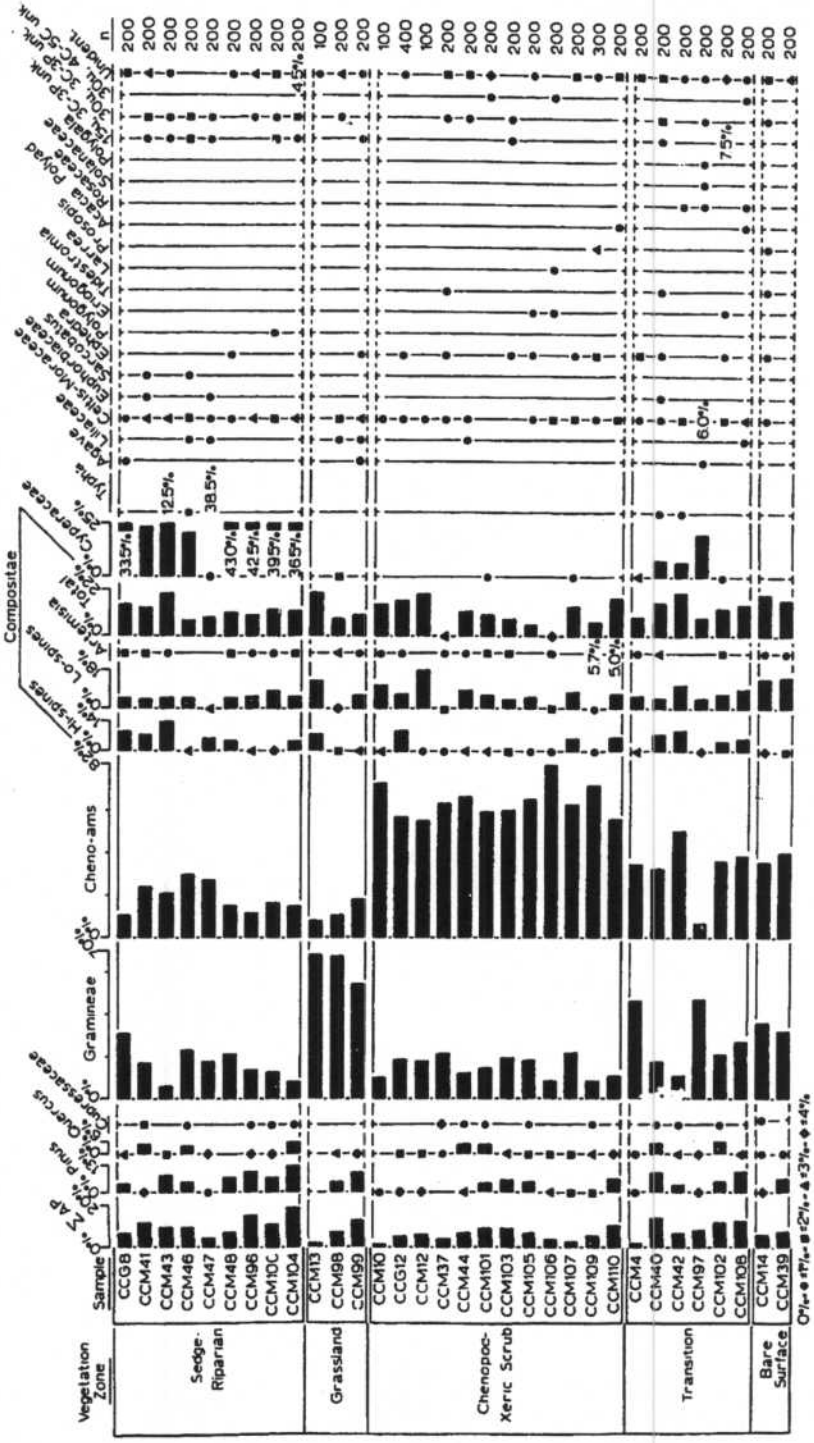
Pollen counts from samples taken in the bajada community on Sierra de San Marcos were statistically similar in both tests. Compositae, AP, and NAP proportions in those samples closely resembled those from sample CCM 119, which was collected in the lower bajada community on Sierra de la Madera (Fig. 7), and also those from sample CCM 8 (AP = 12.5%, NAP = 87.5%, Compositae = 57.5%; n = 200), which was taken in a creosote bush savanna on a bajada extending southward from Sierra de Menchaca (D16). A Chi-square value computed using AP and NAP counts from these four samples was insignificant ($X^2 = 5.6596$, df = 3, $P > 0.1$), indicating pollen rains on the bajada communities to be alike. A Chi-square value calculated using AP and

Compositae counts from the same samples was also insignificant ($X^2 = 5.3494$, df = 3, $P > 0.1$), further emphasizing the control exerted by Compositae pollen in NAP profiles from bajadas in the Cuatro Ciénegas area.

Figs. 3 and 8 present pollen profiles from surface samples gathered on the basin floor. Arboreal pollen comprised 5% to 20% of each, approximating AP values from samples taken on bajadas in the study area. Pollen rains on the valley floor were similar to those 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 rains on the basin floor were dominated by grains from anemophilous, herbaceous, biennials and perennials that characterize plant formations growing there, and GCA pollen comprised at least 58% of each profile from the barrial. Spectra from equivalent edaphic habitats at different locations were extremely similar. Aquatic pollen types exceeded 21% in all profiles from riparian situations, reflecting sedge and cattail abundances. Typha pollen appeared only in spectra from samples collected in cattail beds, and grains from submergent aquatic plants did not appear. All profiles from the mesic, 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, and reflected cospatial existence of sedges, chenopods, and grasses. Control by local vegetation over GCA composition was extreme, and spectra intermediate between those

Figure 8. Pollen profiles from surface samples gathered on the floor of the Cuatro Ciénegas Basin.

Pollen Proportions, Modern Pollen Rain, Cuatro Ciénegas Basin, Coahuila, México



diagnosing the seral habitats came only from samples obtained in ecotonal vegetation. Fig. 3 exemplifies the relationship. Sample CCM 98, gathered in the grassland zone at the core sites only 10 m to 15 m away from sedge beds, contained more than 67% grass pollen, and only 1% sedge pollen. Samples CCM 101 and CCM 105, collected in xeric formations [illegible].5 m to 12 m away from springs where sedges were growing, each contained more than 59% cheno-ams and little or no sedge pollen. Samples from the sedge beds 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 rains falling onto the barrial is further illustrated by the profiles from samples CCM 14 and CCM 39 (bottom, Fig. 8). Both were taken from a 0.5 km^2 section, 8 km SW from the village of Cuatro Ciénegas (center, G12), that is denude of 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. To detect possible seasonal differences in pollen rains in this situation, I collected CCM 14 in January, 1969, and CCM 39 during June, 1969. A Chi-square value calculated from the pollen counts (n = 200 x 2) using AP, grass, cheno-am, Compositae, and "others" classes was insignificant ($X^2 = 2.2518$, df = 4, $P > 0.5$), indicating the summer and winter pollen rains on <u>this</u> location to be equivalent. The profiles from both samples were dominated by pollen from anemophilous components of vegetational assemblages surrounding the bare area, and contained ca. 40% cheno-ams and ca. 30% grasses. Arboreal pollen comprised less than 7%, and the Compositae approximately 18%, of each profile. Compositae proportions from these two samples approximated those of all other samples gathered on the barrial, even though several kinds of composites grow in the seral communities. This suggests that the amount of pollen contributed to local pollen rains by composites inhabiting the basin floor is minimal, and that most Compositae grains reaching the barrial are produced on surrounding bajadas.

When proportional pollen spectra from a number of surface samples obtained in the same vegetational or physiographic unit are statistically similar, counts from different samples may be grouped for a more precise estimate of the profile characteristic of the unit sampled than is offered by the individual spectra. The basic assumption is that the individual counts are independent samples drawn at random from one sampling universe. Since all first-count profiles from the basin floor were quite similar, using AP, GCA, Compositae, and "others" categories, grouping counts to form a mean spectra for each of the seral communities and for the valley floor as a unit was justified. I did so in Table 6, to illustrate the gross homogeneity in pollen rains on the different seral habitats, to approximate a spectrum characterizing the barrial as a whole, and to further contrast differences between pollen rains on the basin lowlands and on surrounding mountains and bajadas. The GCA included roughly 75% of all grains tallied from these samples. The Compositae and AP, dominant pollen types at local, upland sites, together comprised less than 21% of the grouped counts. In Table 6, and in following tables and diagrams, I included samples from

TABLE 6. Pollen proportions, grouped counts from surface samples gathered in habitats on the floor of the Cuatro Ciénegas Basin.

Vegetation zone	Number samples	n	AP number	AP percent	GCA number	GCA percent	Compositae number	Compositae percent	Others number	Others percent
Sedge-riparian	9	1,800	188	10.44	1,289	71.61	221	12.28	102	5.67
Grassland	3	500	41	8.20	380	76.00	57	11.40	22	4.40
Chenopod-xeric scrub	12	2,500	151	6.04	1,987	79.48	279	11.16	83	3.32
Transitions	6	1,200	112	9.33	832	69.33	164	13.67	92	7.67
Bare surface	2	400	26	6.50	288	72.00	72	18.00	14	3.50
Total: grouped	32	6,400	518	8.09	4,776	74.63	793	12.39	313	4.89

stabilized dune communities with those from chenopod and xeric scrub formations. Although these habitats have different origins and appear distinctly different to the eye, pollen rains characterizing them were not separable. All these situations are extremely xeric, support similar vegetation, and were typified by high cheno-am proportions. I did not recover pollen from samples obtained in the active dunes, a surficially-arid local environment where chenopods do not grow.

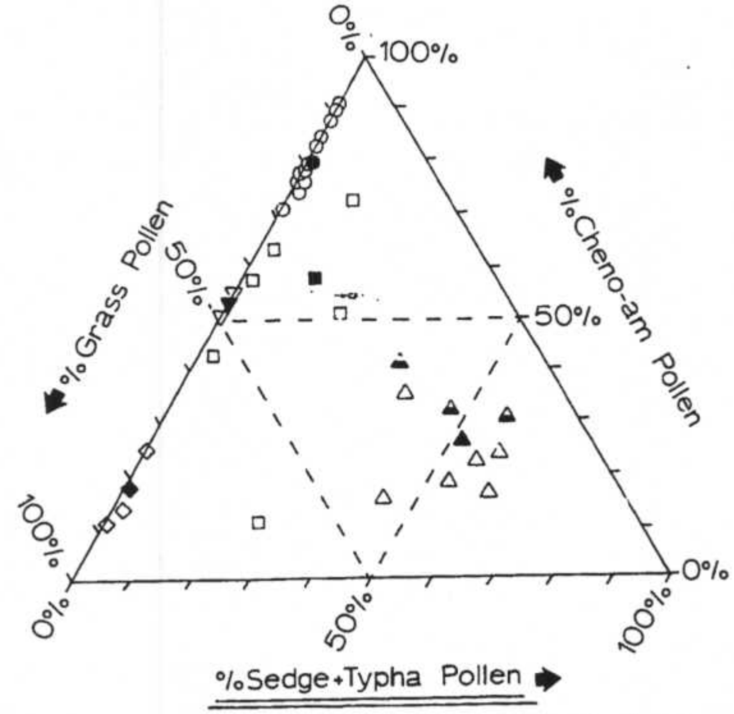
Variations within the GCA category diagnosed samples from different vegetational formations on the basin floor; the relationship is summarized in Fig. 6. The GCA profiles were good indices of local edaphic conditions, but not of total vegetation. The GCA values reflected ecological tolerance limits, and pollen production and dispersal properties of anemophilous indicator species, namely chenopods, grasses, sedges, and cattails. In Fig. 9, I exaggerated differences within the GCA fraction of pollen rains on the seral communities using the "adjusted sum" technique (Faegri and Iversen, 1964; Schoenwetter and Eddy, 1964). In doing so, I separated the GCA sum from each total sample count from the valley floor, calculated relative proportions for the grass, cheno-am, and aquatic pollen type components, and plotted the results in a ternary matrix. This approach is valid since the GCA comprised more than half of each count from the basin floor and exceeded 100 grains in all but two samples from that area, and since variations within the GCA categorized pollen rains on the seral formations. To obtain representative estimates of adjusted GCA proportions from the seral habitats, I again grouped counts from samples collected at different locations. Results are presented in Table 7

TABLE 7. Adjusted pollen proportions, grouped GCA counts from surface samples gathered on the floor of the Cuatro Ciénegas Basin.

	Number	Adjusted	Gramineae		Cheno-ams		Aquatic pollen types	
Vegetation zone	samples	n	number	percent	number	percent	number	percent
Sedge-riparian	9	1,289	306	23.74	349	27.07	643	49.19
Grassland	3	380	311	81.84	67	17.63	2	0.53
Chenopod-xeric scrub	12	1,987	387	19.48	1,596	80.32	4	0.20
Transitions	6	832	343	41.23	402	48.31	87	10.46
Bare surface	2	288	136	47.22	152	52.78		

Figure 9. Adjusted grass, cheno-am, and aquatic pollen type proportions from surface samples gathered on the basin floor.

Grass, Cheno-am, and Aquatic Pollen Proportions,
Modern Pollen Rain,
Cuatro Ciénegas Basin, Coahuila, México



Vegetation Zones and Pollen Sample Symbols

Sedge-Riparian

Single sample ...no Typha pollen -------- △

Single sample...with Typha ---------- ▲

All samples grouped (n=1289) --------- ▲

Grassland

Single sample ---------------- ◇

All samples grouped (n=380) --------- ◆

Chenopod-Xeric Scrub (Including stabilized dune Community)

Single sample ---------------- ○

All samples grouped (n=1987) -------- ●

Transition

Single sample ---------------- □

All samples grouped (n=832) --------- ■

Bare Surface

Single sample ---------------- ▽

All samples grouped (n=288) --------- ▼

and Fig. 9. Cheno-am frequencies were greater than 70% in all GCA counts from xeric locations, and grass proportions exceeded 70% in all samples from mesic, grassland sites. In both situations, pollen from aquatic plants was rare in a few samples, and absent from most. The GCA spectra from riparian sites were more variable, but all contained at least 35% sedge and cattail pollen. Samples from transitional areas were much more variable on this basis, reflecting vegetational variability at such locations, but were consistently different from samples taken in more definitive plant assemblages.

Relationships apparent within the GCA category could be due in part to differential pollen preservation, but appear to reflect pollen production and dispersal characteristics of grasses, chenopods, and aquatic plants growing on the barrial. In xeric sections of the basin floor, iodine bush and seepweed grow at wide and probably uniform intervals. Dropseed, bunchgrass, and saltgrass grow at much closer intervals, giving mesic areas a meadow-like appearance. Within the grouped GCA counts, however, cheno-am and grass proportions were both about 80% in the respective habitats. The chenopods apparently produce much more pollen per plant than do the grasses. Cheno-ams and grass pollen collectively formed ca. 50% of GCA rains on riparian localities, even though sedges and cattails were the only pollen producers in this category growing at such places. This, and the paucity of sedge and cattail pollen in samples from drier areas in the valley, indicates low pollen production by riparian plants, relative to grasses and chenopods, and greater airborn motility by grass grains and cheno-ams when compared to aquatic pollen types. Susceptibility of locally-produced grass pollen and cheno-ams to short-distance transport is also depicted by GCA composition of the two samples from the bare surface locality. In those counts, 288 of 400 grains were grasses and cheno-ams, in roughly equal amounts; no aquatic pollen types appeared. Sedge and cattail pollen do not travel far, or in quantity, from points of origin in the Cuatro Ciénegas Basin. This fact lends independent support to contentions by Mehringer (1967) and Batchelder (1970) that appearance of those pollen types in Quaternary fossil pollen records from arid regions in western North America evidences past aquatic habitats.

The Fossil Records: First Count

Figs. 10 and 11 present preliminary fossil chronologies from Cores E and F. The records include all pollen types encountered during the first count, using sediment samples removed from the cores at ca. 20-cm intervals. Both are dominated throughout by GCA pollen. Compositae pollen, comprised mainly of high- and low-spine pollen types, was present at all depths in both cores, but did not exceed 32% in either record, and did not exhibit significant trends. Artemisia pollen appeared at many levels in the cores, but was a minor component of the fossil profiles. The diagrams are similar on these bases, and closely resemble modern profiles from the basin floor (see Fig. 8 and Table 3). They do not resemble spectra from the montane transects. The GCA was dominated by grass pollen and cheno-ams; grass and cheno-am proportions fluctuated considerably in both records, but did not provide a means

Figure 10. Total pollen proportions, Core E.

Pollen Proportions, Core 'E',
Cuatro Ciénegas Basin, Coahuila, México

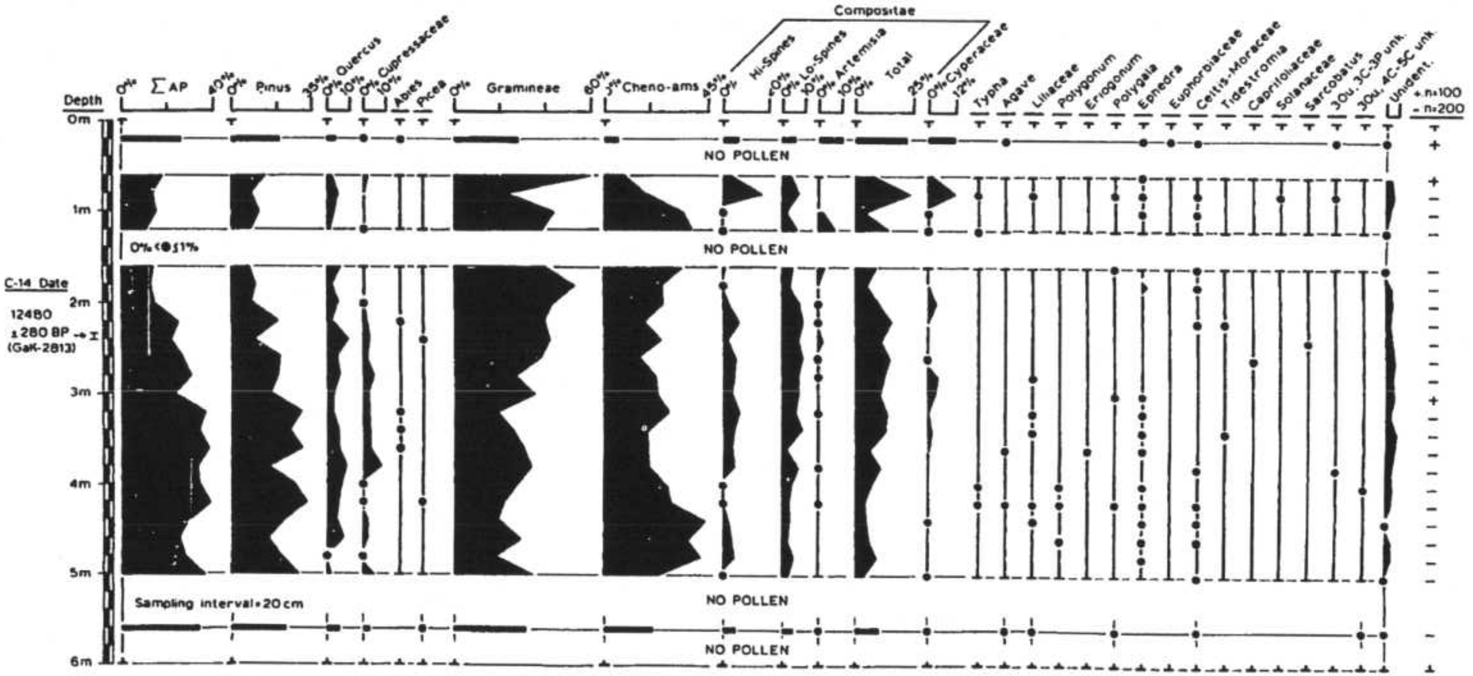
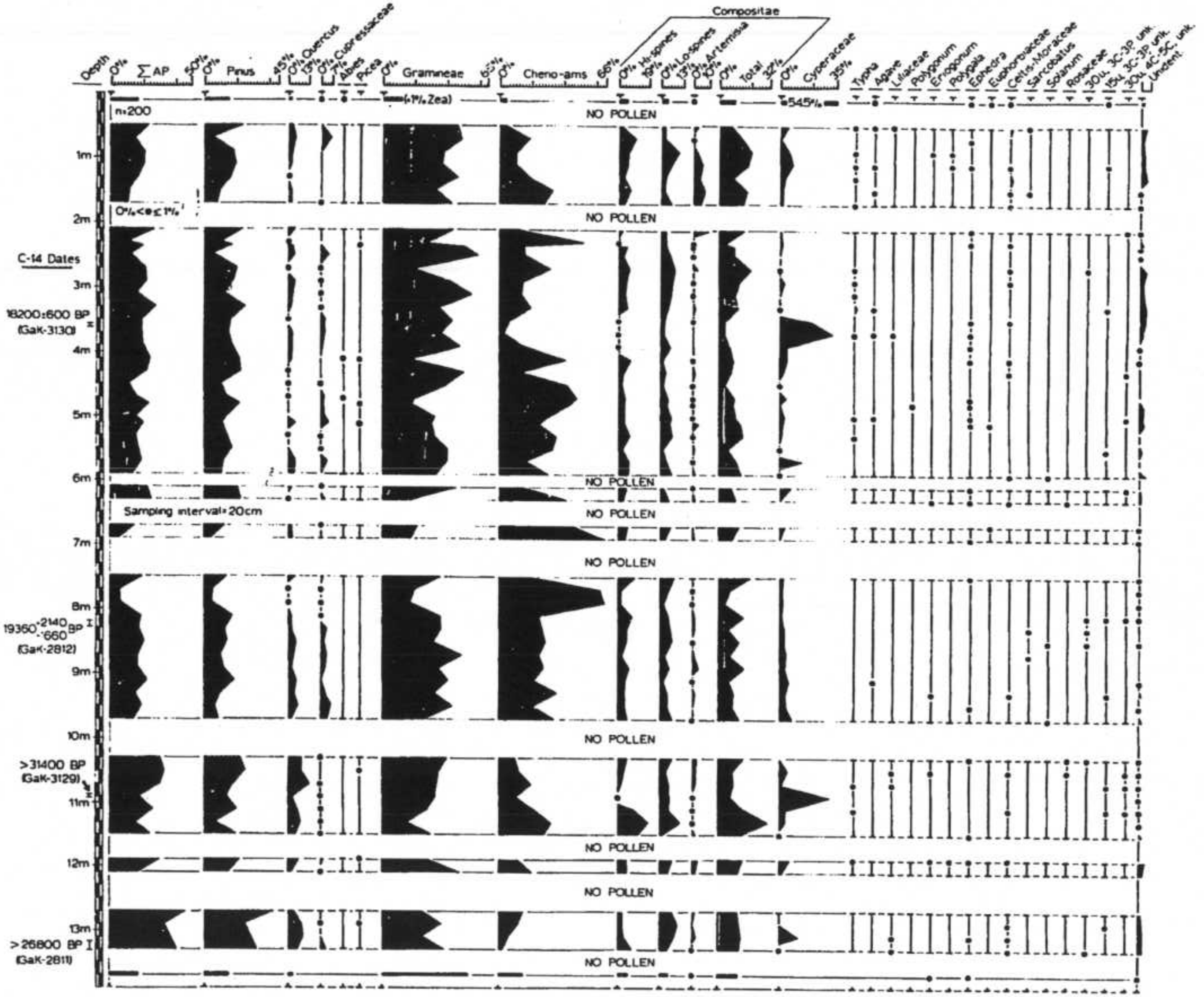


Figure 11. Total pollen proportions, Core F.

Pollen Proportions, Core 'F.'
Cuatro Ciénegas Basin, Coahuila, México



for making stratigraphic correlations between the cores. <u>Typha</u> pollen appeared in a few samples, but did not exceed 1% in either record. Sedge grains were present at most horizons, but sedge frequency did not exceed 12% in Core E, and surpassed 10% at only five places in Core F. Patterns exhibited by the AP were controlled by pine pollen, 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 trends. There are gaps in both records, representing pollen-sterile horizons, and horizons in which pollen was too scarce and poorly-preserved to afford statistically meaningful counts. The gaps, perhaps reflecting oxidative or extremely abrasive depositional environments destructive to pollen, appeared at dissimilar depths in the cores, and could not be correlated using sediment types. Arboreal pollen frequency increased gradually with increasing depth in Core E, but the trend appears artifactual when compared to AP proportions from the upper 6 m in Core F.

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 Figs. 12 to 14. The diagrams are much like the 20-cm-interval chronologies described above. The GCA pollen was again dominant, forming 55% to 83% of all close-interval counts. In the diagrams, I exaggerated relationships within that category using the adjusted sum technique. Aquatic pollen types, although present in most samples, were rare, had little influence on fluctuations within the GCA, and had even less influence on variations within the total spectra. Grass and cheno-am curves from the clay

Figure 12. Close-interval pollen proportions from a peat stratum in Core E.

Close-Interval Pollen Proportions, Peat Stratum, Core 'E', Cuatro Ciénegas Basin, Coahuila, México

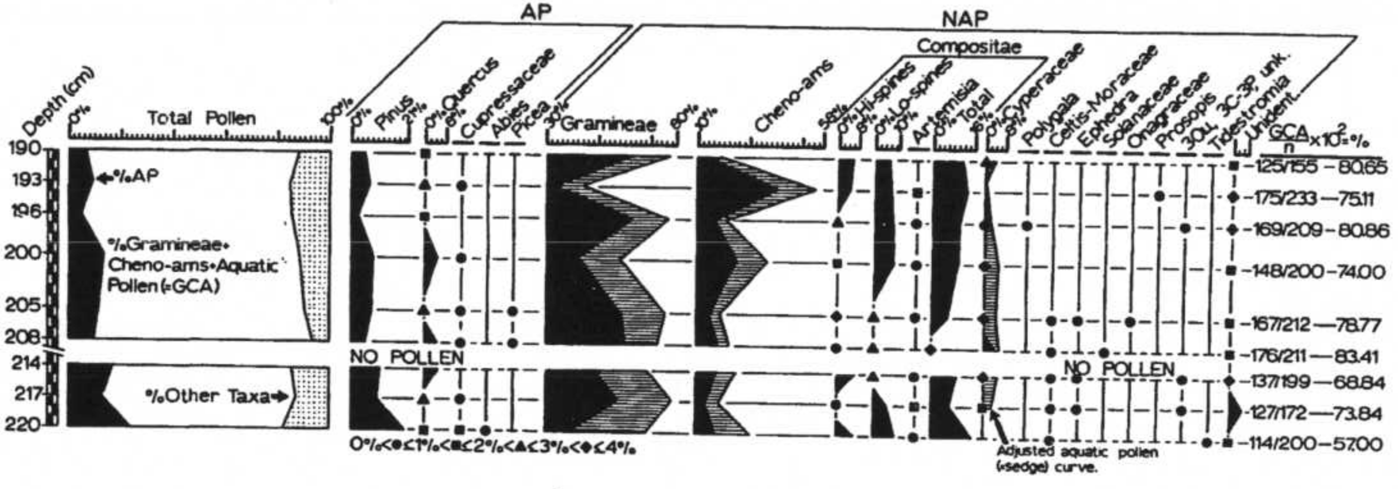


Figure 13. Close-interval pollen proportions from alternating clay and peat horizons in Core F.

Close-Interval Pollen Proportions, Alternating Clay and Peat Horizons, Core 'F,' Cuatro Ciénegas Basin, Coahuila, México

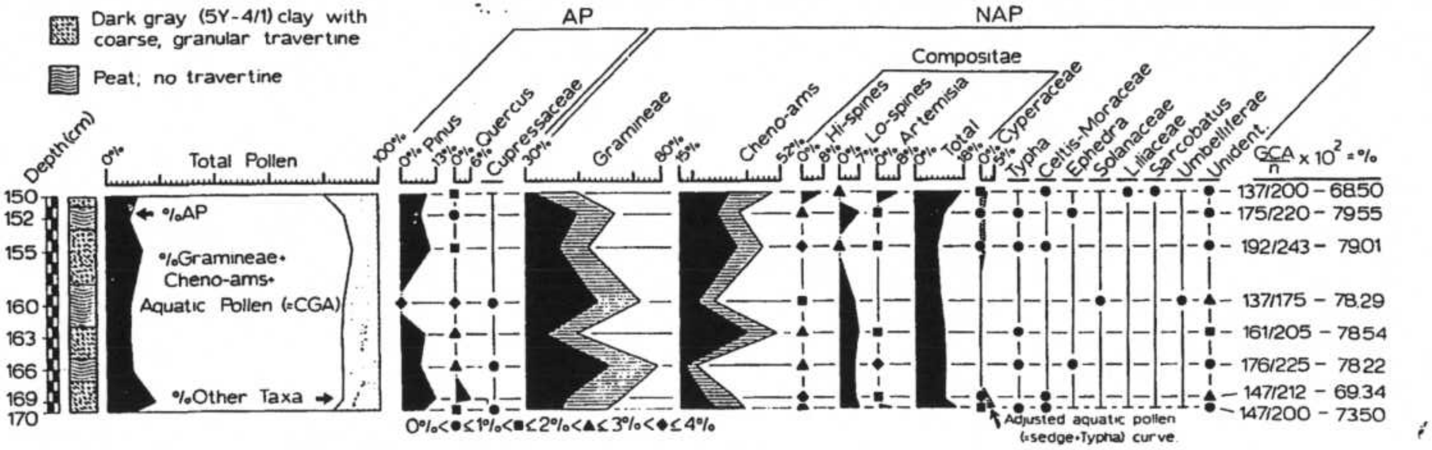
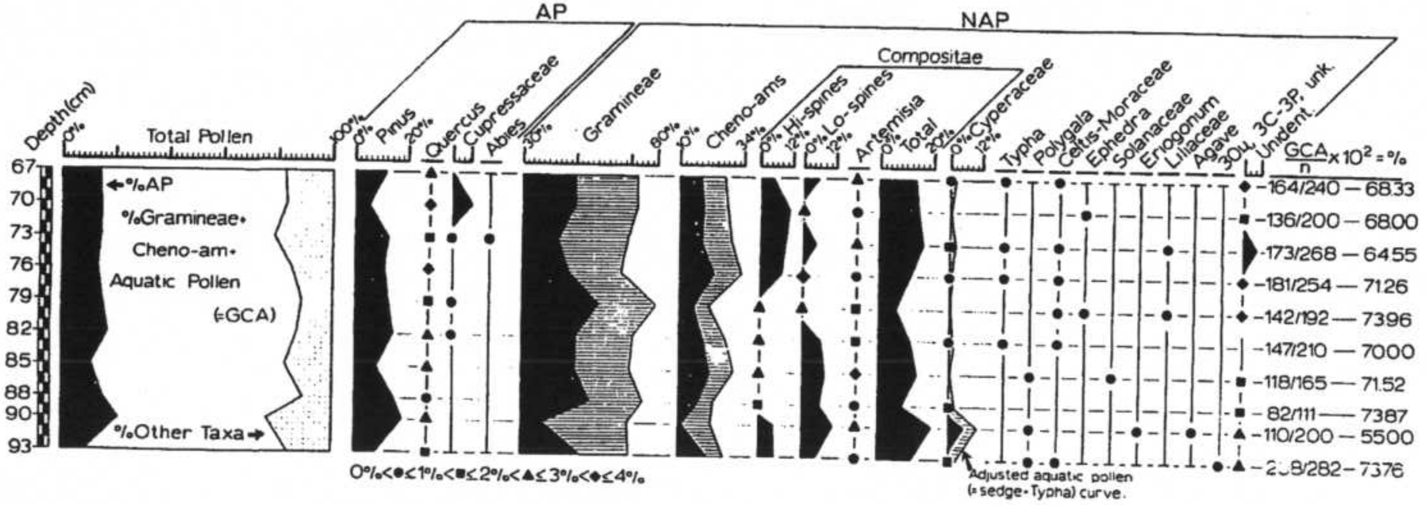


Figure 14. Close-interval pollen proportions from a clay stratum in Core F.

Close-Interval Pollen Proportions, Clay Stratum, Core 'F,' Cuatro Ciénegas Basin, Coahuila, México



stratum in Core F (Fig. 14) were relatively stable, compared to those from the peat stratum in Core E (Fig. 12). In the diagram for the alternating clay and peat horizons from Core F (Fig. 13), a consistent pattern is apparent in the grass and cheno-am profiles. In clays, cheno-am proportions increased at the expense of grasses, while the reverse was true in peats. Arboreal pollen curves were much more stable here than in the wide-interval records, as were those for "other" pollen types (again, 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 hiatuses.

The preliminary fossil chronologies provide a vegetational history since mid-Wisconsin time for the floor of the Cuatro Ciénegas Basin. First-count profiles from all levels of the cores are dominated by grass, cheno-ams, and aquatic pollen types, the same pollen types that are presently diagnostic of different seres in the edaphically-controlled successional formation that exists as a vegetational mosaic on the barrial. This suggests that the valley floor as a unit remained a stable environment throughout the time transgressed by the fossil records. Fluctuations exhibited by pollen curves within the GCA components of these records indicate that location and extent of the seral habitats changed repeatedly during that time, probably in response to changes in the controlling edaphic factors, namely available soil moisture and soil salinity. The preliminary fossil records, being composed primarily of pollen from plants now growing in vegetational formations whose distributions in the study area are controlled by edaphic rather than climatic factors, do not reflect past climatic conditions.

The Second Count

Climate is a major factor in determining vertical ranges of vegetation zones in mountainous regions. Shifts in montane pollen type curves in fossil records from lowland sites in the American Southwest have been demonstrated to reflect past fluctuations in distributions of upland vegetational assemblages, and are well-established indices of late-Quaternary climatic changes (Martin and Mehringer, 1965). In my first-count fossil records, and in all preliminary spectra from the valley floor, patterns exhibited by the AP and Compositae, the dominant pollen types at local upland locations, 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 elevational trends in pollen rains on Sierra de San Marcos and Sierra de la Madera were controlled by AP and the Compositae, and since all AP and most composite 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.

I again grouped counts from modern samples taken at the bare surface location and from within seral communities on the valley floor for estimations of AP-Compositae rains on each habitat, and grouped all sample counts to form a mean spectrum for the barrial. Results are given in Table 8. A homogeneity Chi-square value computed for the grouped counts (excluding the total spectrum) was insignificant ($X^2 = 5.0874$, df = 4, $P > 0.2$), indicating that AP-Compositae rains are essentially the same in all areas of the basin. Statistical homogeneity was even more pronounced when the grouped counts from the bare surface locality were excluded from the Chi-square calculation ($X^2 = 0.5668$, df = 3, $P > 0.9$); the bare surface is apparently a slightly atypical depositional environment for pollen, relative to areas bearing vegetation. Although there are no hard, calichified strata in the cores similar to the modern bare sedimentation surface, and it is doubtful that such a habitat existed right at the core sites during the last 30-40,000 years, it is possible that a similar environment existed near the core sites at different times in the past. During such periods, the pollen spectrum characterizing the springs as depositional environments could have been slightly different than the modern spectrum typifying riparian habitats in the basin because the nearby bare surface as a unit did not contribute to local pollen rains. For this reason, counts from the bare surface were included in the mean, modern AP-Compositae profile for the valley floor.

Second-count profiles from the cores are diagrammed in Figs. 15-16. Pine pollen again controlled total AP curves, although oak, Cupressaceae, fir, and spruce were present throughout both records. High- and low-spine pollen types dominated the Compositae, and <u>Artemisia</u> proportions from the upper 1.5 m in both cores were higher than in any previous diagrams, but did not exceed 20%. Overall trends were most

TABLE 8. Compositae and AP proportions, grouped counts from surface samples gathered on the floor of the Cuatro Ciénegas Basin.

	Number		AP		Compositae	
Sample assemblages	samples	n	number	percent	number	percent
Sedge-riparian	9	900	381	42.33	519	56.67
Grassland	3	237	94	39.66	143	60.34
Chenopod-xeric scrub	12	1,137	427	41.51	665	58.49
Transitions	6	600	250	41.67	350	58.33
Bare surface	2	200	68	34.00	132	66.00
Total; grouped	32	3,074	1,265	41.15	1,089	58.85

Figure 15. Compositae and AP proportions from Core E. Unless otherwise indicated, n = 100.

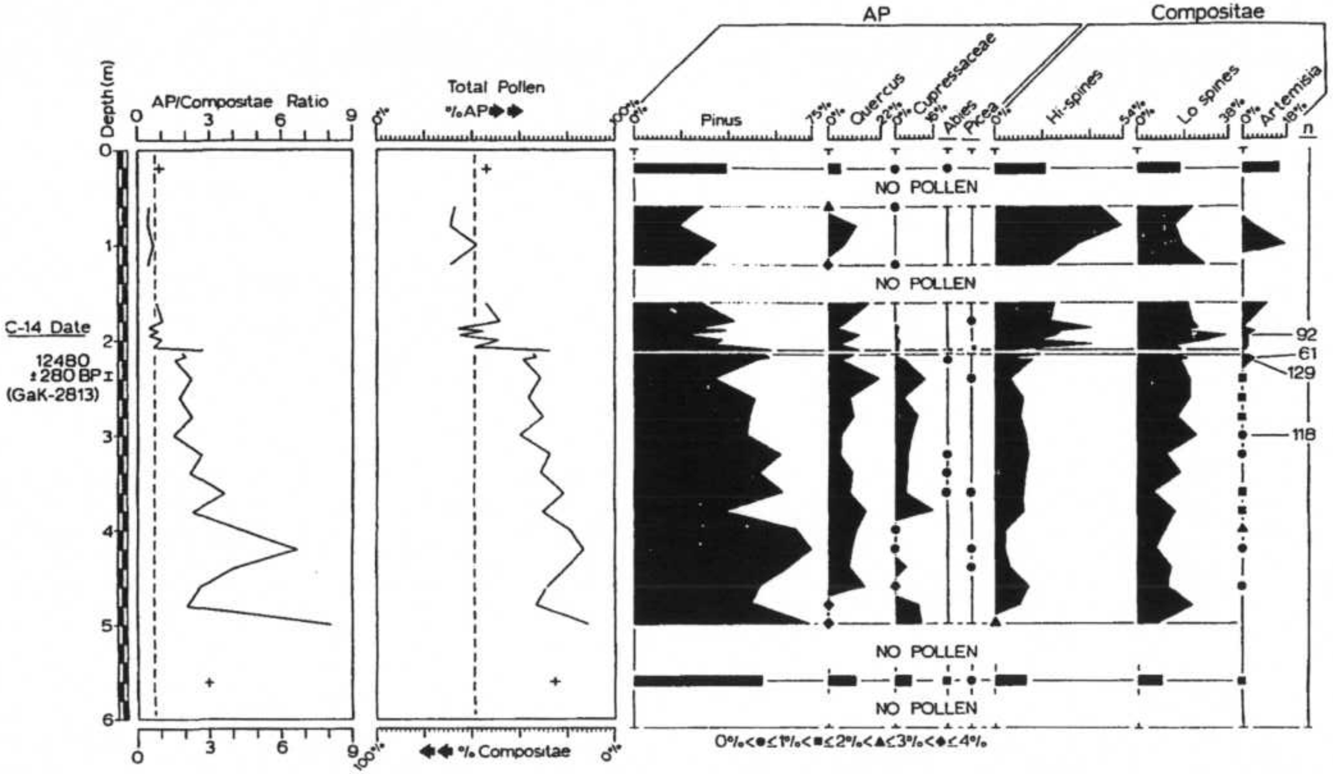
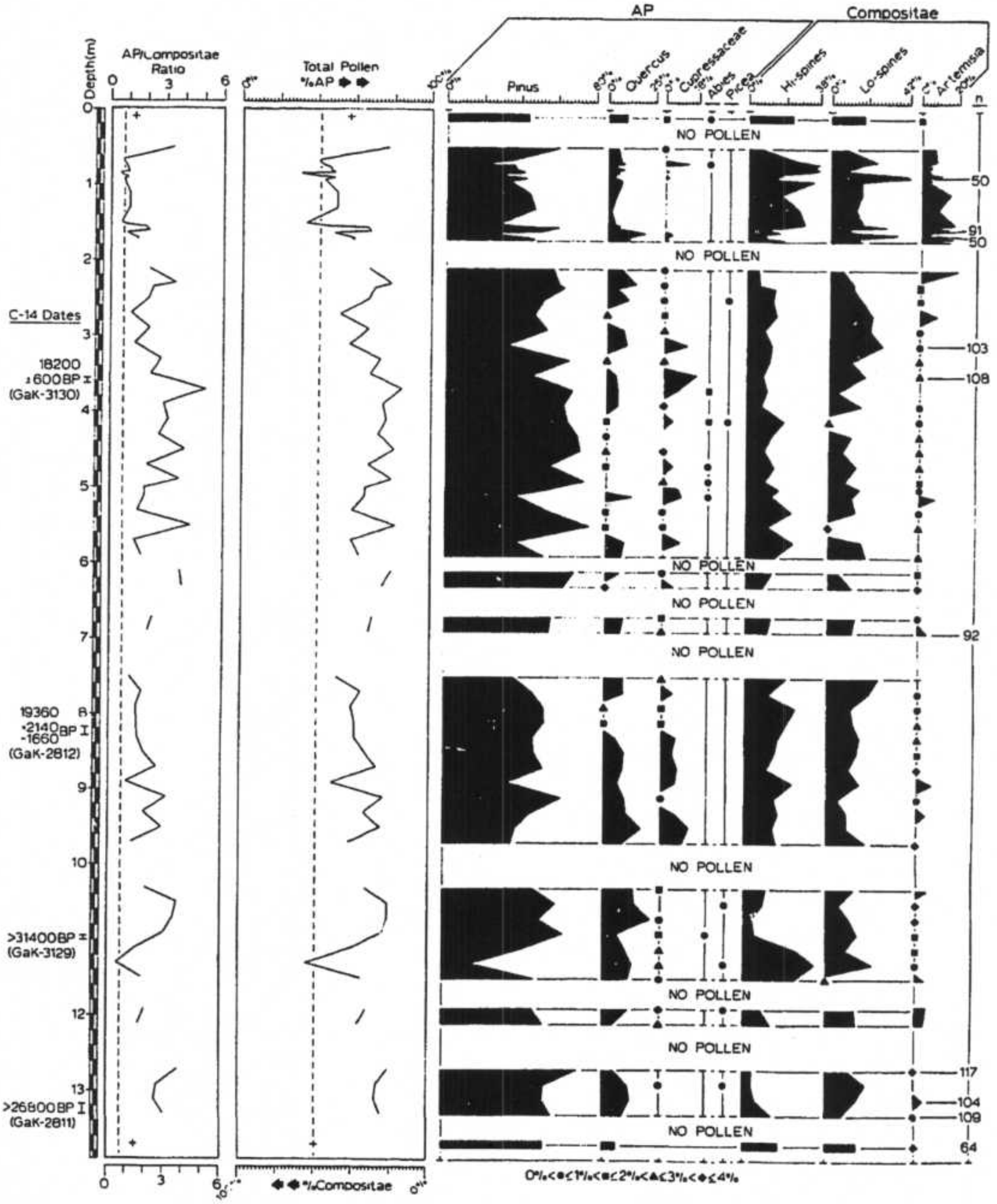

AP
Compositae
Depth (m)
AP/Compositae Ratio
Total Pollen
%AP
% Compositae
Pinus
Quercus
Cupressaceae
Abies
Picea
Hi-spines
Lo spines
Artemisia
n
0%
100%
75%
22%
16%
54%
38%
18%
0
1
2
3
4
5
6
9
NO POLLEN
92
61
129
118
C-14 Date
12480
±280 BP
(GaK-2813)
0%<●≤1%<■≤2%<▲≤3%<◆≤4%

Figure 16. Compositae and AP proportions from Core F. Unless otherwise indicated, n = 100.


AP
Compositae
Depth(m)
AP/Compositae Ratio
0
3
6
Total Pollen
%AP ➡ ➡
0%
100%
Pinus
83%
Quercus
25%
Cupressaceae
18%
Abies
Picea
Hi-spines
38%
Lo-spines
42%
Artemisia
20%
n
NO POLLEN
C-14 Dates
18200 ±600BP
(GaK-3130)
19360 +2140 -1660 BP
(GaK-2812)
>31400BP
(GaK-3129)
>26800BP
(GaK-2811)
0
1
2
3
4
5
6
7
8
9
10
12
13
50
91
50
103
108
92
117
104
109
64
⬅ ⬅ %Compositae
10%
0%
0%<•≤1%<■≤2%<▲≤3%<◆≤4%

apparent when counts were separated as AP and total Compositae. To facilitate comparing fossil profiles with the mean, modern valley surface spectrum (from Table 8), I included the latter in the total pollen sections of Figs. 15 and 16 as a broken, vertical line. I also exaggerated the total fossil curves exponentially in the diagrams, using an AP/Compositae ratio. Similitude between the AP-Compositae proportional curves from Core E, and from the uppermost 6 m in Core F, is striking—when superimposed to scale, the curves are nearly identical. Both approximate the modern, control value from surface to a depth of 1.6 m to 2 m (with one exception, at the 30-cm depth 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 composites. Below 6 m in Core F, AP frequencies remain higher than the control value down to the 11.0 m-11.4 m level, where fossil values shift back to roughly modern. Arboreal pollen proportions are considerably higher than modern below 11.4 m in Core F, except for the deepest sample, in which AP and Compositae frequencies again approximate the control spectrum.

The marked similitude between these chronologies is critically important to following paleoclimatic interpretations. The two cores yielded equivalent, but independent fossil records of pollen produced by upland vegetation that reflect changes during late-Quaternary time in vertical distributions of vegetational formations on mountains surrounding the Cuatro Ciénegas Basin. The AP-Compositae curves from the cores provide a means for making stratigraphic correlations between the cores, independent of both sediment types and 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. These data negate, a priori, contentions that pollen contained in the cored spring sediments was reworked to any appreciable degree, or that variations within the GCA columns of the preliminary fossil records reflect depositional anomalies.

DISCUSSION AND CONCLUSIONS

In certain areas of North America, Quaternary fossil pollen profiles have been developed that seem to have no 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 first-count profiles from Cores E and F appears to be justified. Comparisons of GCA spectra from the cores with those from surface samples gathered in seral communities on the valley floor indicate that aquatic and terrestrial habitats equivalent, if not identical to those now present at different places on the barrial 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 occupied the springs. Horizons dominated by grasses and cheno-ams at the expense of aquatic pollen types reflect 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, halophytic chenopods, and a few mesic sedges such as Eleocharis. The generally high values for grasses and cheno-ams in the fossil chronologies seem to indicate that the core sites have been surrounded by grassland and xeric scrub formations throughout the late-Quaternary. Modern hydrological and edaphic 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 in different areas. Water table changes in the study area have been under observation by biologists for 13 years (Minckley, 1969 and personal communication). Local vegetation responds to variations in available soil moisture, hence the seral communities undergo constant changes in areal extent. By this model, 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 differences within the GCA columns at equivalent depths in the cores.

Obvious parallelisms between the total modern pollen rains on the valley floor and the first-count fossil profiles, particularly with respect to GCA pollen, together with the lack of geological evidence for large, Pleistocene lakes in the study area, support the notion that local habitats in the basin were much like they are now during the last 30-40,000 years. The diverse and highly-endemic aquatic fauna inhabiting this valley is also an indication of environmental antiquity and stability, implying that the unique stream, poso, and laguna habitats it requires have existed since perhaps the Tertiary. The faunal, geological, and palynological evidences collectively suggest 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 (Figs. 15 and 16) provide a partial climatic history for the Cuatro Ciénegas area, and are the first late-Quaternary palynoclimatic sequences available from arid, northeastern Mexico. Downslope expansions during the Pluvial of mesic, upland vegetational formations in montane regions in western North America have been well-documented (e.g., Martin, 1963; Oldfield and Schoenwetter, 1964; Martin and Mehringer, 1965; Mehringer, 1967). In Figs. 15 and 16, total AP values are higher than modern at most horizons below 2 m, transitional between 1.6 m and 2 m, and approximate the control value above 1.6 m. Arboreal pollen from below 2 m in the cores was deposited during mid-Wisconsin time. Climate then was cooler and perhaps moister than at present, and pine forests and woodlands on mountains surrounding the basin were more extensive than they are now. Local oak and pine pollen production was higher than at present, reflecting the greater source, and more AP reached the valley floor than does now. Since there was no significant increase 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 number of Compositae grains reaching the core sites at an earlier time. The 1.6 m to 2 m intervals represent climatic amelioration during late-Pluvial time, and reflect elevational constriction of mesic, upland vegetational assemblages; the amount of AP falling into the basin progressively decreased during that period. The uppermost 1.6 m in both cores represents the Holocene, when AP-Compositae rain at the core sites, and vegetational distributions on mountains around the study area, were sub-modern to modern. These curves, and the radiocarbon dates from the cores, are in general agreement with what is presently known about the late-Quaternary climatic histories of temperate and arid regions of North America (Martin and Mehringer, 1965; Wright, 1971).

The Holocene AP-Compositae sequences from cores E and F 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 profiles. The brief warming trend apparent between 11 m and 11.4 m in Core F (Fig. 16), just below the > 31,400 BP radiocarbon date, may correlate with the Plumb Point Interstadial in Toronto (28-32,000 BP; Mörner, 1971), the Farmdalian Interstadial in Illinois (23-27,000 BP; Frye, Willman, and Black, 1965), the Derenkamp Interstadial in Holland (29-32,000 BP; van der Hammenden <u>et al</u>., 1967), or the Rich Lake Interpluvial in the Llano Estacado, Texas (22.500-32,000 BP; Wendorf, 1961). I do not condone trans-hemispheric climatic correlations based on anything less than conclusive evidences, and mention these possibilities only to point out that Pleistocene climatic changes sufficient in magnitude to have caused even minor retreats of continental ice sheets can often be detected in fossil pollen records from regions far south from the ice margins. In the fossil records from the Cuatro Ciénegas Basin the measure of paleoclimatic trends was provided by pollen that had blown or washed into the valley from surrounding mountains and bajadas, where climate was a major factor controlling vertical plant distributions during late-Quaternary time. The patterns became obvious,

TABLE 9. Numbers and proportions of fragmented pine grains in modern and fossil samples.

Sample assemblages	Samples with fragmented pine grains/total samples tallied	Fragmented pine grains/total pine grains	Percent pine fragments
	<u>Modern</u>		
Sedge-riparian	8/9	66/124	53.23
Grassland	2/3	17/29	58.62
Chenopod-xeric scrub	7/10	26/73	35.62
Transitions	6/6	28/65	43.08
Bare surface	2/2	11/21	52.38
Total modern	25/30	148/312	47.44
	<u>Fossil</u>		
Core E	14/14	337/445	75.73
Core F	55/55	1,452/1,773	81.90
Total fossil	69/69	1,789/2,218	80.66

however, only after a second count was performed to eliminate constraint imposed upon proportions of montane pollen types, namely composites and AP, by pollen from plants growing in seral communities whose distributions in the study area are controlled by edaphic factors rather than climate.

Based on studies of plant macrofossils from woodrat (Neotoma sp.) middens from different elevations in the Chisos Mountains, Big Bend Park, Texas, Wells (1966) concluded that Pluvial displacements of montane vegetation in that area involved piñons and scrub oaks, but not plants from the high-elevation, ponderosa pine zone, and that during Pluvial time xerophyllous woodland existed as much as 800 m downslope from the modern woodland zone. I attempted to test Wells' hypothesis in the Cuatro Ciénegas area by separating larger, ponderosa-type pine grains from smaller, piñon-type grains in modern and fossil counts, but pine grains in my samples were too battered and fragmented to permit reliable segregation. Most grains I tallied during the first count while trying to do so were broken and impossible to measure accurately (Table 9), and the majority of intact pine grains were too distorted in appearance to be identified below generic level. If Wells is correct, however, and if his findings apply to my study area, the ponderosa pine forests capping Sierra de la Madera and Sierra de San Marcos may exist in relict, environmental refugia that perhaps predate the Quaternary. During Wisconsin time, scrub oak-piñon-acacia woodland probably extended onto bajadas surrounding the basin, but the unique edaphic nature of most of the valley floor would have prohibited expansion of woodland beyond the bajadas.

LITERATURE CITED

Adam, D. P. 1967. Late-Pleistocene and Recent palynology in the central Sierra Nevada, California, p. 275-302. In E. J. Cushing and H. E. Wright, Jr. (eds.) Quaternary paleoecology. Yale Univ. Press, New Haven and London.

_________ 1970. Some palynological applications of multivariate statistics. Unpublished Ph.D. dissertation. University of Arizona, Tucson. 132 p.

Antevs, E. 1955. Geologic-climatic dating in the west. Amer. Antiquity 20: 317-335.

Baker, R. H. 1956. Mammals of Coahuila. Univ. Kans. Publ. Mus. Nat. Hist. 9: 125-335.

Barkley, F. A. 1934. The statistical theory of pollen analysis. Ecology 15(3): 283-289.

Batchelder, G. L. 1970. Postglacial ecology at Black Lake, Mono County, California. Unpublished Ph.D. dissertation. Arizona State University, Tempe. 180 p.

Bent, A. M. and H. E. Wright, Jr. 1963. Pollen analyses of surface materials and lake sediments from the Chuska Mountains, New Mexico. Geol. Soc. Amer. Bull. 74: 491-500.

Bryant, V. M., Jr. 1966. Pollen analysis: its environmental and cultural implications in the Amistad reservoir area. Unpublished M.A. thesis. University of Texas, Austin. 101 p.

_______________ and R. K. Holz. 1968. The role of pollen in the reconstruction of past environments. Pennsylvania Geographer 6(1): 11-19.

_______________ and D. A. Larson. 1968. Pollen analysis of the Devil's Mouth site, Val Verde County, Texas, p. 57-69. In W. M. Sorrow (ed.) The Devil's Mouth site, the third season-1967. Pap. Tex. Archaeol. Salvage Proj. 14, Austin.

Clisby, K. and P. B. Sears. 1955. Palynology in southern North America. III. Microfossil profiles under Mexico City correlated with sedimentary profiles. Bull. Geol. Soc. Amer. 66: 511-520.

_______________________ 1956. San Augustin Plains—Pleistocene climatic changes. Science 124(3221): 537-538.

Cole, G. A. and W. L. Minckley. 1972. Occurrence of the asellid subfamily Stenasellinae (Crustacea, Isopoda) in the Western

Lytle, G. L. 1972. Cyprinid fishes of the subgenus Cyprinella of Notropis from southeast Texas, U.S.A., and northeast Mexico. M.S. thesis. Arizona State University, Tempe. In preparation.

Maher, L. J., Jr. 1963. Pollen analyses of surface materials from the southern San Juan Mountains, Colorado. Geol. Soc. Amer. Bull. 74: 1485-1504.

Martin, P. S. 1963. The last 10,000 years: a fossil pollen record of the American Southwest. Univ. Arizona Press, Tucson. 87 p.

__________ and J. Gray. 1962. Pollen analysis and the Cenozoic. Science 137(3524): 102-111.

__________ and P. J. Mehringer, Jr. 1965. Pleistocene pollen analysis and biogeography of the Southwest, p. 433-451. In H. E. Wright, Jr. and D. G. Frey (eds.) The Quaternary of the United States. Princeton Univ. Press, Princeton.

__________ and J. E. Mosimann. 1965. Geochronology of Pluvial Lake Cochise, southern Arizona. III. Pollen statistics and Pleistocene metastability. Amer. J. Sci. 263: 313-358.

__________, B. E. Sables, and D. Schutler, Jr. 1961. Rampart Cave coprolite and ecology of the shasta ground sloth. Amer. J. Sci. 259: 102-127.

__________ and F. W. Sharrock. 1964. Pollen analysis of prehistoric human feces: a new approach to ethnobotany. Amer. Antiquity 30: 168-180.

McAndrews, J. H. 1967. Pollen analysis and vegetational history of the Itasca region, Minnesota, p. 219-236. In E. J. Cushing and H. E. Wright, Jr. (eds.) Quaternary paleoecology. Yale Univ. Press, New Haven and London.

McCoy, C. J. and W. L. Minckley. 1972. Herpetofauna of the Cuatro Ciénegas Basin, Coahuila, Mexico. Unpublished manuscript.

Mehringer, P. J., Jr. 1967. Pollen analysis of the Tule Springs site, Nevada, p. 130-200. In H. M. Wormington and D. E. Ellis (eds.) Pleistocene studies in southern Nevada. Nevada State Mus. Anthropol. Pap. 13, Carson City.

________________ and C. V. Haynes, Jr. 1965. The pollen evidence for the environment of early man and extinct mammals at the Lehner mammoth site, southeastern Arizona. Amer. Antiquity 31: 17-23.

Miller, R. R. 1968. Two new fishes of the genus Cyprinodon from the Cuatro Ciénegas Basin, Coahuila, Mexico. Occ. Pap. Mus. Zool. Univ. Mich. 659: 1-15.

Minckley, W. L. 1969. Environments of the Bolsón of Cuatro Ciénegas, Coahuila, México, with special reference to the aquatic biota. Univ. Tex. El Paso Stud. Sci. Ser. 2: 1-65.

Mörner, Nils-Axel. 1971. The Plumb Point Interstadial: age, climate, and subdivision. Canadian J. Earth Sci. 8: 1423-1431.

Morrison, R. B. 1965. Quaternary geology of the Great Basin, p. 265-286. In H. E. Wright, Jr. and D. G. Frey (eds.) The Quaternary of the United States. Princeton Univ. Press, Princeton.

Mosimann, J. E. 1962. On the compound multinomial distribution, the multivariate beta-distribution, and correlation among proportions. Biometrica 49: 65-82.

____________ 1963. On the compound negative multinomial distribution and correlations among inversely sampled pollen counts. Biometrica 50: 47-50.

____________ 1965. Statistical methods for the pollen analyst: multinomial and negative multinomial techniques, p. 636-673. In B. Kummel and D. Raup (eds.) Handbook of paleontological techniques. W. H. Freeman and Co., San Francisco.

Müller, C. H. 1947. Vegetation and climate in Coahuila, México. Madrono 9: 33-57.

Oldfield, F. and Schoenwetter, J. 1964. Late Quaternary environments and early man on the southern high plains. Antiquity 38(151): 226-229.

Pinkava, D. J. 1969. Preliminary investigations of the flora and vegetation of the Cuatro Ciénegas Basin, Coahuila, México. Proc. Supplement J. Ariz. Acad. Sci. 1969: 13 (Abstr.).

Preston, R. J. 1966. North American trees. Mass. Inst. Tech. Press, Cambridge. 395 p.

Schoenwetter, J. and F. W. Eddy. 1964. Alluvial and palynological reconstruction of environments, Navajo Reservoir District. Mus. New Mexico Pap. Anthropol. 13: 1-155.

Sears, P. B. 1937. Pollen analysis as an aid to dating cultural deposits in the United States, p. 61-66. In G. G. MacCurdy (ed.) Early man. Lippincott, Co., London.

__________ and K. Clisby. 1955. Palynology in southern North America. IV. Pleistocene climate in México. Bull. Geol. Soc. Amer. 66: 521-530.

Shields, L. M. 1956. Zonation of vegetation within the Tularosa Basin, New Mexico. Southwest. Nat. 1: 49-68.

Shreve, F. 1922. Conditions indirectly affecting vertical distributions on desert mountains. Ecology 3: 269-274.

_________ 1942. The desert vegetation of North America. Bot. Rev. 8: 195-246.

_________ 1944. Rainfall in northern México. Ecology 25: 105-111.

Taylor, D. W. 1966. A remarkable snail fauna from Coahuila, México. Veliger 9: 152-228.

Taylor, W. W. 1956. Some implications of the carbon-14 dates from a cave in Coahuila, México. Bull. Tex. Archeol. Soc. 27: 215-234.

Tsukada, M. 1966. The pollen sequence, p. 63-69. In U. M. Cowgill, G. E. Hutchinson, A. A. Racek, G. E. Goulden, R. Patrick, and M. Tsukada, The history of Laguna de Petenxil, a small lake in northern Guatemala. Mem. Conn. Acad. Arts and Sci. 17: 1-126.

_________ and E. S. Deevey, Jr. 1967. Pollen analyses from four lakes in the southern Maya area of Guatemala and El Salvador, p. 303-332. In E. J. Cushing and H. E. Wright, Jr. (eds.) Quaternary paleoecology. Yale Univ. Press, New Haven and London.

Van der Hammenden, T., G. C. Maarleveld, J. C. Vogel, and W. H. Zagwijn. 1967. Stratigraphy, climate, succession, and radiocarbon dating of the last glacial in the Netherlands. Geol. Mijnbouw 46: 79-95.

Von Post, L. 1967. Forest tree pollen in south Swedish peat bog deposits. Pollen et Spores 9(3): 375-402.

Wells, P. V. 1966. Late Pleistocene vegetation and degree of Pluvial climatic change in the Chihuahuan Desert. Science 153(3739): 970-975.

Wendorf, F. 1961. An interpretation of late Pleistocene environments of the Llano Estacado, p. 115-133. In F. Wendorf (ed.) Paleoecology of the Llano Estacado. Fort Burgwin Res. Center Publ. 1, Mus. New Mexico Press, Santa Fe.

West, R. C. 1964. Surface configuration and associated geology of Middle America, p. 33-83. In R. C. West (ed.) Handbook of Middle American Indians, vol. I, natural environment and early culture. Univ. Texas Press, Austin.

Whiteside, M. C. 1965. Paleoecological studies of Potato Lake and its environs. Ecology 46(6): 807-816.

Williams, S. C. 1968. Scorpions from northern México: five new species of *Vejovis* from Coahuila, México. Occ. Pap. Calif. Acad. Sci. 68: 1-24.

Wright, H. E., Jr. 1971. Late Quaternary vegetational history of North America, p. 425-464. In K. K. Turekian (ed.) The late-Cenozoic glacial ages. Yale Univ. Press, New Haven.

APPENDICES

Appendix 1. Description of Core E.

1 a. Core segment lengths.

Segment	Length (cm)
E-1	77
E-2	94
E-3	83
E-4	43
E-5	98
E-6	98
E-7	69
E-8	20
E-9	36
Total length	618

1 b. Stratigraphy of the core.

Depth (cm)	Sediment Type and Munsell Color	Travertine
surface-3.0	Orange-brown (7.5YR-5/8) root mat	absent
3.0-13.0	Mixed, yellow (2.5Y-7/8) clay and peat.	fine
13.0-27.0	Dark gray (5Y-4/1) clay.	coarse
27.0-42.0	Peat.	fine
42.0-69.5	Dark gray (5Y-4/1) clay.	coarse
69.5-100.2	Peat.	fine
100.2-120.0	Transition.	fine to coarse
120.0-147.0	Gray (5Y-5/1) clay.	coarse
147.0-151.0	Dark gray (5Y-4/1) clay.	coarse
151.0-173.5	Transition.	coarse to absent
173.5-257.0	Peat.	absent

Appendix 1 b (concluded).

Depth (cm)	Sediment type and Munsell Color	Travertine
257.0-392.0	Very dark gray (5Y-3/1) clay.	coarse
392.0-526.7	Gray (5Y-5/1) clay.	coarse
526.7-561.0	Pale yellow (5Y-7/3) clay.	coarse
561.0-582.5	Mixed, peats and gray and yellow clays.	coarse
582.5-618.0	Light gray (5Y-6/1) clay.	coarse

Appendix 2. Description of Core F.

2 a. Core segment lengths.

Segment	Length (cm)
F-1	79
F-2	82
F-3	66
F-4	88
F-5	45
F-6	58
F-7	50
F-8	34
F-9	25
F-10	84
F-11	99
F-12	96
F-13	100
F-14	100
F-15	96
F-16	65
F-17	41
F-18	86
Total Length	1,386

2 b. Stratigraphy of the Core.

Depth (cm)	Sediment Type and Munsell Color	Travertine
surface-28.0	Orange-brown (7.5YR-5/8) root mat.	absent
28.0-109.0	Dark gray (5Y-4/1) clay.	coarse
109.0-119.0	Peat.	coarse
119.0-146.0	Dark gray (5Y-4/1) clay.	coarse
146.0-149.0	Peat.	coarse
149.0-151.0	Dark gray (5Y-4/1) clay.	coarse
151.0-153.0	Peat.	coarse
153.0-158.0	Dark gray (5Y-4/1) clay.	coarse
158.0-162.0	Peat.	coarse

Appendix 2 b (cont'd.).

Depth (cm)	Sediment Type and Munsell Color	Travertine
162.0-165.0	Dark gray (5Y-4/1) clay.	coarse
165.0-167.0	Peat.	coarse
167.0-170.0	Dark gray (5Y-4/1) clay.	coarse
170.0-171.0	Peat.	coarse
171.0-198.0	Dark gray (5Y-4/1) clay.	fine
198.0-217.5	Olive-gray (5Y-5/2) clay.	fine
217.5-228.5	Peat.	coarse
228.5-244.5	Dark gray (5Y-4/1) clay.	coarse
244.5-254.0	Light brownish-gray (2.5Y-6/2) clay.	fine
254.0-254.5	Dark gray (5Y-4/1) clay.	absent
254.5-255.0	Light brownish-gray (2.5Y-6/2) clay.	fine
255.0-255.5	Dark gray (5Y-4/1) clay.	fine
255.5-264.7	Light brownish-gray (2.5Y-6/2) clay.	fine
264.7-265.7	Very dark grayish-brown (2.5Y-3/2) clay	absent
265.7-266.1	Pale yellow (2.5Y-7/4) clay.	absent
266.1-267.0	Very fine, alternating, peat and dark brown (10YR-3/3) clay horizons (varves ?).	absent
267.0-267.5	Pale yellow (2.5Y-7/4) clay.	absent
267.5-269.3	Peat.	absent
269.3-271.3	Peat.	fine
271.3-273.3	Peat.	absent
273.3-282.8	Very dark gray (5Y-3/1) clay with extremely narrow bands of pale yellow (2.5Y-7/4) clay (varves ?).	fine
282.8-283.8	Light gray (5Y-7/1) clay.	absent

Appendix 2 b (cont'd.).

Depth (cm)	Sediment Type and Munsell Color	Travertine
283.8-284.6	Peat.	absent
284.6-287.0	Very dark gray (5Y-3/1) clay.	fine
287.0-287.6	Peat.	absent
287.6-288.1	Dark gray (5Y-4/1) clay.	fine
288.1-288.9	Dark gray (5Y-4/1) clay.	coarse
288.9-290.4	Very dark gray (5Y-3/1) clay.	absent
290.4-293.4	Dark gray (5Y-4/1) clay.	coarse
293.4-294.9	Very dark gray (5Y-3/1) clay.	fine
294.9-296.4	Peat.	absent
296.4-315.8	Dark gray (5Y-4/1) clay.	coarse
315.8-316.8	Very dark gray (5Y-3/1) clay.	absent
316.8-319.3	Mixed yellow and gray clays.	very coarse
319.3-320.4	Very dark gray (5Y-3/1) clay.	fine
320.4-321.3	Light brownish-gray (2.5Y-6/2) clay.	fine
321.3-323.0	Very dark grayish-brown (2.5Y-3/2) clay.	absent
323.0-324.3	Very fine, alternating, peat and dark brown (10YR-3/3) clay horizons (varves ?).	absent
324.3-325.0	Dark grayish-brown (2.5Y-4/2) clay.	absent
325.0-340.5	Dark grayish-brown (2.5Y-4/2) clay.	coarse
340.5-346.5	Peat.	absent
346.5-348.0	Mixed peat and gray clays.	coarse
348.0-349.0	Peat.	absent
349.0-351.3	Mixed peat and gray clays.	coarse
351.3-352.8	Peat.	absent
352.8-359.8	Mixed peat and gray clays.	coarse

Appendix 2 b (cont'd.).

Depth (cm)	Sediment Type and Munsell Color	Travertine
359.8-361.0	Peat.	absent
361.0-371.4	Very fine, alternating, peat and gray and yellow clay horizons (varves ?).	coarse
371.4-391.6	Very fine, alternating, peat and brown and gray clay horizons (varves ?).	fine to coarse
391.6-414.1	Mixed peat and brown, gray, and yellow clays.	fine to coarse
414.1-426.6	Mixed brown, yellow, and gray clays.	Coarse
426.6-428.3	Peat.	absent
428.3-434.3	Mixed peat and brown, gray, and yellow clays.	absent
434.3-478.8	Mixed yellow and gray clays.	coarse
478.8-530.0	Transition: upper, very dark gray (5Y-3/1) clay to lower, gray (5Y-5/1) clay.	coarse
530.0-593.0	Mixed dark gray (5Y-4/1) and brown (10YR-4/3) clays.	coarse
593.0-594.0	Peat.	absent
594.0-644.5	Mixed dark gray (5Y-4/1) and brown (10YR-4/3) clays.	coarse
644.5-704.5	Light brownish gray (2.5Y-6/2) clay.	coarse
704.5-748.5	Light gray (5Y-7/2) clay.	coarse
748.5-808.0	Mixed yellow, dark gray, and light gray clays.	coarse
808.0-812.0	Peat wedge in above sediments.	absent
812.0-817.0	Mixed yellow, dark gray, and light gray clays.	coarse
817.0-828.0	Peat.	absent
828.0-835.0	Dark gray (5Y-4/1) clay.	coarse

Appendix 2 b (cont'd.).

Depth (cm)	Sediment Type and Munsell Color	Travertine
835.0-856.0	Alternating, ca. 1-cm strata of dark gray (5Y-4/1) clay without travertine and light gray (5Y-7/2) clay with coarse travertine.	coarse to absent
856.0-861.0	Peat.	absent
861.0-869.0	Alternating, ca. 1-cm strata of dark gray (5Y-4/1) clay without travertine and light gray (5Y-7/2) clay with coarse travertine.	coarse to absent
869.0-875.0	Peat.	absent
875.0-930.0	Mixed peat and light and dark gray clays.	coarse
930.0-933.0	Peat.	absent
933.0-955.0	Grayish-brown (2.5Y-5/2) clay.	coarse
955.0-1007.0	Light gray (5Y-7/1) clay	coarse
1007.0-1013.0	Transition.	coarse
1013.0-1130.0	Peat.	coarse
1130.0-1177.0	Mixed dark and light gray clays.	coarse
1177.0-1255.0	Mixed yellow, brown, gray, and green clays.	coarse to absent
1255.0-1258.0	Peat.	absent
1258.0-1279.0	Mixed gray and yellow clays.	coarse
1279.0-1281.0	Peat.	absent
1281.0-1288.0	Mixed gray and yellow clays.	coarse
1288.0-1291.0	Peat.	absent
1291.0-1298.0	Mixed peat and gray and yellow clays.	coarse
1298.0-1344.0	Complex series of narrow, alternating, peat horizons without travertine, and gray and yellow clay horizons with coarse travertine.	coarse to absent
1344.0-1370.5	Pale yellow (5Y-8/4) clay.	coarse

Appendix 2 b (concluded).

Depth (cm)	Sediment Type and Munsell Color	Travertine
1370.5-1386.0	Complex series of narrow, alternating, peat horizons without travertine, and gray and yellow clay horizons with coarse travertine.	coarse to absent

Appendix 3. Collection localities of modern, surficial sediment samples from the Cuatro Ciénegas area. Compass grid coordinates are from Fig. 2.

Sample	Location	Sample	Location
CCG 8	NE¼, NW¼, H 13	CCM 43	SW¼, SW¼, G 13
CCG 12	NW¼, NW¼, M 17	CCM 44	SE¼, SW¼, G 12
CCG 16	NW¼, SE¼, M 14	CCM 46	center, K 12
CCG 17	NW¼, SW¼, M 14	CCM 47	NW¼, NW¼, H 12
CCG 18	center, M 15	CCM 48	SW¼, NW¼, H 12
CCM 4	SW¼, NE¼, H 12	CCM 96	NW¼, SW¼, H 12
CCM 8	NW¼, SW¼, D 16	CCM 97	NW¼, SW¼, H 12
CCM 10	NW¼, SW¼, E 14	CCM 98	NW¼, SW¼, H 12
CCM 12	SW¼, SW¼, F 13	CCM 99	NW¼, SW¼, H 12
CCM 13	center, NW¼, G 12	CCM 100	NW¼, SW¼, H 12
CCM 14	center, G 12	CCM 101	NW¼, SW¼, H 12
CCM 15	center, W border, M 14	CCM 102	NW¼, SW¼, H 12
CCM 16	center, M 14	CCM 103	NW¼, SW¼, H 12
CCM 17	center, W border, M 15	CCM 104	NW¼, SW¼, H 12
CCM 18	center, W border, M 16	CCM 105	NW¼, SW¼, H 12
CCM 19	center, M 16	CCM 106	NW¼, NE¼, J 14
CCM 20	center, W border, M 17	CCM 107	SW¼, NE¼, M 17
CCM 37	SE¼, NE¼, E 14	CCM 108	SW¼, NW¼, M 18
CCM 39	center, G 12	CCM 109	NW¼, NE¼, M 18
CCM 40	NW¼, SE¼, G 12	CCM 110	NW¼, SE¼, K 12
CCM 41	SE¼, SE¼. G 12	CCM 113	NW¼, NW¼, E 11
CCM 42	SW¼, SW¼, G 13	CCM 114	SW¼, SW¼, D 11

Appendix 3 (concluded).

Sample	Location
CCM 115	NW$\frac{1}{4}$, SW$\frac{1}{4}$, D 11
CCM 116	SW$\frac{1}{4}$, NW$\frac{1}{4}$, D 11
CCM 117	NW$\frac{1}{4}$, NW$\frac{1}{4}$, D 11
CCM 118	SW$\frac{1}{4}$, SW$\frac{1}{4}$, C 11
CCM 119	NW$\frac{1}{4}$, SW$\frac{1}{4}$, C 11

Appendix 4. First-count pollen data arranged by sample assemblages. Pollen type names are abbreviated in the tables.

Abies = Abi

Acacia = Aca

Agave = Aga

Artemisia = Art

Caprifoliaceae = Cap

Celtis-Moraceae type = CM

Cheno-ams = CA

Cupressaceae = Cup

Cyperaceae = Cyp

Ephedra = Eph

Eriogonum = Eri

Euphorbiaceae = Eup

Gramineae = GRA

High-spine Compositae = HS

Larrea = Lar

Liliaceae = Lil

Low-spine Compositae = LS

Onagraceae = Ona

Opuntia = Opu

Picea = Pic

Pinus = Pin

Polygala = Pla

Polygonum = Plm

Prosopis = Pro

Quercus = Que

Rosaceae = Ros

Sarcobatus = Sar

Solanaceae = Sol

Tidestromia = Tid

Typha = Typ

Umbelliferae = Umb

15-u, 3C-3P, unidentified pollen type = A

30-u, 3C-3P, unidentified pollen type = B

30-u, 4C-5C, unidentified pollen type = C

Miscellaneous unidentified grains = Unk

Appendix 4 a. First-count pollen data from Core E.

Depth (cm)	Pin	Que	Cup	Abi	Pic	Gra	CA	HS	LS	Art	Cyp	Eph	CM	Eup	Lil	Aga	Pla	Sol
20	21	04	01	1	0	027	05	06	05	10	11	1	2	1	0	1	0	0
40						No pollen												
60	15	02	01	0	0	060	09	04	04	00	02	1	0	0	0	0	0	0
80	17	10	00	0	0	043	37	34	14	00	23	2	6	0	2	0	1	1
100	24	06	00	0	0	087	68	01	04	03	01	6	2	0	0	0	0	0
120	17	03	01	0	0	076	69	02	13	14	01	0	0	0	0	0	0	0
140						No pollen												
160	16	12	00	0	0	081	69	03	09	06	00	0	1	0	0	0	1	0
180	21	04	00	0	0	106	50	02	07	00	00	4	2	0	0	0	0	0
190	08	02	00	0	0	97	24	09	08	00	04	0	0	0	0	0	0	0
193	16	05	01	0	0	078	97	11	15	04	00	0	0	0	0	0	0	0
196	05	04	00	0	0	131	35	05	15	01	03	0	0	0	0	0	1	0
200	17	09	02	0	0	086	55	04	15	01	07	0	0	0	0	0	0	0
205	17	05	01	0	1	127	33	07	06	01	07	1	1	0	0	0	0	0
208	10	09	01	0	1	128	39	02	06	00	09	0	1	0	0	0	0	1
211						No pollen												
214	23	10	00	0	0	093	37	13	05	01	07	1	1	0	0	0	0	0
217	17	04	01	0	0	100	24	01	09	02	03	1	2	0	0	0	0	0
220	41	04	03	1	0	079	35	14	17	01	00	0	1	0	0	0	0	0
240 I	18	19	05	0	1	084	50	04	15	03	00	0	0	0	0	0	0	0
240 II	26	09	12	0	0	082	45	04	13	00	01	0	0	0	0	0	0	0
260	42	08	03	0	0	076	29	10	18	02	02	0	0	0	0	0	0	0
280	40	11	10	0	0	054	44	09	14	2	08	0	0	0	1	0	0	0

Appendix 4 a (cont'd.).

Depth (cm)	Ona	Pro	Tid	Sar	Plm	Eri	Typ	A	B	C	Gap	Unk	n
20	0	0	0	0	0	0	0	0	1	0	0	3	100
40					No pollen								
60	0	0	0	0	0	0	0	0	0	0	0	2	100
80	0	0	0	0	0	0	2	1	1	0	0	6	200
100	0	0	0	0	0	0	0	0	0	0	0	3	200
120	0	0	0	0	0	0	1	0	0	0	0	3	200
140					No pollen								
160	0	0	0	0	0	0	0	0	0	0	0	2	200
180	0	0	0	0	0	0	0	0	0	0	0	4	200
190	0	0	0	0	0	0	0	0	0	0	0	3	155
193	0	1	0	0	0	0	0	0	0	0	0	5	233
196	0	0	0	0	0	0	0	0	1	0	0	8	209
200	0	0	0	0	0	0	0	0	0	0	0	4	200
205	1	0	0	0	0	0	0	0	0	0	0	4	212
208	0	0	0	0	0	0	0	0	0	0	0	4	211
211					No pollen								
214	0	0	0	0	0	0	0	0	1	0	0	7	199
217	0	0	0	0	0	0	0	0	1	0	0	7	172
220	0	0	1	0	0	0	0	0	0	0	0	3	200
240 I	0	0	0	1	0	0	0	0	0	0	0	0	200
240 II	0	0	0	0	0	0	0	0	0	0	0	8	200
260	0	0	0	0	0	0	0	0	0	0	3	7	200
280	0	0	0	0	0	0	0	0	0	0	0	7	200

Appendix 4 a (cont'd.).

Depth (cm)	Pin	Que	Cup	Abi	Pic	Gra	CA	HS	LS	Art	Cyp	Eph	CM	Eup	Lil	Aga	Pla	Sol
300 I	34	07	04	0	0	071	46	07	15	00	07	1	0	0	0	0	1	0
300 II	22	00	04	0	0	028	23	03	14	01	02	1	0	0	0	0	0	9
320	61	05	05	1	0	038	57	14	12	01	00	1	0	0	1	0	0	0
340	51	10	05	1	0	053	37	09	17	00	03	1	0	0	4	0	0	0
360	61	09	05	1	0	062	38	08	04	00	00	1	0	0	0	2	0	0
380	32	16	16	0	0	068	38	09	13	01	00	0	2	0	0	0	0	0
400	54	12	01	0	0	055	53	02	08	03	00	2	0	0	0	0	0	0
420	66	09	01	0	1	044	57	02	05	01	00	1	2	0	3	2	1	0
440	46	08	04	0	0	038	88	03	06	00	02	1	1	0	1	0	0	0
460	32	14	04	0	0	058	73	07	05	00	00	1	1	0	0	0	0	0
480	44	02	09	0	0	036	84	09	10	00	00	2	0	0	0	0	0	0
500	59	03	11	0	0	070	47	01	05	00	01	0	1	0	0	0	0	0
520							No pollen											
540							No pollen											
560	48	11	06	0	2	062	42	10	09	02	01	0	1	0	1	1	1	0
580							No pollen											

Appendix 4 a (concluded).

Depth (cm)	Ona	Pro	Tid	Sar	Plm	Eri	Typ	A	B	C	Cap	Unk	n
300 I	0	0	0	0	0	0	0	0	0	0	0	7	200
300 II	0	0	0	0	0	0	0	0	0	0	0	2	100
320	0	0	0	0	0	0	0	0	0	0	0	4	200
340	0	0	1	0	0	0	0	0	0	0	0	8	200
360	0	0	0	0	0	2	0	1	1	0	0	5	200
380	0	0	0	0	0	0	0	0	2	0	0	3	200
400	0	0	0	0	1	0	2	0	0	2	0	5	200
420	0	0	0	0	1	0	1	0	0	0	0	3	200
440	0	0	0	0	0	0	0	0	0	0	0	2	200
460	0	0	0	0	1	0	0	1	0	0	0	3	200
480	0	0	0	0	0	0	0	0	0	0	0	4	200
500	0	0	0	0	0	0	0	0	0	0	0	2	200
520					No pollen								
540					No pollen								
560	0	0	0	0	0	0	0	0	0	1	0	2	200
580					No pollen								

Appendix 4 b. First-count pollen data from Core F.

Depth (cm)	Pin	Que	Cup	Abi	Pic	Gra	CA	HS	LS	Art	Cyp	Eph	CM	Eup	Lil	Aga	Pla	Sol
10	27	03	02	1	0	020	009	11	08	01	109	1	1	1	0	1	0	0
30						No pollen												
50	48	05	00	0	0	093	009	03	06	06	015	0	3	0	2	1	0	0
67	27	07	00	0	0	117	044	10	14	07	002	0	2	0	0	0	0	0
70	09	08	13	0	0	098	038	21	06	02	000	2	0	0	0	0	0	0
73	33	04	01	1	0	117	051	25	12	06	003	0	1	0	1	0	0	0
76	27	08	00	0	0	119	059	20	08	01	002	0	1	0	0	0	0	0
79	24	03	01	0	0	112	030	04	05	03	000	1	2	0	1	0	0	0
82	30	06	01	0	0	104	040	05	16	04	002	0	1	0	0	0	0	0
85	14	04	00	0	0	082	036	04	14	06	000	0	0	0	0	0	1	1
88	16	01	00	0	0	062	019	02	07	01	001	0	0	0	0	0	0	0
90	36	06	00	0	0	076	022	12	23	05	012	0	0	0	0	1	1	0
93	23	05	00	0	0	146	057	17	16	02	005	0	1	0	0	0	2	0
110	39	04	00	0	0	073	021	11	13	12	015	1	1	0	0	1	1	0
130	33	01	00	0	0	093	039	05	05	07	005	0	3	0	0	0	0	0
150	20	03	00	0	0	067	067	15	05	15	003	0	1	0	1	0	0	0
152	17	02	00	0	0	109	064	05	15	03	001	1	0	0	0	0	0	0
155	26	04	00	0	0	102	087	08	07	04	002	0	1	0	0	0	0	0
160	07	07	01	0	0	099	038	07	10	00	000	0	0	0	0	0	0	1
163	11	07	00	0	0	078	082	05	14	03	000	0	0	0	0	0	0	0
166	15	05	01	0	0	137	038	06	12	07	000	1	0	0	0	0	0	0
169	26	11	00	0	0	095	051	07	12	03	001	0	1	0	0	0	0	0
170	16	04	01	0	0	087	056	06	14	09	003	0	1	0	0	0	0	0
190						No pollen												

Appendix 4 b (cont'd.).

Depth (cm)	Sar	Plm	Eri	Ros	Typ	A	B	C	Umb	Unk	n
10	0	0	0	0	0	1	0	0	0	04	200
30					No pollen						
50	1	0	0	0	1	0	0	0	0	07	200
67	0	0	0	0	1	0	0	0	0	09	240
70	0	0	0	0	0	0	0	0	0	00	200
73	0	0	0	0	2	0	0	0	0	11	268
76	0	0	0	0	1	0	0	0	0	08	254
79	0	0	0	0	0	0	0	0	0	06	192
82	0	0	0	0	1	0	0	0	0	00	210
85	0	0	0	0	0	0	0	0	0	03	165
88	0	0	0	0	0	0	0	0	0	02	111
90	0	0	1	0	0	0	0	0	0	05	200
93	0	0	0	0	0	0	1	0	0	07	282
110	0	0	0	0	2	1	0	0	0	05	200
130	0	0	0	0	1	0	0	0	0	08	200
150	1	0	0	0	0	0	0	0	0	02	200
152	0	0	0	0	1	0	0	0	0	02	220
155	0	0	0	0	1	0	0	0	0	01	243
160	0	0	0	0	0	0	0	0	1	04	175
163	0	0	0	0	1	0	0	0	0	04	205
166	0	0	0	0	1	0	0	0	0	02	225
169	0	0	0	0	0	0	0	0	0	05	212
170	0	0	0	0	1	0	0	0	0	02	200
190					No pollen						

Appendix 4 b (cont'd.).

Depth (cm)	Pin	Que	Cup	Abi	Pic	Gra	CA	HS	LS	Art	Cyp	Eph	CM	Eup	Lil	Aga	Pla	Sol
210	48	07	00	0	0	088	021	05	07	20	000	1	0	0	0	0	0	0
230	21	01	00	0	0	055	106	01	07	01	003	1	1	0	0	0	0	0
236	35	05	00	0	1	103	032	11	08	01	003	0	0	0	0	0	0	0
250	09	07	10	0	0	119	033	05	13	02	000	0	0	0	0	0	0	0
270	41	02	01	0	0	039	065	14	19	07	001	0	1	0	0	0	0	0
290	36	08	02	0	0	086	030	10	15	01	006	0	1	0	0	0	0	0
310 I	09	06	11	0	0	125	024	06	16	00	000	0	0	0	0	0	0	0
310 II	26	05	02	0	0	111	028	08	13	01	000	0	0	0	0	0	0	0
330	51	03	02	0	0	073	040	11	10	03	002	0	0	0	0	0	0	0
350 I	18	03	14	0	0	072	032	08	16	02	032	0	0	0	0	0	0	0
350 II	32	02	05	0	0	087	014	02	05	01	039	0	0	0	1	0	0	0
370	31	04	05	0	0	072	07	03	04	00	001	1	0	0	0	0	0	0
390	34	05	03	0	0	096	031	01	13	00	009	1	0	0	1	1	0	0
410	43	04	00	1	2	036	084	15	03	01	009	1	0	0	0	0	0	0
430	45	01	00	0	0	102	028	06	07	03	005	1	1	0	0	0	0	0
450	21	02	01	0	0	079	085	04	04	01	001	0	1	0	0	0	0	0
470	28	01	04	1	0	041	096	08	10	02	008	1	0	0	0	0	0	0
480	44	00	03	0	1	036	089	08	09	02	000	1	0	0	0	0	0	0
500	28	00	04	0	0	065	060	07	14	01	006	3	0	0	0	1	0	0
510	22	09	09	2	0	061	051	08	12	08	005	5	0	1	0	0	0	0
530	28	02	01	0	0	064	071	14	15	01	003	0	0	0	0	0	0	0
550	34	00	01	0	0	081	066	05	04	03	001	0	0	0	0	0	0	0
570	23	08	08	0	0	079	033	13	08	01	027	0	0	0	0	0	0	0
590	21	07	00	0	0	066	062	12	14	03	02	0	1	0	0	0	0	2

Appendix 4 b (cont'd.).

Depth (cm)	Sar	Plm	Eri	Ros	Typ	A	B	C	Umb	Unk	n
210	0	0	0	0	0	0	0	1	0	02	200
230	0	0	0	0	0	0	0	0	0	03	200
236	0	0	0	0	0	0	0	0	0	01	200
250	0	0	0	0	0	0	0	0	0	02	200
270	0	0	0	0	1	0	1	0	0	08	200
290	0	0	0	0	1	0	0	0	0	04	200
310 I	0	0	0	0	0	0	0	0	0	03	200
310 II	0	0	0	0	1	0	0	0	0	05	200
330	0	0	0	0	0	0	0	0	0	05	200
350 I	0	0	0	0	0	0	0	0	0	03	200
350 II	0	0	0	0	3	1	0	0	0	08	200
370	0	0	0	0	0	0	0	0	0	07	200
390	0	0	0	0	2	0	0	0	0	03	200
410	0	0	0	0	0	0	0	0	0	01	200
430	0	0	0	0	0	0	0	0	0	01	200
450	0	0	0	0	0	0	0	1	0	00	200
470	0	0	0	0	0	0	0	0	0	00	200
480	0	1	0	0	0	0	0	0	0	06	200
500	0	0	0	0	2	0	0	3	0	06	200
510	0	0	0	0	0	0	0	0	0	07	200
530	0	0	0	0	1	0	0	0	0	00	200
550	0	0	0	0	0	1	0	0	0	14	200
570	0	0	0	0	0	0	0	0	0	00	200
590	0	0	0	0	0	0	0	0	0	10	200

Appendix 4 b (cont'd.).

Depth (cm)	Pin	Que	Cup	Abi	Pic	Gra	CA	HS	LS	Art	Cyp	Eph	CM	Eup	Lil	Aga	Pla	Sol
600	No pollen																	
610	40	03	02	0	0	090	030	11	04	01	014	1	0	0	0	0	0	0
630	44	02	05	0	0	034	083	06	11	04	000	1	2	0	0	0	0	0
650	No pollen																	
670	25	04	01	0	0	044	093	12	14	00	005	0	0	1	0	0	0	0
690	07	05	00	0	0	035	132	08	06	03	000	2	0	0	0	0	0	0
710	No pollen																	
730	No pollen																	
750	28	09	03	0	0	072	040	21	19	00	006	1	0	0	0	0	0	0
770	11	01	01	0	0	041	126	03	11	01	004	0	0	0	0	0	0	0
790	10	02	02	0	0	034	136	03	05	01	005	0	0	0	0	0	0	0
810	35	03	01	0	0	071	050	18	11	03	003	0	0	0	0	0	0	0
830	25	04	07	0	0	073	054	11	13	3	007	0	0	0	0	0	0	0
850	29	10	04	0	0	062	058	11	14	01	007	0	0	0	0	0	0	1
870	21	07	07	0	0	089	050	05	07	03	010	0	0	0	0	0	0	0
890	24	05	06	0	0	069	056	13	12	08	007	0	0	0	0	0	0	0
910	38	09	00	0	0	081	044	09	04	01	012	0	0	0	0	1	0	0
930	20	07	05	0	0	063	072	07	09	04	007	0	1	0	0	0	0	0
950	14	13	13	0	0	087	042	09	09	00	009	1	0	0	0	0	0	0
970	18	04	08	0	0	051	069	11	14	02	017	0	0	0	0	0	0	2
990	No pollen																	
1010	No pollen																	
1030	45	16	02	0	0	081	020	11	15	06	000	1	0	0	0	0	0	0
1050	51	16	00	0	1	070	026	07	07	04	011	0	1	0	1	0	0	0

Appendix 4 b (cont'd.).

Depth (cm)	Sar	Plm	Eri	Ros	Typ	A	B	C	Umb	Unk	n
600					No pollen						
610	0	0	0	0	0	0	0	1	0	03	200
630	0	0	3	1	0	0	0	0	0	04	200
650					No pollen						
670	0	0	0	0	0	0	0	0	0	01	200
690	0	0	0	0	0	0	0	0	0	02	200
710					No pollen						
730					No pollen						
750	0	0	0	0	0	0	0	0	0	01	200
770	0	0	0	0	0	0	0	0	0	01	200
790	0	0	0	0	0	0	0	0	0	02	200
810	0	0	0	0	0	1	0	1	0	03	200
830	1	0	0	0	0	0	0	0	0	02	200
850	0	0	0	0	0	0	0	0	0	03	200
870	1	0	0	0	0	0	0	0	0	00	200
890	0	0	0	0	0	0	0	0	0	00	200
910	0	0	0	0	0	0	0	0	0	00	200
930	0	0	1	0	0	1	0	0	0	03	200
950	0	0	0	0	0	0	0	0	0	03	200
970	0	0	0	0	0	0	0	0	0	04	200
990					No pollen						
1010					No pollen						
1030	0	0	0	1	0	0	0	0	0	02	200
1050	0	0	1	1	0	0	1	0	0	02	200

Appendix 4 b (cont'd.).

Depth (cm)	Pin	Que	Cup	Abi	Pic	Gra	CA	HS	LS	Art	Cyp	Eph	CM	Eup	Lil	Aga	Pla	Sol
1070	36	25	01	0	0	067	041	04	12	04	003	0	0	0	1	0	0	0
1090	28	06	02	0	0	065	020	02	12	01	063	0	0	0	0	0	0	0
1110	40	11	02	0	0	054	044	20	11	02	008	0	3	0	0	0	0	0
1130	13	15	02	0	1	031	066	37	25	01	007	0	0	0	0	0	0	0
1150	39	09	01	0	0	060	056	23	03	04	001	1	0	0	0	0	0	0
1170						No pollen												
1190	44	14	04	0	1	056	022	10	15	6	013	1	2	0	0	0	1	0
1210	29	03	02	0	0	097	041	11	10	04	003	0	0	0	0	0	0	0
1230						No Pollen												
1250						No Pollen												
1270	86	07	00	0	0	050	030	05	15	04	000	0	0	0	0	0	0	0
1290	50	16	01	0	1	073	024	05	22	00	000	0	1	0	0	0	0	0
1310	57	18	00	0	0	048	012	07	17	05	025	1	3	0	1	0	0	0
1330	65	11	06	0	0	076	004	17	09	01	002	0	2	0	1	0	0	0
1350						No pollen												
1370	30	04	00	0	0	106	031	12	11	o2	000	1	0	0	0	0	0	0

Appendix 4 b (concluded)

Depth (cm)	Sar	Plm	Eri	Ros	Typ	A	B	C	Umb	Unk	n
1070	0	0	0	0	2	1	0	2	0	01	200
1090	0	0	0	0	0	0	0	0	0	00	200
1110	0	0	0	0	1	1	0	1	0	02	200
1130	0	0	0	0	0	0	0	0	0	02	200
1150	0	0	0	0	0	0	0	0	0	03	200
1170					No pollen						
1190	0	0	1	0	2	0	0	0	0	08	200
1210	0	0	0	0	0	0	0	0	0	00	200
1230					No pollen						
1250					No pollen						
1270	0	0	0	0	0	0	0	0	0	00	200
1290	0	0	0	0	0	2	0	0	0	05	200
1310	0	0	0	0	0	0	0	0	0	06	200
1330	0	0	0	0	0	0	0	0	0	06	200
1350					No pollen						
1370	0	0	1	0	0	0	0	0	0	02	200

Appendix 4 c. First-count pollen data from montane transects. Counts are arranged in elevational sequence.

Sample	Pin	Que	Cup	Abi	Spr	Gra	CA	HS	LS	Art	Eph	CM	Eup	Lil	Aga	Pla	Lar	Aca
Sierra de San Marcos																		
CCG 17	136	25	03	0	0	08	06	13	04	00	0	2	0	0	0	2	0	0
CCM 15	116	32	01	0	0	20	09	05	13	00	1	0	0	0	0	0	0	0
CCG 16	063	32	03	0	0	24	29	07	32	01	0	1	0	4	0	0	0	0
CCM 16	054	33	00	0	0	41	21	15	23	01	0	2	0	0	7	0	0	0
CCM 17	046	19	01	0	0	44	23	19	33	00	0	2	0	0	6	1	0	0
CCG 18	039	00	01	0	0	47	18	16	46	00	2	0	0	0	0	0	0	0
CCM 18	063	18	00	1	0	28	23	32	26	00	2	1	3	0	1	0	0	0
CCM 19	002	18	01	0	0	06	07	27	35	00	0	0	0	0	0	0	0	0
CCM 20	009	10	00	0	0	13	08	22	32	00	1	0	0	0	0	0	1	0
Sierra de la Madera																		
CCM 113	144	22	12	0	0	07	01	01	02	00	0	2	0	0	1	0	0	0
CCM 114	065	98	10	1	0	13	03	01	04	00	1	0	0	0	3	0	0	0
CCM 115	034	85	09	0	1	18	13	07	21	00	2	1	0	0	0	0	0	0
CCM 116	054	58	09	0	0	14	07	05	38	01	0	1	1	0	3	0	0	3
CCM 117	036	37	08	0	0	29	17	25	39	00	1	0	0	0	6	0	0	0
CCM 118	044	25	05	0	0	33	15	29	33	01	2	3	0	0	4	0	0	1
CCM 119	029	11	01	0	0	27	20	33	65	00	2	1	0	3	3	0	0	0
Sierra de Menchaca																		
CCM 8	017	06	02	0	0	45	06	37	72	06	2	1	0	0	0	0	0	0

Appendix 4 c (concluded).

Sample	B	Opu	Unk	n
Sierra de San Marcos				
CCG 17	0	0	1	200
CCM 15	0	0	3	200
CCG 16	0	0	4	200
CCM 16	0	0	3	200
CCM 17	5	0	1	200
CCG 18	0	0	6	175
CCM 18	0	0	2	200
CCM 19	0	0	4	100
CCM 20	0	0	4	100
Sierra de la Madera				
CCM 113	5	0	3	200
CCM 114	1	0	0	200
CCM 115	0	0	9	200
CCM 116	0	0	6	200
CCM 117	0	0	2	200
CCM 118	0	0	5	200
CCM 119	0	0	5	200
Sierra de Menchaca				
CCM 8	0	1	5	200

Appendix 4 d. First-count pollen data from valley floor surface samples. Counts are arranged by vegetational formation.

Sample	Pin	Que	Cup	Gra	CA	HS	LS	Art	Cyp	Eph	CM	Eup	Lil	Aga	Pla	Sol	Pro
Sedge-riparian formation																	
CCG 8	08	05	00	062	023	19	10	01	67	0	1	0	0	1	0	0	0
CCM 41	15	07	02	034	049	15	09	03	47	0	6	1	0	0	0	0	0
CCM 43	16	00	03	013	042	28	10	02	50	0	6	0	0	0	0	0	0
CCM 46	10	08	01	047	061	05	10	00	43	0	4	0	2	0	0	0	0
CCM 47	02	07	00	036	054	11	06	00	01	0	1	1	1	0	0	0	0
CCM 48	14	00	00	043	031	09	10	04	86	1	1	0	0	0	0	0	0
CCM 96	20	08	02	028	025	06	12	02	85	0	5	0	0	0	0	0	0
CCM 100	14	07	01	026	034	08	16	01	79	0	3	0	0	0	0	0	0
CCM 104	25	11	02	017	030	09	11	04	73	0	5	0	0	0	0	0	0
Grassland formation																	
CCM 13	02	00	00	068	008	08	13	00	00	0	0	0	0	0	0	0	0
CCM 98	09	05	00	135	023	03	08	05	02	0	3	0	1	0	0	0	0
CCM 99	18	07	00	108	036	06	12	02	00	5	0	1	1	0	0	0	0
Chenopod-xeric scrub formation																	
CCM 10	01	00	00	010	073	03	11	01	00	0	1	0	0	0	0	0	0
CCG 12	15	07	00	076	227	39	28	03	00	1	2	0	0	0	0	0	0
CCM 12	04	02	00	018	055	02	18	00	00	0	1	0	0	0	0	0	0
CCM 37	00	01	07	044	127	01	04	01	00	1	2	0	0	0	0	0	0
CCM 44	03	09	01	024	133	05	17	01	00	0	2	0	1	0	0	0	0
CCM 101	09	09	01	029	119	06	13	03	02	0	0	0	0	0	0	0	0
CCM 103	11	06	00	040	122	04	09	04	00	1	0	0	0	0	0	0	0

Appendix 4 d (cont'd.).

Sample	Lar	Tid	Sar	Plm	Eri	Ros	Aca	Typ	A	B	C	Unk	n
Sedge-riparian formation													
CCG 8	0	0	0	0	0	0	0	00	0	0	0	3	200
CCM 41	0	0	1	0	0	0	0	00	1	4	0	6	200
CCM 43	0	0	0	0	0	0	0	25	1	2	0	2	200
CCM 46	0	0	1	0	0	0	0	01	3	4	0	0	200
CCM 47	0	0	0	0	0	0	0	77	1	2	0	0	200
CCM 48	0	0	0	0	0	0	0	00	0	0	0	1	200
CCM 96	0	0	0	0	0	0	0	00	0	2	0	5	200
CCM 100	0	0	0	1	0	0	0	00	4	2	0	4	200
CCM 104	0	0	0	0	0	0	0	00	1	3	0	9	200
Grassland formation													
CCM 13	0	0	0	0	0	0	0	00	0	0	0	1	100
CCM 98	0	0	0	0	0	0	0	00	0	1	0	5	200
CCM 99	0	0	0	0	0	0	0	00	1	0	0	2	200
Chenopod-xeric scrub formation													
CCM 10	0	0	0	0	0	0	0	00	0	0	0	0	100
CCG 12	0	0	0	0	0	0	0	00	0	0	0	2	400
CCM 12	0	0	0	0	0	0	0	00	0	0	0	0	100
CCM 37	0	1	0	0	0	0	0	00	0	3	0	8	200
CCM 44	0	0	0	0	0	0	0	00	0	1	0	3	200
CCM 101	0	0	0	0	0	0	0	00	0	0	2	7	200
CCM 103	0	0	0	0	0	0	0	00	0	2	1	0	200

Appendix 4 d (cont'd.).

Sample	Pin	Que	Cup	Gra	CA	HS	LS	Art	Cyp	Eph	CM	Eup	Lil	Aga	Pla	Sol	Pro
CCM 105	10	03	01	037	131	01	11	00	00	1	2	0	0	0	0	0	0
CCM 106	05	03	00	017	163	02	04	01	00	1	2	0	0	0	0	0	0
CCM 107	03	03	00	044	112	12	16	00	02	1	3	0	0	0	0	0	0
CCM 109	05	08	03	026	222	03	02	17	00	4	1	0	0	0	0	0	8
CCM 110	13	08	00	022	112	13	14	10	00	0	3	0	0	0	0	0	0
Transitional formations																	
CCM 4	02	02	00	093	070	05	12	01	06	3	3	0	0	0	0	0	0
CCM 40	18	09	01	035	066	16	10	05	15	1	2	1	0	0	0	0	0
CCM 42	07	05	02	022	101	20	22	00	14	0	3	0	0	0	0	0	0
CCM 97	08	08	00	095	014	08	09	00	39	0	12	0	0	1	1	2	0
CCM 102	10	12	02	042	073	10	13	03	02	2	3	0	0	0	0	0	0
CCM 108	20	06	00	056	078	12	17	01	00	0	5	0	1	0	0	0	0
Bare surface																	
CCM 14	08	02	01	072	071	08	28	02	00	1	1	0	0	0	0	0	1
CCM 39	13	02	00	064	081	03	30	01	00	0	0	0	0	0	0	0	0

Appendix 4 d (concluded).

Sample	Lar	Tid	Sar	Plm	Eri	Ros	Aca	Typ	A	B	C	Unk	n
CCM 105	0	0	0	0	1	0	0	00	0	0	0	2	200
CCM 106	1	0	0	0	0	0	0	00	0	0	1	0	200
CCM 107	0	0	0	0	0	0	0	00	0	0	0	4	200
CCM 109	0	0	0	0	0	0	0	00	0	0	0	1	300
CCM 110	0	0	0	0	0	0	1	00	0	0	0	4	200
Transitional formations													
CCM 4	0	0	0	0	0	0	0	00	0	0	0	3	200
CCM 40	0	1	0	0	0	0	0	10	1	5	0	4	200
CCM 42	0	0	0	0	0	1	0	01	0	0	0	2	200
CCM 97	0	0	0	0	0	1	0	00	0	1	0	1	200
CCM 102	0	0	0	0	1	0	0	00	15	5	0	7	200
CCM 108	0	0	0	0	0	1	1	00	0	0	1	1	200
Bare surface													
CCM 14	0	1	0	0	0	0	0	00	0	1	0	3	200
CCM 39	0	0	0	0	0	0	0	00	0	0	0	6	200

Appendix 5. Second-count pollen data.

Appendix 5 a. Core E.

Depth (cm)									
20	39	05	01	1	0	21	18	15	100
40				No pollen					
60	29	03	01	0	0	44	23	00	100
80	19	12	00	0	0	53	16	00	100
100	35	07	00	0	0	34	19	05	100
120	26	04	01	0	0	23	28	18	100
140				No pollen					
160	29	17	00	0	0	23	21	10	100
180	43	08	00	0	1	22	23	03	100
190	28	04	02	0	0	41	25	00	100
193	39	07	01	0	0	28	20	02	100
196	20	12	00	0	0	24	34	02	092
200	37	11	02	0	0	19	29	02	100
205	34	05	01	0	1	41	16	02	100
208	58	13	01	0	1	08	18	01	100
211				No pollen					
214	55	11	00	0	0	19	13	02	100
217	35	5	01	0	0	04	13	03	061
220	52	05	04	1	0	16	18	04	100
240	44	28	17	0	1	08	28	03	129
260	51	09	04	0	0	12	22	02	100

Appendix 5 a (concluded).

Depth (cm)	Pin	Que	Cup	Abi	Pic	HS	LS	Art	n
280	49	11	10	0	0	11	17	02	100
300	56	07	08	0	0	16	20	02	118
320	62	05	05	1	0	14	12	01	100
340	53	10	05	1	0	13	18	00	100
360	63	09	05	1	1	12	07	02	100
380	38	16	16	0	0	12	16	02	100
400	68	12	01	0	0	04	12	03	100
420	75	10	01	0	1	04	08	01	100
440	65	09	05	0	1	06	14	00	100
460	53	15	04	0	0	14	13	01	100
480	53	04	10	0	0	10	23	00	100
500	74	04	11	0	0	03	08	00	100
520				No pollen					
540				No pollen					
560	54	11	07	2	1	13	10	02	100

Appendix 5 b. Core F.

Depth (cm)	Pin	Que	Cup	Abi	Pic	HS	LS	Art	n
10	44	10	02	1	0	23	18	02	100
30				No pollen					
50	71	05	01	0	0	07	09	07	100
67	34	07	00	0	0	26	25	08	100
70	19	09	13	0	0	38	17	04	100
73	37	04	01	1	0	36	15	06	100
76	38	09	00	0	0	38	11	04	100
79	40	06	01	0	0	32	16	05	100
82	42	06	01	0	0	17	28	06	100
85	27	04	00	0	0	18	40	11	100
88	19	2	00	0	0	07	21	01	050
90	43	06	00	0	0	18	27	06	100
93	35	08	00	0	0	35	18	04	100
110	45	05	00	0	0	18	17	15	100
130	48	02	00	0	0	27	14	09	100
150	30	04	00	0	0	30	18	18	100
152	38	07	00	0	0	20	30	05	100
155	61	05	00	0	0	10	09	15	100
160	47	14	01	0	0	16	13	00	091
163	12	10	02	0	0	05	18	03	050
166	44	12	01	0	0	11	15	17	100
169	47	12	00	0	0	20	17	04	100
170	46	10	02	0	0	09	18	15	100

Appendix 5 b (cont'd.).

Depth (cm)	Pin	Que	Cup	Abi	Pic	HS	LS	Art	n
190				No pollen					
210	58	08	01	0	0	06	07	20	100
230	61	16	01	0	0	07	13	02	100
236	64	06	00	0	0	15	13	02	100
250	53	12	01	0	1	14	17	02	100
270	48	03	01	0	0	16	23	09	100
290	55	09	03	0	0	10	22	01	100
310	35	11	13	0	0	14	29	01	103
330	67	03	03	0	0	12	12	03	100
350	50	05	19	0	0	10	21	03	108
370	69	06	07	0	0	11	05	00	100
390	64	06	04	0	0	08	17	01	100
410	66	02	05	2	1	20	03	01	100
430	71	01	00	0	0	13	12	03	100
450	73	03	04	0	0	10	07	03	100
470	57	04	05	1	0	15	15	03	100
480	75	00	03	0	1	10	09	02	100
500	58	00	07	0	0	17	17	01	100
510	39	14	10	2	0	14	13	08	100
530	55	02	02	0	0	24	15	02	100
550	78	02	01	0	0	12	04	03	100
570	38	10	09	0	0	25	18	00	100
590	54	08	00	0	0	15	20	03	100

Appendix 5 b (cont'd.).

Depth (cm)	Pin	Que	Cup	Abi	Pic	HS	LS	Art	n
600				No pollen					
610	70	07	02	0	0	14	05	02	100
630	64	04	06	0	0	09	13	04	100
650				No pollen					
670	58	10	02	0	0	14 -	15	01	100
690	52	07	03	0	0	12	13	05	092
710				No pollen					
730				No pollen					
750	38	10	03	0	0	22	27	00	100
770	48	10	06	0	0	13	22	01	100
790	54	03	02	0	0	27	13	01	100
810	55	04	02	0	0	22	14	03	100
830	48	06	07	0	0	18	18	03	100
850	49	11	06	0	0	16	16	02	100
870	54	10	08	0	0	12	12	04	100
890	35	07	07	0	0	25	18	08	100
910	64	11	01	0	0	16	06	02	100
930	47	12	07	0	0	18	11	05	100
950	39	20	15	0	0	15	11	00	100
970	37	10	11	0	0	17	21	04	100
990				No pollen					
1010				No pollen					
1030	49	16	02	0	0	12	15	06	100

Appendix 5 b (concluded).

Depth (cm)	Pin	Que	Cup	Abi	Pic	HS	LS	Art	n
1050	61	17	00	0	1	10	07	04	100
1070	52	25	01	0	0	05	13	04	100
1090	65	07	02	1	0	06	17	02	100
1110	44	12	03	0	0	28	11	02	100
1130	16	16	03	0	1	38	25	01	100
1150	50	14	01	0	0	27	03	05	100
1170				No pollen					
1190	49	14	04	0	1	10	16	06	100
1210	55	05	03	0	0	15	17	05	100
1230				No pollen					
1250				No pollen					
1270	86	07	00	0	0	05	15	04	100
1290	55	16	01	0	1	05	22	00	100
1310	57	18	00	0	0	07	17	05	104
1330	65	11	06	0	0	17	09	01	109
1350				No pollen					
1370	35	04	00	0	0	12	11	02	064

Appendix 5 c. Valley floor surface samples. Counts are arranged by vegetational formation.

Sample	Pin	Que	Cup	Abi	Pic	HS	LS	Art	n
Sedge-riparian formation									
CCG 8	21	06	00	0	0	47	25	01	100
CCM 41	33	09	03	0	0	28	23	04	100
CCM 43	26	06	00	0	0	49	17	02	100
CCM 46	28	17	01	0	0	17	36	01	100
CCM 47	22	10	00	0	0	35	31	02	100
CCM 48	34	07	01	0	0	21	33	04	100
CCM 96	42	10	02	0	0	18	25	03	100
CCM 100	34	13	01	0	0	21	29	02	100
CCM 104	38	15	02	0	0	14	25	06	100
Grassland formation									
CCM 13	07	03	00	0	0	11	16	00	037
CCM 98	30	15	00	0	0	19	29	07	100
CCM 99	27	11	01	0	0	29	27	05	100
Chenopod-xeric scrub formation									
CCM 10	11	04	00	0	0	06	23	01	045
CCG 12	16	08	00	0	0	42	31	03	100
CCM 12	04	02	00	0	0	03	18	00	027
CCM 37	26	10	01	0	0	11	46	06	100
CCM 44	26	19	01	0	0	10	40	04	100
CCM 101	27	15	03	0	0	16	34	05	100

Appendix 5 c (concluded).

Sample	Pin	Que	Cup	Abi	Pic	HS	LS	Art	n
CCM 103	32	10	07	0	0	15	27	09	100
CCM 105	43	09	00	0	0	26	18	04	100
CCM 106	51	05	00	0	0	15	24	05	100
CCM 107	21	06	00	0	0	42	30	01	100
CCM 109	59	19	03	0	0	19	33	32	165
CCM 110	23	11	00	0	0	21	31	14	100
Transitional formations									
CCM 4	23	13	00	0	0	26	36	02	100
CCM 40	29	15	01	0	0	25	25	05	100
CCM 42	13	06	02	0	0	45	34	00	100
CCM 97	34	15	00	0	0	16	28	07	100
CCM 102	31	16	02	0	0	20	23	08	100
CCM 108	41	09	00	0	0	20	29	01	100
Bare surface									
CCM 14	14	13	02	0	0	15	54	02	100
CCM 39	32	07	00	0	0	10	48	03	100

BIOGRAPHICAL SKETCH

Edward Raymond Meyer was born 6 November 1943 in Chicago, Illinois. He entered Indiana University, Bloomington, Indiana, during September, 1961, and received a Bachelor of Arts degree in Zoology in June, 1966. He accepted a Graduate Research Assistantship at the Water Resources Laboratory, University of Louisville, Louisville, Kentucky, during June, 1966, and completed the requirements for a Master of Science degree in Biology in August, 1968. He enrolled as a graduate student in the Department of Zoology at Arizona State University in September, 1968, where he held at different times a Teaching Assistantship, a Teaching Associateship, a Research Assistantship, an Arizona State University Graduate Summer Fellowship, a N.D.E.A. Predoctoral Fellowship, and a N.S.F. grant-sponsored Research Associateship. He received a Doctor of Philosophy degree in Zoology from Arizona State University in June, 1972.