

POLLEN EVIDENCE FOR CLIMATIC VARIABILITY AND CULTURAL DISTURBANCE IN THE MAYA LOWLANDS

Barbara W. Leyden

Department of Geology, University of South Florida, Tampa, FL 33620, USA

Abstract

Palynology provides a record of past environmental change in the Maya Lowlands. The underlying principles are simple, but, as with all proxies, there are limitations. During the late glacial period, environmental change was governed by climate, which was cooler and much drier and supported sparse temperate vegetation. The early Holocene epoch was warmer and very wet in the southern Lowlands when mesic tropical forests predominated, while the northern Yucatan Peninsula was edaphically dry until eustatic sea level rose. The modern distributions of plant associations and climatic gradients were established at the end of the early Holocene. Climatic variability continued throughout the Holocene. However, the ability of palynology to identify climatic events is hindered after the Maya became numerous in the Lowlands. Then, multidisciplinary studies provide a better interpretation of events, especially during the late Holocene. Pollen records poorly reflect cyclical droughts seen in isotopic records, as natural vegetation has adapted to these fluctuations.

Explanations for the rise and fall of past civilizations are often formulated within a deterministic framework. Societies are either infinitely adaptable or hopelessly at the mercy of an unpredictable environment. Reality rarely cooperates with such simplistic approaches. Cultures are neither powerless nor infinitely adaptable to climatic change (deMenocal 2001), and the same may be said for vegetation. Paleoecological studies can be used to provide some understanding of how and to what extent the natural environment and societies interacted and adapted in the past. The history of the ancient Maya of lowland Central America provides us with one “experiment” that can be coaxed from the paleoenvironmental record (Deevey 1969). As with many experiments, we are often left with more new questions than answers to old ones.

This paper focuses on the contributions of pollen analysis to understanding the environmental history of the Maya Lowlands. The interactions among climate, culture, and the physical and biological environment are reciprocal and dynamic and form a multi-dimensional response surface that integrates all of the factors into a unique response. When one factor such as climate or culture dominates the others, a single approach may yield accurate interpretations. When the factors are more equal, multidisciplinary studies provide a more robust accounting of the integrated response. Each approach—whether biological, geochemical, or anthropological—has limitations that curtail its usefulness. Thus, the strengths and the weaknesses of each approach need to be understood so that the data are used appropriately. For instance, all studies of climate predating instrumental and written records use indirect indices of climate that have limits on accuracy and completeness of coverage. The protocol for each study must therefore

clearly define what the proxy is actually measuring and what it is attempting to represent. All factors that might potentially affect either one need to be clearly understood, especially those unrelated to the problem of interest, so that observations are not ascribed to the wrong mechanism. The pollen record is one proxy for past vegetational change that can be used as an indicator of climatic variation. However, human actions can have a profound impact on both climate and vegetation, thus contributing to the complexity of interactions and interpretations of the past. I will present the strengths and weaknesses of tropical pollen analysis. I will then discuss the pollen evidence for climatic variability over the past 36,000 years in the Maya Lowlands, as well as pollen evidence of cultural forces acting on those varying environmental conditions.

THE MAYA LOWLANDS

The Maya Lowlands extend across the Yucatan Peninsula, a low limestone platform (ca. <200 m above sea level [asl]) with a few areas of slightly greater elevation (>600 m asl) (Figure 1). The karst topography contains numerous lakes and smaller depressions, particularly in the Peten lake district of Guatemala. The climate is seasonal, with a mean annual temperature ranging between 25°C and 28°C. Precipitation increases from the northwest to the southeast (ca. <500 mm to 1,900 mm yr⁻¹) on the Yucatan Peninsula (Flores and Carvajal 1994), and to the south (ca. 3,000 to 4,000 mm yr⁻¹) in southern Belize and eastern Guatemala (Deevey et al. 1980).

Today, the drier areas of the northwestern Yucatan Peninsula support deciduous subtropical dry forests. Leguminous trees are

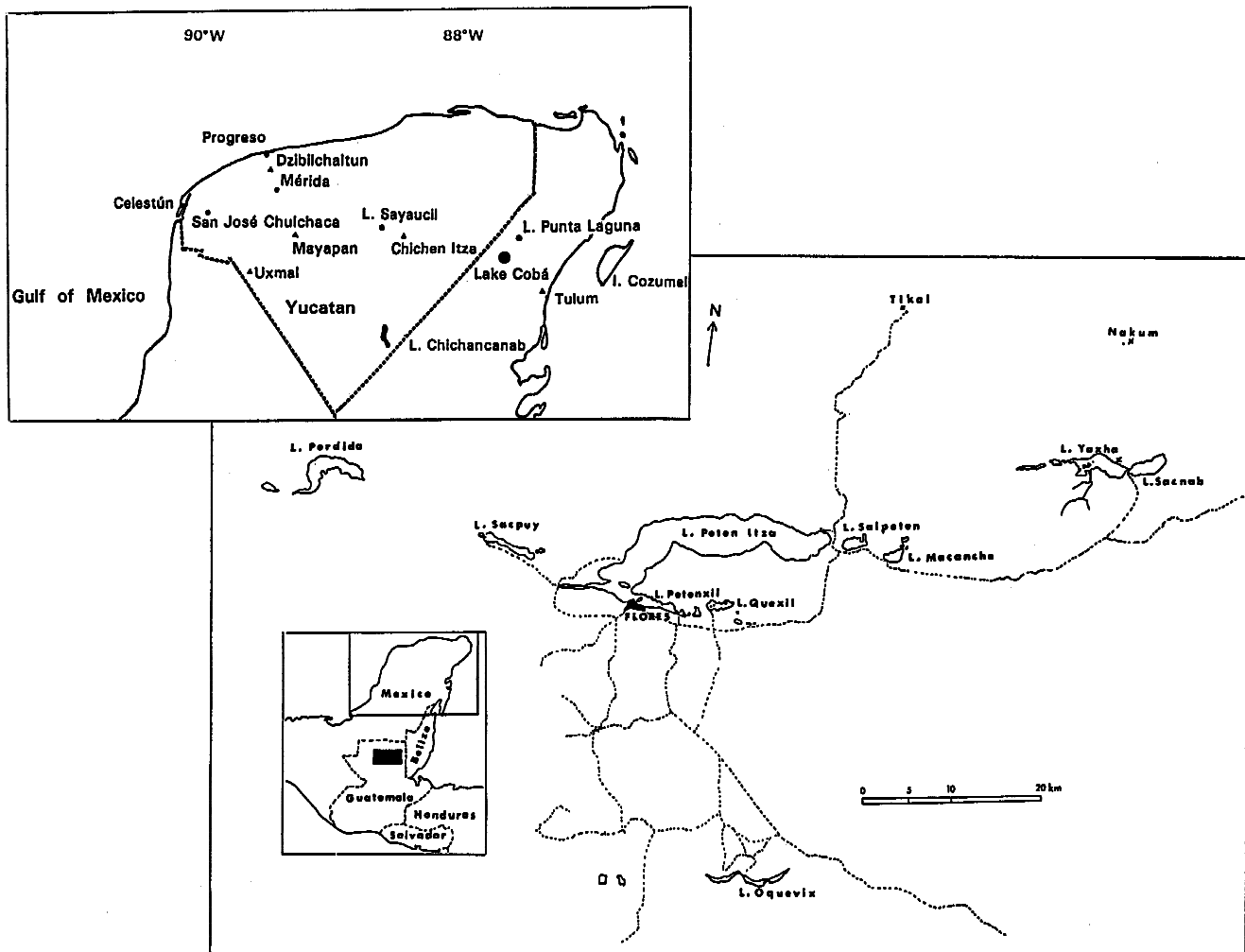


Figure 1. Area map showing the location of sites mentioned in the text. The blackened area in the small inset shows the location of the Peten lake district to the right, which includes the primary sites mentioned. The larger rectangle in the small inset includes the northern Yucatan Peninsula, with the sites indicated in the enlargement above. The La Venta/San Andres region of Tabasco, Mexico is just to the center-left of the area shown in the small inset.

prominent, and include Jamaican dogwood (*Piscidia piscipula*), *Acacia* spp., and *Pithecellobium* spp. Cacti are frequently present, as are gumbo limbo (*Bursera simaruba*), *Metopium brownei*, and *Gymnopodium floribundum*. Tropical semi-evergreen and evergreen forests extend to the south. In addition to many of the taxa already mentioned, these forests contain breadfruit (*Brosimum alicastrum*), sapodilla (*Manilkara zapote*), *Spondias mombin*, *Trema micrantha*, *Cecropia paltata*, and *Ceiba petandra* (Flores and Carvajal 1994). Breadfruit contributes about 40–60% of the modern pollen rain in the Peten lakes district (Leyden 1987; Vaughan et al. 1985) (Figure 2). There also are smaller areas of pine (*Pinus*) forest and savanna, patches of oak (*Quercus*) forest, and mangrove fringing the coasts. The nearest temperate associations occur above ca. 1,200 m asl and more than 200 km from the Peten. Moist temperate associations are a mixture of coniferous and broad-leaved trees, including *Alfaroa*, elm (*Ulmus*), sweetgum (*Liquidambar*), *Myrsine*, and sweet gale (*Myrica*), while drier associations include pine-oak forest and throne-scrub with *Juniperus*.

THE BASICS OF POLLEN ANALYSIS

The underlying principles of pollen analysis are quite simple. Flowering plants and ferns produce pollen and spores, respectively, which are dispersed by wind, insects, and animals to produce a “pollen rain” that is deposited on land and water surfaces in vast quantities. The outer, diagnostic walls of pollen and spores often can be identified to the species level and, under appropriate conditions, can be preserved indefinitely. In general, any deposit that is either anaerobic or permanently dry will preserve pollen. A temporal framework for pollen data is provided by radiometric dating or a stratigraphic context for the pollen-bearing sediments. In practice, lake sediments provide the best sites for long-term preservation and continuous deposition of pollen and spores. Archaeological and other types of sediments can provide a temporal context, but the preservation of pollen is less certain. Lake sediments are also less prone to complications from post-depositional disturbances, especially sediments from deep central-basin loca-

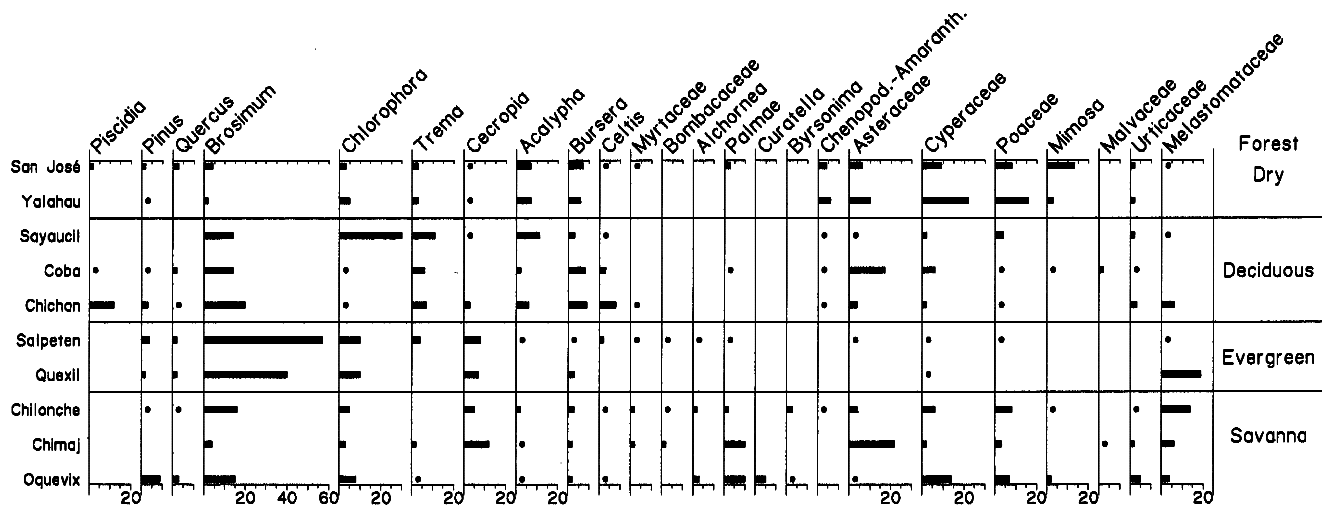


Figure 2. Pollen percentage diagram of core top samples from lakes in the Maya Lowlands illustrating the regional variation in pollen deposition. The site names are listed down the left column. “Chichan” is Lake Chichancanab. Lake Yalahau is just west of Lake Sayaucil in the Yucatan. Arboreal taxa are listed first to the left, followed by herbaceous taxa. Vegetational associations are listed on the right. “Deciduous” represents semi-evergreen forests. Values represented by a blackened circle are less than 2%.

tions. Pollen is separated from the sediment matrix using a series of chemical and physical treatments (Leyden et al. 1998). Sub-samples of the residue are mounted on microscope slides, which are systematically or entirely scanned for pollen grains that are tabulated by taxon.

Pollen data are generally presented as diagrams (Figure 2). These typically are constructed by grouping taxa together by life form such as trees, herbs, and aquatics, or by plant formation such as temperate and tropical forest. For each taxon, a profile is constructed, with age or depth represented on the y-axis and percent of a pollen sum or some other quantitative amount presented on the x-axis. Most diagrams present percentages of a pollen sum. The pollen sum may include all taxa encountered in a sample or exclude taxa that may be overrepresented, such as aquatic macrophytes because they are very local or pine trees because they produce massive amounts of pollen that can travel great distances. Influx rates may also be calculated and plotted if the concentration of pollen and deposition rate of the sediments is determined. This eliminates the compression or expansion of minor taxa in percentage diagrams when dominant taxa fluctuate. The percentage or influx diagram may be subdivided into stratigraphic zones that group levels with common properties or designate defined time periods.

Past environmental change can be discerned through an interpretation of the data presented in pollen diagrams. The principle of uniformitarianism in pollen analysis is interpreted as “the present is the key to the past.” If the modern environmental requirements of plants or the modern climatic parameters of the vegetative associations are known, then past climate and climatic change over time can be inferred using a variety of statistical (Birks and Gordon 1985) and qualitative methods. Many types of algae also persist in pollen preparations from lake sediments and provide additional environmental information. However, when past plant associations have no modern counterparts, interpretations are less secure.

Pollen analysis cannot answer all questions with regard to climatic change because of inherent limitations, and multiple prox-

ies are needed to provide a robust interpretation of past conditions. The sensitivity and precision of pollen analysis is limited by the responsiveness of plants to environmental change and the ability to identify pollen to the lowest possible taxonomic level. Pollen production by a plant generally is not in direct proportion to its presence in the community, and this must be factored into the analysis. The interpretation of results can be further constrained if pollen concentrations are very low. Autochthonous carbonates can rapidly precipitate out of the water column in shallow, hard-water tropical lakes, thus diluting pollen present in the lake sediment. Infrequent pollen types are less likely to be encountered in a preparation and included in proxy calculations. And, as discussed later, cultural disturbance can mimic climate signals in the pollen diagram. Despite these limitations, pollen data do record the integration of multiple climatic forces by a plant community. This vegetative response may be more meaningful to societies than separate measures of precipitation or temperature trends, much as the wind-chill index shows what the temperature “feels like” compared with the air temperature alone.

NEOTROPICAL POLLEN ANALYSIS

Given these constraints, it was long thought that pollen analysis would be impractical in tropical regions. A great number of tropical and subtropical plants are pollinated by insects, thus producing considerably less pollen that is distributed over shorter distances than wind-pollinated taxa. Many assumed that the great diversity of plants in the tropics produced a “pollen rain” that was equally diverse and thus too complex to interpret. The tropics also were believed to have had an essentially stable environmental history compared with that of temperate regions of the world, leading to monotonous pollen profiles. Fortunately, this has proved not to be the case, and in most respects, tropical pollen analysis now lags behind its temperate counterpart primarily in the number of studies that have been completed. The ability to identify tropical pollen taxa is comparable to temperate taxa, and the overall production of pollen is often comparable, as well. Several pollen-identification

keys are available for tropical regions, such as the one for Quintana Roo, Mexico, and Barro Colorado Island, Panama (Chávez et al. 1991; Roubik and Moreno 1991).

Pollen spectra from tropical and subtropical regions clearly reflect their respective plant formations, with definable environmental parameters (Horn 1985; Islebe and Hooghiemstra 1995; Jacobs 1982; Lozano-Garcia 1984), and document past climatic fluctuations. Pollen spectra from a representative suite of core-top samples taken from lakes in the Maya Lowlands document clear differences (Figure 2). Unfortunately, transfer functions (Webb and Bryson 1972) are not available yet for the Maya Lowlands. These functions derive quantitative measures of climate from modern pollen and climatic data, which are then applied to the fossil pollen record. Although primarily qualitative, early pollen studies conducted in the highlands of Mexico (Hutchinson et al. 1956; Sears and Clisby 1955), Costa Rica (Martin 1964), Guatemala (Cowgill et al. 1966; Tsukada and Deevey 1967), and Panama (Bartlett and Barghoorn 1973) demonstrated that neotropical plant associations changed through time. Studies from northern South America (Bradbury et al. 1981; Leyden 1985; van der Hammen 1974) and Guatemala (Leyden 1984) further demonstrated that some changes represented climatic fluctuations as pronounced as those at higher latitudes. The records of late Pleistocene and Holocene climatic change in Mexico have recently been reviewed (Metcalf et al. 2000).

The problem of accurately dating lake sediments and the events within them must be mentioned as a final caveat. This is discussed in greater detail in Brenner et al. (2002). Caution is particularly necessary when comparing sequences from numerous lakes. The difficulties are due to a number of factors: (1) the need to re-evaluate dates obtained many years ago, which are often rejected (Vaughan et al. 1985); (2) an inconsistency in the presentation of dates in the literature (i.e., uncalibrated and uncorrected for isotopic fractionation); (3) the incorporation of “dead” carbon leading to hard-water lake error, in which the dates are too old (Deevey and Stuiver 1964); (4) the interpolation of ages among radiocarbon dates that are often widely spaced (Brenner et al. 2002); and (5) the late glacial to early Holocene C-14 age plateau caused by fluctuations in the production of atmospheric C-14 (Becker et al. 1991). Shifts in ocean circulation may also affect the concentration of C-14 (Hughen et al. 2000). The task of comparing sequences is further exacerbated by sedimentation rates that vary widely within and among lake sequences. The ages of adjacent samples in a core can differ by decades to centuries. As a result, the precision with which an event can be identified and dated varies greatly in the various pollen records. The radiocarbon ages of the Pleistocene sediments to be discussed here extend beyond calibrated ages in calendar years. Therefore, the Pleistocene dates are presented as radiocarbon years before present (C-14 B.P.), while calendar dates within the calibrated range are presented as B.C. and A.D.

LATE PLEISTOCENE CLIMATIC CHANGE IN THE MAYA LOWLANDS

There is a growing consensus that lowland temperatures were at least 5°C cooler during the last glacial maximum throughout Latin America (Bush et al. 2001). In the Peten, both temperature and precipitation declined sharply. As a result, only the deepest lakes retain a record of the wide-scale displacement of plant formations during the late Pleistocene (Leyden 1984; Leyden et al. 1993,

1994). The deeper portions of Lake Peten-Itza have not been studied but are likely to contain Pleistocene sediments. For now, only Lake Quexil and perhaps Lake Salpeten have provided sedimentary records that extend beyond the Holocene (Figure 3). Both lakes have a maximum depth of 32 m. A core from Lake Quexil was taken from beneath 29 m of water and contains a continuous record across the Pleistocene–Holocene boundary. A core from Lake Salpeten was taken from a slightly shallower depth (26 m) and has a questionable record of this time. Thus, the water table during the late Pleistocene was at least 26 m lower, and perhaps as much as 30–40 m lower than today (Deevey et al. 1983).

The lowest levels from Lake Salpeten with sufficient pollen to count may date to the earliest Holocene, and will be discussed later. However, the late Pleistocene record from Lake Quexil is likely to be representative of much of the Maya Lowlands (Figure 4). The pollen record can be divided into three discrete climatic periods—interstadial, full glacial, and late glacial—and is in agreement with sediment geochemistry and stable isotopic data (Leyden et al. 1993, 1994). The record from 36,000 to 24,000 C-14 B.P. corresponds with Interstadial Stage 3. The climate was moist but drier than today and supported mesic temperate forests with pine, oak, *Alfaroa*, and smaller amounts of other temperate trees in wetter areas. The extant oaks near Lake Quexil may represent relict populations present since the Pleistocene (Gómez-Pompa 1973). *Juniperus* occupied drier and more exposed areas in the Lowlands. Paleotemperatures can be calculated using estimated elevational changes for the vegetation associations that are represented and moist adiabatic lapse rates. These calculations suggest temperatures were as much as 4.7–6.5°C colder than today.

During the last glacial maximum (24,000 to 14,000 C-14 B.P.) pollen concentrations were minimal, and the high pine percentages reflect long-distance transport of pollen from outside the region. Only sparse thorn-scrub, grasses, and cacti occupied the Peten. The prevalence of marsh taxa suggests that Lake Quexil may have been ephemeral, pointing to an increase in the ratio of evaporation to precipitation. The maximum temperature decline may have been from 6.5°C to 8°C colder than today, with the most severe conditions during the latter part of this period.

Climate conditions were ameliorated sufficiently at the onset of the late glacial (14,000 to 10,000 C-14 B.P.) to permit expansion of mesic temperate oak and hardwood forest into the Peten, although continuing low pollen concentrations suggest that vegetation remained sparse. Temperatures initially were slightly warmer than during the last glacial maximum. The predominance of halophytic herbs is indicative of brackish conditions, and lake levels are likely to have fluctuated throughout this period as E/P declined. The second half of this period is contemporary with the Younger Dryas climatic reversal of higher latitudes (Leyden 1995). In the Peten, arboreal pollen was almost totally absent, and forest expansion was curtailed. The prior warming was reversed, and the temperature declined by up to 1.5°C. However, aquatic macrophytes increased as the modest decrease in E/P continued. The increased deposition of charcoal reflects an increase in the fire regime, perhaps due to more frequent or more severe thunderstorms igniting lightning-induced fires. Thus, lowland subtropical forests were absent from the Maya Lowlands prior to 10,000 C-14 B.P. (Figure 4). Pollen from warm, mesic forest taxa are below detectable levels for at least 25,000 years, although small populations of these species must have persisted at isolated sites. The hypothesis that extensive rainforest refuges existed in this region

Pre-cultural				Cultural				
Site Name (References)	Late Pleistocene	Pleistocene /Holocene	Early Holocene	Mid to Late Holocene				
				Archaic	Preclassic	Classic	Post-classic	Post-Maya
Quexil (1)								
Salpeten (2)								
Peten-Itza (3)								
Coba (4)								
Chichancanab (5)								
Sacnab (6)								
San José Chulchaca (7)								
L. de Cocos (8)								
San Andres (9)								
Cobweb Swamp (10)								
Cob Swamp (11)								
Tamarandito (12)								
Petenxil (13)								
Macanche (14)								
Yaxha (15)								
L. Catemaco (16)								
L. Yoja (17)								
Cerros (18)								
San Antonio (19)								
Los Pozas (20)								
Izabal (21)								
Petapilla Swamp (22)								
Chilonche (23)								
Chimaj (24)								
Oquevix (25)								
Santa Ana Vieja (26)								
Pulltrouser Swamp (27)								

Figure 3. A list of lakes with pollen data in the Maya Lowlands and the relative maximum age, loosely defined, of each record. (1) Deevey et al. 1979; Leyden 1984; Leyden et al. 1993, 1994; Vaughan et al. 1985; Wiseman 1985. (2) Leyden 1984, 1987; present paper. (3) Islebe et al. 1996. (4) Leyden et al. 1998. (5) Present paper. (6) Deevey et al. 1979; Vaughan et al. 1985. (7) Brenner et al. 2000; Leyden et al. 1996. (8) Hansen 1990. (9) Pope et al. 2001; Rush and Leyden 1994; present paper. (10) Jacob 1994; Jones 1995. (11) Pohl et al. 1996. (12) Dunning et al. 1997, 1998. (13) Cowgill et al. 1966. (14) Vaughan et al. 1985. (15) Deevey et al. 1979. (16) Byrne and Horn 1989. (17) Rue 1987. (18) Crane 1996. (19) Wiseman 1990. (20) Johnston et al. 2001. (21) Tsukada and Deevey 1967. (22) Rue 1987. (23) Brenner et al. 1990. (24) Brenner et al. 1990. (25) Brenner et al. 1990; present paper. (26) Cowgill and Hutchinson 1966. (27) Wiseman 1983.

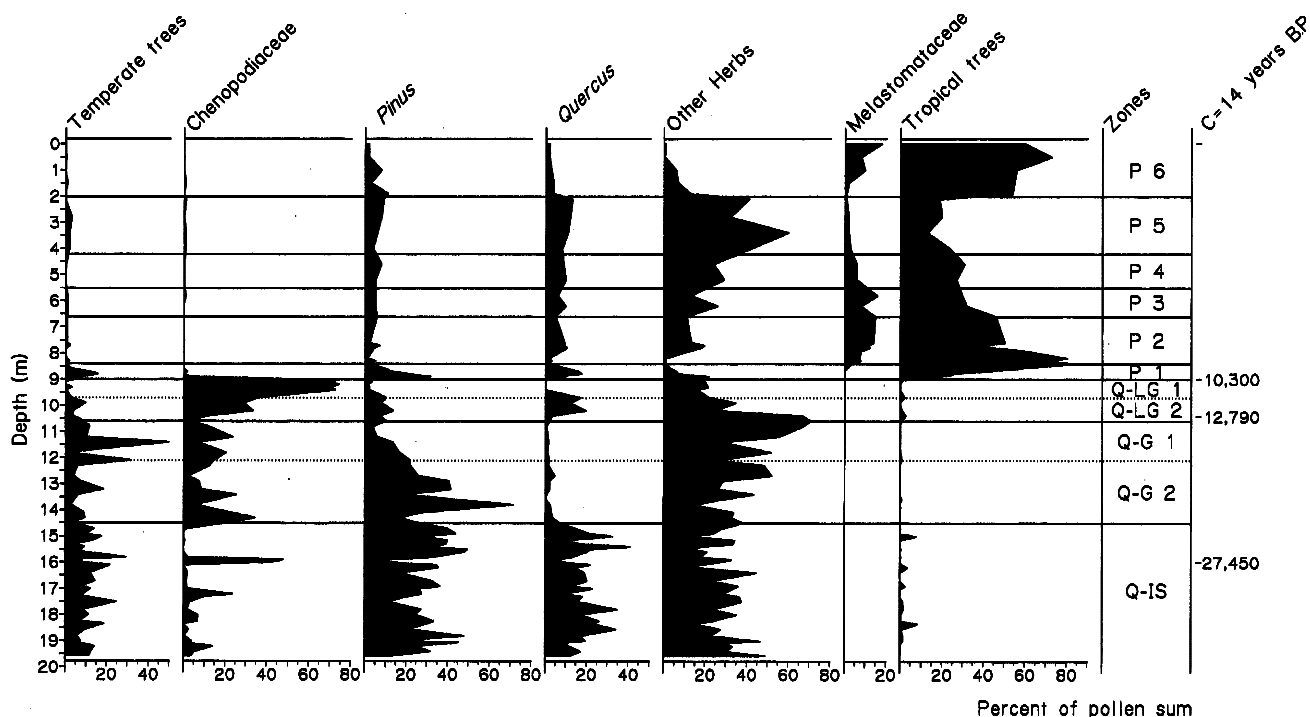


Figure 4. Composite summary pollen percentage diagram for Lake Quexil. The Pleistocene portion of the record is provided from core 80-I, while the Holocene section is from core H analyzed by S. E. Garrett-Jones (Vaughan et al. 1985). These pollen groups contain a majority of the pollen taxa present. The temperate trees include both mesic and xeric taxa: *Juglans*, *Cornus*, Onagraceae, *Ostrya-Carpinus*, *Betula*, *Fraxinus*, *Rapanea*, *Ilex*, *Hedyosmum*, and *Juniperus*. Chenopodiaceae represents the Chenopodiaceae-Amaranthaceae pollen type. The Moraceae are predominant in the tropical trees grouping. Pollen zones are on the right side of the figure: Q-IS, interstadial; Q-G 1 and Q-G 2, Glacial; Q-LG1 and Q-LG 2, Late Glacial; P1–P6, Holocene subdivisions of the Peten (Vaughan et al. 1985); P1, Pre-Maya; P2, Early and Middle Preclassic; P3, Late Preclassic; P4, Early Classic; P5, Late Classic and Postclassic; P6, Post-Maya.

during the last glacial maximum is not supported by the pollen data.

EARLY HOLOCENE CLIMATE CHANGE BEFORE THE MAYA (CA. 10,000–6000 B.C.)

The date of the first peopling of the Americas remains controversial, but the accepted date is constantly being pushed farther back in time. An increase in charcoal deposition at the end of the Pleistocene, as seen at Lake Quexil, is present at a number of sites throughout Central America and northern South America. In Panama, the increase continued unabated into the Holocene and is attributed to the initial presence of Paleo-Indians (Piperno et al. 1990). However, the number of people probably remained small in the Maya Lowlands during the early Holocene. Any effect on the environment would have been limited in coverage; plant communities would not have been greatly altered; and observed change in the pollen record due to the presence of people would also be minimal.

Instrumental records extend for only a few decades, in most cases, and provide limited insight into the potential variability of the climatic system. Paleoclimatic studies have documented much greater fluctuations during the Holocene than those measured within the instrumental record (Baker et al. 2001; Hodell et al. 2001). However, the dominant mechanisms influencing Holocene cli-

mate appear to be the same: for instance, orbital forcing of solar insolation (Hodell et al. 1995; Leyden et al. 1993), ocean-atmosphere interactions (Baker et al. 2001), and variations in solar activity (Hodell et al. 2001). Although these climatic fluctuations were not as severe during the Holocene as in the Pleistocene, they nevertheless had a discernable effect on vegetation, especially during the early Holocene.

Three lakes besides Quexil and Salpeten contain pollen records of early Holocene conditions (Figure 3): a relatively shallow water core (7.6 m of water) from Lake Peten-Itza, Guatemala (Curtis et al. 1998; Islebe et al. 1996); Lake Coba within the Coba archaeological site in Yucatan, Mexico (Leyden et al. 1998); and Cenote San José Chulchaca (Brenner et al. 2000; Leyden et al. 1996; Whitmore et al. 1996). Other lakes undoubtedly lack a record of the early Holocene, because groundwater levels continued to be depressed and basins were slow to fill. This is particularly true on the northern Yucatan Peninsula. Groundwater levels there are strongly influenced by sea level, which did not reach modern levels until the mid-Holocene. In northwestern Yucatan, the water table is very shallow, and a relatively thin freshwater lens floats on top of denser saltwater (Doehring and Butler 1974).

The pollen record from Lake Quexil depicts unique conditions before about 8000 B.C. (Figure 4). Charcoal deposition ceased, while the concentration of pollen rose dramatically and primarily consisted of arboreal taxa. Pine, oak, and mesic temperate hard-

woods were initially prevalent, together with some lingering presence of juniper. Moraceae taxa quickly increased and ultimately contributed 80% of the pollen sum (Leyden 1987; Leyden et al. 1993, 1994). Tropical forest associations were not fully developed until later, and these earliest Holocene forests lack modern analogues. Climatic interpretations are therefore less secure. Temperatures appear to have warmed gradually from values that initially were 3–4.7°C cooler than today. These cooler conditions may have helped the Moraceae to become dominant, as some species of *Brosimum* can withstand lower temperatures than other tropical taxa. Extensive cattail marshes occupied the Lake Quexil basin as it filled with water and reflect E/P ratios that continued to decline.

The basal 2 m or so of clayey sediments from Lake Salpeten contain insufficient pollen for reliable counts because of post-depositional degradation, which indicates that the lake was dry much of the time. The pollen that is present represents the same taxa as noted earlier (Figure 5). This pollen consists of oak, *Juniperus*, and halophytic herbs that reflect scrub and marsh vegetation comparable to late-glacial vegetation present at Lake Quexil less than 15 km away (Leyden 1987). The presence of water hyacinth (*Eichhornia*) pollen reflects at least periodic standing water.

Radiocarbon dates from near the top of this section fall within the late glacial to early Holocene C-14 age plateau caused by fluctuations in the production of atmospheric C-14 (Becker et al. 1991), and the true ages lie within a large temporal range. The dates were calibrated using INTCAL98 (Stuiver et al. 1998), with a 50-year running average and a 2-sigma range. The calibrations

yielded late Pleistocene to early Holocene age ranges of 11,509 to 6166 B.C., with a midpoint of 8632 B.C. (9400 ± 1100 C-14 B.P.) for wood and 8775 to 7080 B.C., with a midpoint of 7945 B.C. (8815 ± 345 C-14 B.P.) for 20 cm of bulk sediments. The calibrated age for the end of the late glacial at Lake Quexil is 10,860 to 9625 B.C., with a midpoint of 10,160 B.C. Thus, the Salpeten pollen record may extend into the late glacial period but primarily affirms the persistence of glacial floras into the earliest Holocene, as seen at Lake Quexil.

Lake Salpeten sediments above these basal levels consist of about 2 m of granular gypsum crystals that formed as the lake filled with saline water. A similar gypsum layer was also deposited in Lake Chichancanab as it filled in the early Holocene (Hodell et al. 1995). Pollen, including Moraceae, is well preserved but extremely sparse in the Salpeten sediments. The gypsum was deposited over a relatively short period of time, probably much less than 225 years. Lake levels were at least 17 m higher by 7900 B.C. (Rosenmeier et al. 2002), which is an average increase of nearly 2.5 cm yr⁻¹.

Warm and moist conditions prevailed from ca. 8000 to 6000 B.C. around Lakes Quexil and Salpeten (Figures 4, 5), which was the wettest period of the past 36,000 or so years in the Peten (Leyden 1987; Leyden et al. 1993, 1994; Vaughan et al. 1985). Semi-evergreen forest was well established by 8000 B.C. at Lake Peten-Itza (Islebe et al. 1996) and throughout the Peten lake district. Moraceae predominated in the forests, and herbs and temperate taxa were scarcely represented (Figure 6). Lakes on the

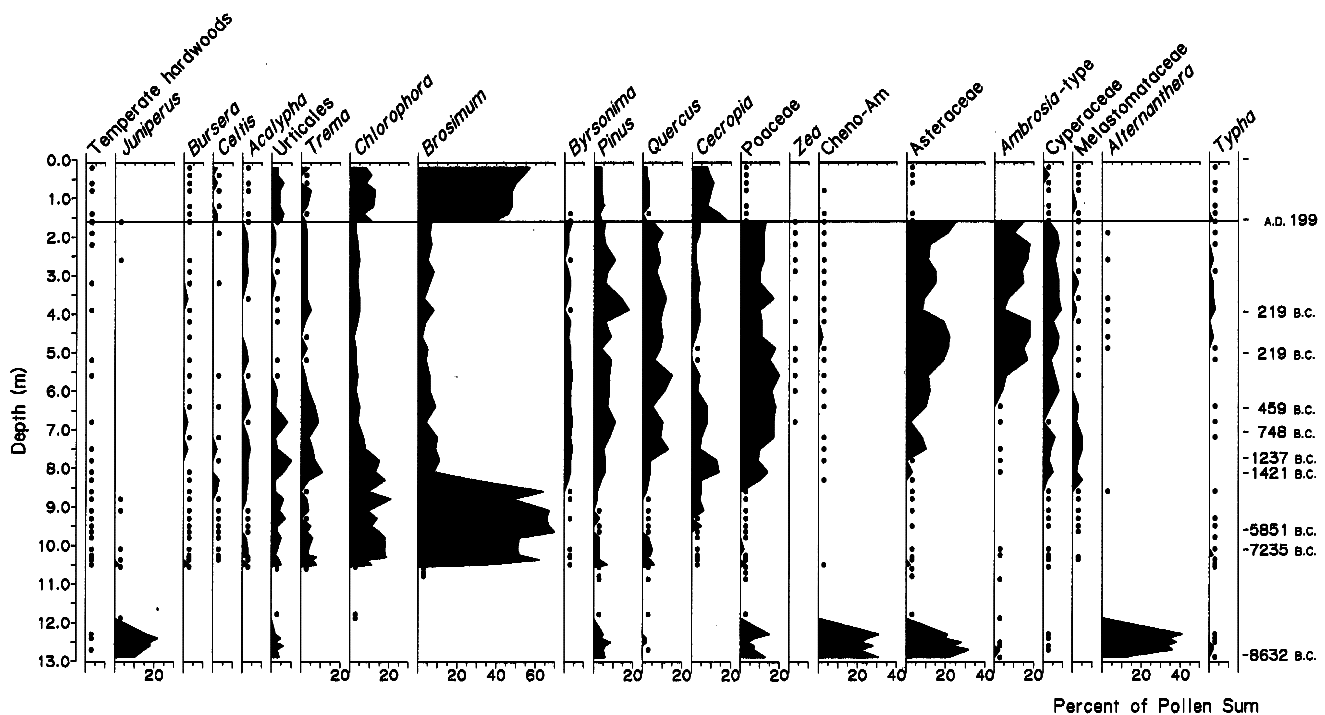


Figure 5. Composite pollen percentage diagram for Lake Salpeten. The top 1.6 m are from a mud-water interface core (MWI) taken 10-V-80 in 26.5 m of water. The basal 2 m of core 80-I with scant pollen is not included in the figure. Circles represent values less than 2%, except in the gypsum zone centered on 11 m, where circles signify only the presence of pollen types. *Eichhornia* is present between 12 m and 13 m. The temperate hardwood group includes *Fraxinus*, *Ostrya/Carpinus*, *Liquidambar*, and *Ulmus*. *Alternanthera* and *Typha* percentages are based on a pollen sum from which they have been excluded. Chen-Am = Chenopodiaceae-Amaranthaceae pollen type. The dates shown to the right of the figure (Rosenmeier et al. 2002) indicate that a considerable hiatus exists between the top of core 80-I and the base of the MWI core.

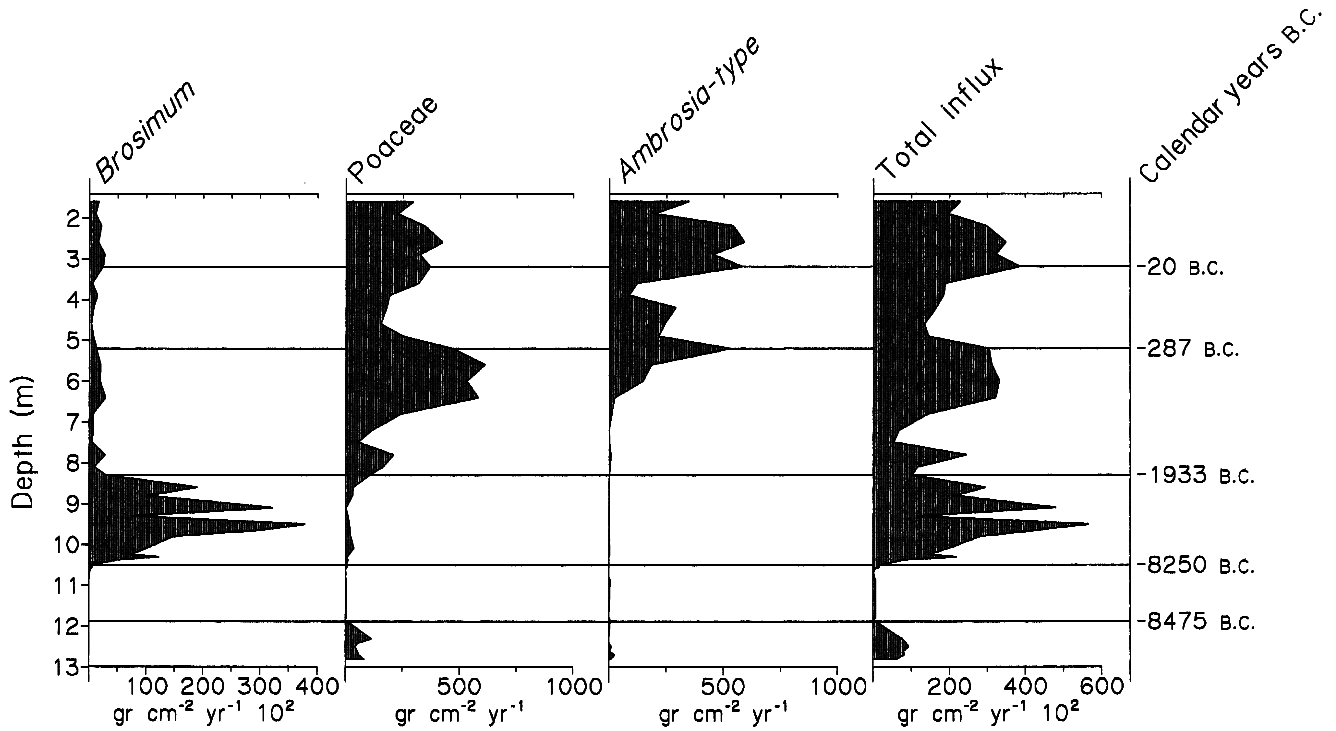


Figure 6. Lake Salpeten Core 80-1 pollen influx diagram. Radiocarbon dates from Rosenmeier et al. (2002) were used to convert pollen counts into annual influx. Note the different scales for influx. Removal of the tropical forest is clearly evident and is not the result of suppression by increased herbaceous representation.

Yucatan Peninsula were just beginning to retain water in the latter part of the early Holocene. Lake Coba in the northeast was beginning to fill by 6400 B.C. (Leyden et al. 1998), and Cenote San José Chulchaca in the northwest began to fill prior to 6200 B.C. (Bren-

ner et al. 2000; Leyden et al. 1996; Whitmore et al. 1996) in response to rising sea level. Vegetation here was under greater control of local edaphic conditions. The basal pollen zone from Lake Coba reflects a wooded swamp, or *Akalche*, that graded into

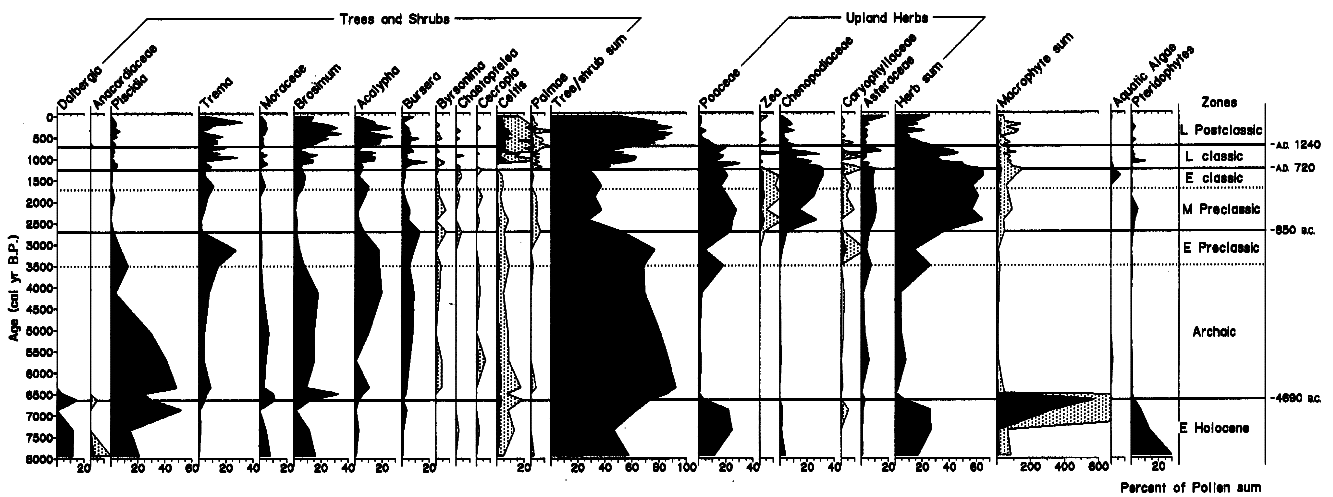


Figure 7. Lake Coba pollen percentage diagram of selected taxa and group sums plotted on a time scale rather than a depth scale. The figure was plotted using calibrated years B.P., with selected calibrated calendar dates on the right. Chenopodiaceae represents the Chenopodiaceae-Amaranthaceae pollen type. Aquatic taxa and fern spores have been excluded from the pollen sum. Stippled curves reflect a 5% exaggeration of the pollen percentages. The zones indicate the archaeological periods included in pollen zones I-5. Dotted lines separate multiple archaeological periods within pollen zones.

surrounding upland semi-deciduous forest (Figure 7). At Cenote San José Chulchaca, the water level in the cenote remained below the fringing rim, and the region supported dry deciduous forest (Figure 8).

Thus, the basic distribution of contemporary lowland vegetation associations was established by the end of the early Holocene, and this implies that essentially modern gradients of temperature and precipitation had also been established. Drier associations existed in the northwestern portions of the Yucatan Peninsula, and more mesic associations developed to the east and south. Subtropical dry deciduous forests around Cenote San José Chulchaca included *Bursera*, *Trophis*, *Acalypha*, *Piscidia*, and *Brosimum*. Today, the vegetation in northwestern Yucatan is transitional between subtropical dry forest and tropical arid or thorn forest; this pattern was established by the end of the early Holocene. At Lake Coba, *Dalbergia* and *Metopium* are representative of the *Akalche*, or wooded swamp, and semi-deciduous forest that are common in the region today. The northern Yucatan Peninsula never supported pine savannas like those found in Belize today and was never as wet as the Peten, where semi-evergreen forest was established.

THE MAYA VERSUS CLIMATE IN THE MID- TO LATE HOLOCENE, 6000 B.C. TO THE PRESENT

Whereas cultural forces were not a significant factor during the Pleistocene or earlier periods during the Holocene, native societies were a major force in altering the environment and regional flora of the Maya Lowlands during the late Holocene. An earlier presence of a significant number of people cannot be discounted. The earliest archaeological evidence of occupation in the Low-

lands dates to the Archaic period, primarily in coastal regions (Coe 1999). There is widespread evidence of early Preclassic settlement throughout Belize and for Middle Preclassic settlement in the interior Maya Lowlands (Culbert and Rice 1990; Rice and Rice 1990). During the Classic period, the Maya were widespread and had a massive effect on the natural vegetation and landscape. Lakes in the Peten have layers of “Maya clay” in their basins that can be many meters thick as a result of severe erosion of the surrounding watershed soils. Swamps were farmed (Pohl and Bloom 1996; Pohl et al. 1996), and water was diverted into cisterns (Scarborough 1996). Undoubtedly, even the most “pristine” modern forests were culturally modified at some time during the Classic period.

Mid- to late Holocene pollen spectra thus reflect the reciprocal interactions connecting not only climate and vegetation but also societies. Climate determines the distribution of plant biomes, while vegetation modifies that climate in numerous ways, including through variations in the interception of precipitation and solar radiation and through differences in transpiration (Lean and Warrilow 1989; Sahin and Hall 1996). Extensive exploitation of vegetation by a society can profoundly alter the structure and composition of a plant association, frequently resulting in modification of the regional climate. Further, climate shapes the large-scale geographic features that constrain societies, while cultural transformation of the landscape can have a climatic effect. In the pollen record, cultural disturbance can mimic climatic forcing (Vaughan et al. 1985). The clearing of forests increases the representation of herbaceous taxa and increases the distances that pollen can be transported by the wind from other plant associations. These changes are similar to what occurs during periods of increased aridity. Nevertheless, some climatic information can still be discerned when the pollen record is studied carefully. Increases

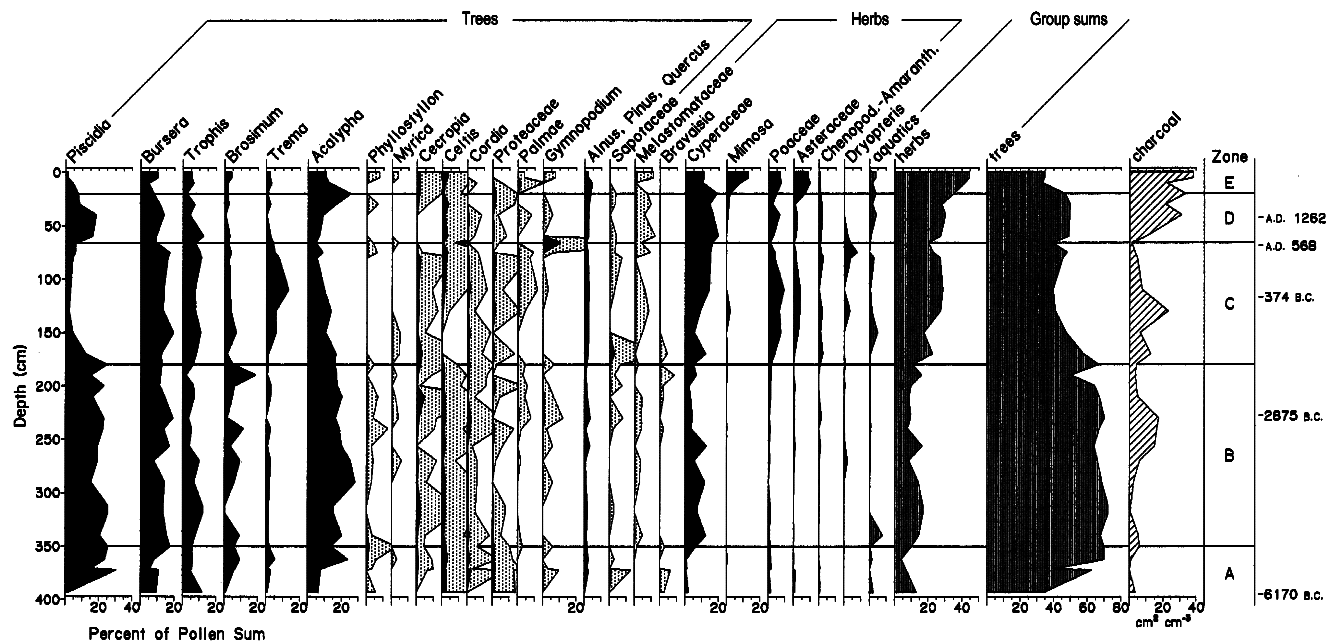


Figure 8. Cenote San José Chulchaca pollen percentage diagram. Ferns and aquatic taxa have been excluded from the pollen sum. Stippled curves represent a 5% exaggeration of the percentage curves. The shaded curves are group sums, and the plot for charcoal represents the calculated volume of charcoal in the entire sample.

in charcoal deposition and the presence of agricultural pollen help to identify periods of cultural disturbance.

Numerous studies address the environmental impact of the lowland Maya but do not include pollen data (Binford 1983; Binford et al. 1987; Bloom et al. 1983; Bradbury et al. 1990; Brenner 1983; Covich 1976; Covich and Stuiver 1974; Curtis et al. 1996; Dahlin 1983; Deevey 1978; Deevey and Rice 1980; Deevey, Brenner, and Binford 1983; Deevey, Brenner, Flannery, and Yezdani 1980; Deevey, Rice, Rice, Vaughan, Brenner, and Flannery 1979; Gill 2000; Hodell, Curtis, and Brenner 1995; Hodell, Brenner, Curtis, and Guilderson 2001; Rice and Rice 1983; Rice et al. 1985). Studies with pollen records for the mid- to late Holocene include a variety of settings, from archaeological excavations to small aguadas. Archaeological settings often have little or no discernable climatic signal, but they do document the initiation of forest clearance in the region (Byrne and Horn 1989; Crane 1996; Dunning et al. 1998; Hansen 1990; Jacob 1992; Jacob and Hallmark 1996; Jones 1991, 1994; Pohl et al. 1996; Wiseman 1983, 1990).

The Southern Sites

Pollen data from the Peten lakes suggest that climatic conditions remained relatively moist until about 4500 B.C. Climate may have become drier from about 4500 to 2000 B.C. Vegetation around Lakes Quexil, Sacnab (Deevey et al. 1979; Vaughan et al. 1985) and Peten-Itza (Islebe et al. 1996) became more open. Pollen of grasses, oak, Melastomataceae, and *Byrsonima* became more prevalent (Figures 4, 5), reflecting an increase in savanna-like associations. The vegetation around Lake Salpeten (Leyden 1987) experienced an increase in secondary trees such as *Trema* and *Cecropia* (Figure 5) and a decline in the influx of total pollen (Figure 6) before the herbaceous taxa became prevalent. However, the region remained primary forested until about 2000 B.C. Debate continues over whether this initial reduction of forest represents climatic or cultural effects on the vegetation. Solar insolation peaked and began to decline during the mid-Holocene in the Caribbean region. The movement of the intertropical convergence zone, and thus the intensity of the annual cycle, are governed to a great extent by insolation (Hodell et al. 1991; Leyden et al. 1994). Precipitation tends to decline when the annual cycle is weaker. This provides a strong inference that the deforestation was at least partly the result of increased aridity. However, initial clearing of the forests also leads to declining arboreal pollen percentages, and charcoal abundance rises abruptly in the Sacnab and Quexil cores at this time (Vaughan et al. 1985). In terms of archaeology, this seems to be an early date for significant occupation of the interior regions of the Maya Lowlands, but changing conditions in coastal regions may have motivated people to migrate into the interior areas.

Definite indicators of disturbance become prominent in all cores after about 2000 to 1900 B.C. In Belize, this marked increase in forest destruction began around 2500 B.C. (Pohl et al. 1996). While synchronous events in the pollen record may reflect either climatic or cultural effects, asynchronous changes in the late Holocene are almost certainly anthropogenic. Climatic signals become extremely difficult to detect in the pollen data when cultural disturbances are as extensive as in the Maya Lowlands. The pollen-influx data from Lake Salpeten clearly illustrate that very little forest remained by about 2000 B.C. (Figure 6). One interesting example of a cultural effect on the nonarboreal pollen record is the

curve for *Ambrosia*-type pollen with double maxima that is seen in all central Peten lake cores in the upper portion of the Maya clay but not at sites from Belize or to the north. The intervening minimum in the *Ambrosia* sequence was first interpreted in Vaughan et al. (1985) as reflecting the Late Classic Collapse. It is dated to the Early Preclassic at Sacnab and to the Middle Preclassic at Petenxil, while a similar minimum is dated to between the Early and Late Classic at Lake Peten-Itza. The minimum spans about 270 years during the transition between the Middle and Late Preclassic at Lake Salpeten (Figure 6), during a period of higher lake levels (Rosenmeier et al. 2002). Some of the discrepancy may be due to dating error, as the *Ambrosia* curve is stratigraphically in the same relative position in all the cores, just prior to the increase in arboreal representation. *Zea* is strongly associated with *Ambrosia*, but the timing of the first appearance of corn is also asynchronous among the sites. *Zea* first occurs in the Salpeten sediments at the beginning of the Middle Preclassic, before the marked increase in *Ambrosia* percentages (Figure 5), but is essentially concurrent with the *Ambrosia* rise in the Late Preclassic at Lake Peten-Itza. (Islebe et al. 1996).

Afforestation of the Peten began at some time after the Terminal Classic and may be another example of asynchronous change due to cultural forces, although climate is also implicated (Brenner, Leyden, and Binford 1990; Brenner, Rosenmeier, Hodell, and Curtis 2002). The timing for the return of forest cover in the Maya Lowlands has been variously assigned from immediately after the Collapse at Lakes Quexil and Peten-Itza (Islebe et al. 1996; Wiseman 1985) to as late as post-European contact in the savannas south of the lake district (Brenner et al. 1990). Some central Peten locations maintained substantial Postclassic populations (Rice and Rice 1990), and reforestation in these areas was likely delayed. The top of Salpeten core 80-1 is now dated to A.D. 190 (Rosenmeier et al. 2002), and thus lacks a record of this period. However, the forests around Copan, Honduras, expanded after 750 C-14 years ago (Rue 1987). Further, forests in marginal portions of the Río de la Pasión drainage may have been cleared for the first time in the Postclassic as adjacent areas recovered (Johnston et al. 2001).

Evidence for climatic forcing of afforestation comes from the savannas south of the lake district. Lake Oquevix is the largest of the savanna lakes and aguadas that have been studied and has the longest pollen record (Brenner et al. 1990) (Figure 9). Dating of this core and another from Aguada Chimaj is by correlation with a pollen sequence from Aguada Chilonche that has a basal radiocarbon date on wood. These aguadas filled in the 1500s, and it was thought that this was concurrent with post-Maya reforestation (Brenner et al. 1990). Another undated savanna pollen sequence from Aguada Santa Ana Vieja shows a similar increase in forest representation in the top 10–15 cm of the core that appears to be relatively recent (Cowgill and Hutchinson 1966). The increased moisture availability reflected in the aguada sequences could have contributed to regional afforestation, as is also believed to have been the case around Petapilla Swamp (Rue 1987). The pollen records from the small aguadas may also simply reflect changes in their fringing forests and, thus, local hydrological changes rather than more regional afforestation. Lake Oquevix is large enough to record a regional signal, but the record of reforestation is not directly dated and could be older. Additional studies into the relationship between vegetation and hydrology, such as Rosenmeier et al. (2002), are needed to evaluate the savanna records further.

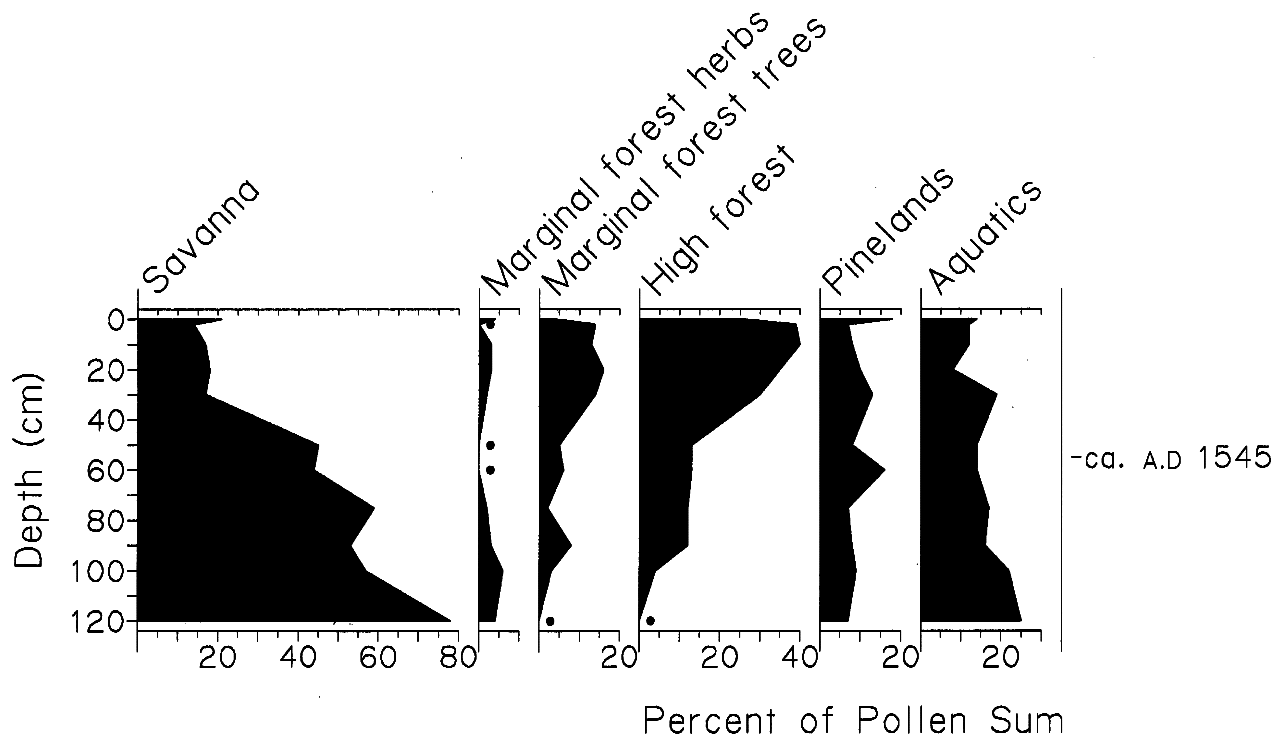


Figure 9. Summary pollen percentage diagram for Lake Oquevix. The age is an estimate based on comparison with a dated pollen profile from Aguada Chilonche. Aquatics, algae, ferns, and unidentifiable grains were excluded from the pollen sum. Circles represent values less than 2%. Pollen types are loosely grouped from left to right as savanna (Poaceae, Cyperaceae, *Byrsonima*); marginal forest herbs (Melastomataceae, Asteraceae); marginal forest trees and shrubs (*Cecropia*, *Trema*, *Celtis*, *Bursera*); high forest (primarily Moraceae); and pinelands, which includes pollen transported from greater distances. The pinelands group primarily consists of *Pinus* and *Quercus*, with varying amounts of *Podocarpus*, *Alnus*, *Ulmus*, *Ostrya-Carpinus*, *Liquidambar*, *Rapanea*, *Myrica*, and *Juniperus*-type.

The Northern Sites

The mid- to late Holocene pollen records from sites to the north differ from those from the Peten lakes district. Cenote San José Chulchaca and Lake Coba, within the archaeological site of Coba, represent the extremes of cultural disturbance on the northern Yucatan Peninsula. The cenote lies about 55 km west of Merida in a region that experienced little cultural activity until relatively late, and there are no known archaeological sites within a 15 km radius. Significant signs of disturbance do not occur until the start of the Colonial period. In contrast, there is archaeological evidence for agricultural settlement in the area surrounding Coba beginning in the Late Preclassic, and the site was a major ceremonial center in the Late Classic. Lake Coba was extensively modified with causeways on three sides and an apparent dike on the other. Several apparent canals also connect with the lake. Although late Holocene climatic signals in the pollen record from this extensively modified setting are muted, some climatic inferences can be made from the pollen data that are corroborated by other paleoenvironmental analyses at both sites (Brenner et al. 2000; Leyden Brenner, and Dahlin 1998; Leyden, Brenner, Whitmore, Curtis, Piperno, and Dahlin 1996; Whitmore et al. 1996).

Initially the water level in Cenote San José Chulchaca was low and the surrounding region was edaphically dry (Figure 8). Con-

ditions had improved enough by about 5700 B.C. to support mesic forests regionally. The appearance of sedges in the pollen record indicates that the cenote rim was flooded by about 5100 B.C., and correlates with maximum sea-level transgression from 5100 to 4300 B.C. (Pope et al. 2001). Despite high water-table levels, *Brosimum* is absent between 5100 and 4100 B.C. This section of the core comprises numerous fragments of *Chara*, an aquatic alga that can occur in brackish water. This could reflect a period of greater aridity, but may also indicate some saltwater contamination of regional groundwater. The most mesic period of the Holocene for the northwestern Yucatan Peninsula was between about 4100 to 1800 B.C. *Brosimum* is more prevalent and reflects a regional expansion of forests similar to those of southern Campeche. This wetter period is supported by isotopic data from Lake Chichancanab (Covich and Stuiver 1974; Hodell et al. 1995) and contrasts with the climatic record from the Peten, where conditions were possibly becoming drier. Because earlier climatic fluctuations were synchronous throughout the Maya Lowlands, all aspects of this apparent discrepancy need to be evaluated. As mentioned earlier, the interactions between climate and vegetation are complex. Changes in the coverage of dry forest are thought to have a lesser effect on hydrological conditions than changes in the coverage of mesic forests (Sahin and Hall 1996), but the northern Yucatan Peninsula may prove to be a special case.

Questions also remain about the timing of later events at Cenote San José Chulchaca, as a short core from the cenote has differing dates for the sequence. Radiocarbon dates were not adjusted for the incorporation of old carbon that might cause hard-water lake error, as the dates appear reasonable otherwise. In the main core, a significant and prolonged drying trend started midway through the Early Preclassic period and persisted through the Early Classic (1800 B.C. to A.D. 600). The local forest canopy opened, allowing greater coverage by grasses, while *Trema* replaced *Brosimum* in the regional vegetation. A slight increase of more mesic elements within the dry forest increased during the Late Classic and Early Postclassic periods. Drier conditions returned at the start of the Late Postclassic around A.D. 1250, and the vegetation was dominated by disturbance taxa and *Zea*. In the short core, the sequence begins and ends earlier. Isotopic data suggest more seasonal conditions prevailed (Leyden et al. 1996), but this late mesic period is not noted elsewhere. To the contrary, isotopic records for other northern sites consistently record a severe drought during this period (Curtis et al. 1996; Hodell, Curtis, and Brenner 1995; Hodell, Brenner, Curtis, and Guilderson 2001). Cultural activities in the region may have been greater than currently believed to be the case. If so, the pollen data might reflect a response by the vegetation to a relaxation to cultural disturbances, as discussed later.

The mid- to late Holocene record from Lake Coba underscores why multi-proxy studies are necessary for robust interpretations when cultural influences are pervasive (Figure 7). The region around Lake Coba continued to support wooded swamp and semi-deciduous forests until 4700 B.C. As groundwater levels rose and precipitation increased, the *Akalche* was drowned within the lake basin and more mesic elements of the dry forest increased regionally. The forests started to become more open during the Early Preclassic, around 1650 B.C. As elsewhere, initial deforestation

precedes the first appearance of maize. The forest reduction is concurrent with indices of increased aridity but may also represent the first wave of land clearance. Subsequently, extensive milpas were cultivated very near the lake, and the ability to discern climatic change through pollen analysis is severely restricted. However, toward the end of the Early Classic, a diverse aquatic assemblage occurs, suggesting that a variety of littoral habitats developed and expanded while the terrestrial record continued to be dominated by disturbance taxa. Diatoms concurrently record a pronounced deepening of the lake (Leyden et al. 1998; Whitmore et al. 1996). Lake Coba appears intentionally to have been modified and connected with other water bodies by canals at this time. The greater need for a secure water supply may reflect increased drought conditions that are evident in isotopic studies from nearby lakes (Curtis et al. 1996; Hodell, Curtis, and Brenner 1995; Hodell, Brenner, Curtis, and Guilderson 2001).

At the time of the Classic Collapse, Coba may have been abandoned briefly, but substantial occupation continued through the Early Postclassic. Significant forest regrowth did not begin until after about A.D. 1240, as was the case at some of the southern locations. At the time of the Classic Collapse, there was a temporary decline in agricultural activity, reflected in the pollen diagram and a rebound response by the native vegetation to a relaxation of disturbance. A high-resolution, stable isotope record from Lake Chichancanab records a 200-year drought coincident with the Maya Classic Collapse (Hodell, Curtis, and Brenner 1995; Hodell, Brenner, Curtis, and Guilderson 2001). Close-interval sampling provides a detailed pollen record across this section of the core (Figure 10). Cultural effects in the area around Lake Chichancanab are thought to have been slight. Nevertheless, the pollen spectra before the drought reflect typical disturbance vegetation, with maize and suppressed arboreal percentages. The native vegetation appears to be unaffected by the drought, as pollen percent-

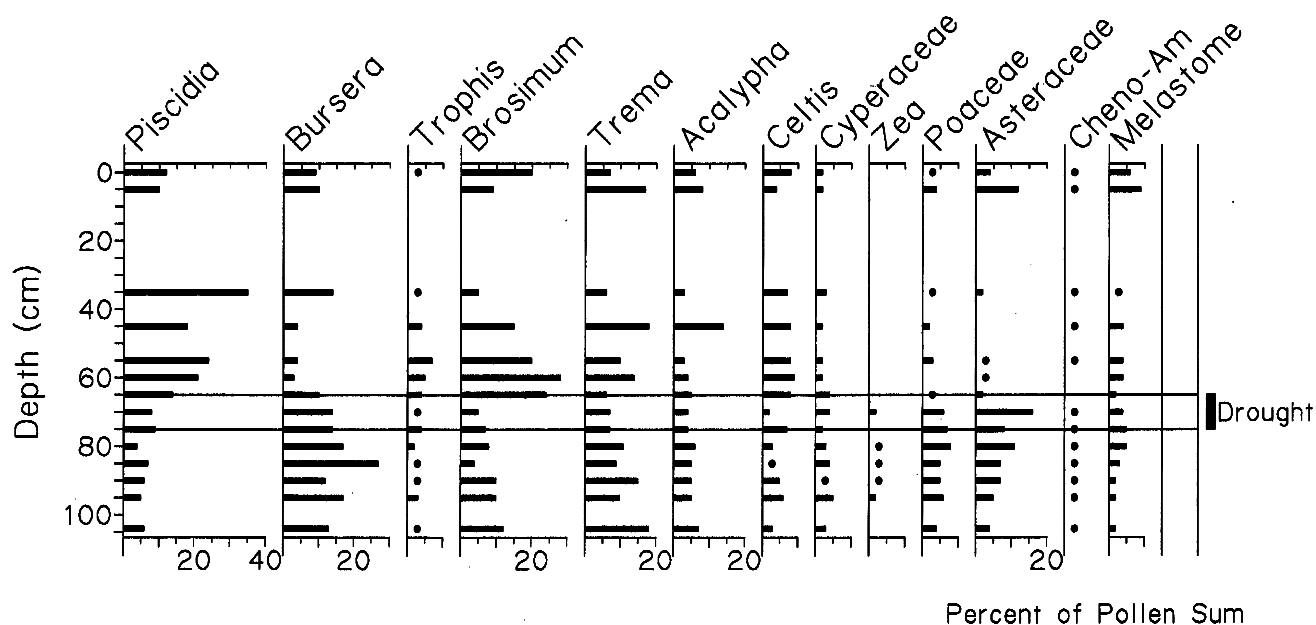


Figure 10. Lake Chichancanab pollen percentage diagram. Cheno-Am, Chenopodiaceae-Amaranthaceae pollen type; Melastome, Melastomataceae. Circles represent values less than 2%. The section of the core between about 65 cm and 75 cm is the interval of maximum drought identified in the stable isotopic record from the same sediment core (Hodell et al. 1995).

ages change very little across the drought interval. After the drought, individual taxa responded rapidly to the relaxation of cultural stresses and the end of agricultural activities.

The diverse subtropical forests of the Maya Lowlands withstood changes in available moisture throughout the Holocene. Native taxa that are adapted to the cyclical droughts on the northern Yucatan Peninsula (Hodell et al. 2001) are able to take advantage of the improved conditions that follow the end of each cycle. As long as tolerance levels are not exceeded, the vegetation will persist. The diversity within the vegetation generates overlapping tolerance levels that ensure that some portion of the subtropical forest is maintained. Many of the understory plants in the semi-evergreen forest are the dominants in the dry forest and thus are positioned to take over when there is a moisture deficit. The pattern is reversed when moisture availability increases. However, maize, with its proscribed growing conditions, is more difficult to maintain. The Maya, who were heavily dependent on maize cultivation, would not have been able to sustain their social framework. Subtropical forests that are resilient when subjected to fluctuating stresses about a mean value can still be displaced by extreme environmental and cultural forces. But pollen records may be unable to detect cyclical droughts that nevertheless are devastating for cultivars and dependent cultures.

Pollen records from coastal Tabasco, Mexico, primarily reflect sea-level rise and cultural manipulations, but variable climate may have contributed to fluctuations in stream discharge. The distribution of coastal plant communities is controlled by sea level, stream discharge, and deltaic processes. Channel development and abandonment alter micro-topography, water levels, and salinity, which in turn strongly influence the distribution of vegetation. Over time, as local conditions change, communities can change from marine and lagoonal systems to brackish mangrove estuaries and freshwater marsh. Additional information is needed to ascertain the relative significance of each factor that influenced the coastal region during the late Holocene, but the available pollen data provide a starting point.

The La Venta-San Andres region was occupied as early as 5100 B.C. and extensively cleared by 4800 B.C. (Pope et al. 2001). Deltaic processes, agricultural activities, and fluctuations in stream discharge are also recorded in a younger San Andres levee section (Rust and Leyden 1994), and the pollen diagram is presented here for the first time (Figure 11). Four pollen zones can be distinguished, and their calibrated age ranges may be about 250 years older than the C-14 ages presented here. The initial zone reflects mangrove associations on an expanding mudflat or low levee. Some cultivation is inferred due to the presence of *Zea*. In Zone II, the representation of red mangrove declines, non-halophytic herbs increase, and non-mangrove forest taxa have maximum representation. *Zea* is again present. Zones I and II span the Early Preclassic Early Bari period (ca. 2250 to 1750 B.C.) (Rust and Leyden 1994; Rust and Sharer 1988). Although non-climatic deltaic processes and cultivation account for much of the observed changes, increased stream discharge at the end of this period appears to reflect greater regional precipitation, as seen on the northern Yucatan Peninsula.

Zone III dates from the Middle Bari period (ca. 1750 to 1400 B.C.) (Rust and Leyden 1994) and reflects a return to more saline conditions, with maxima for red and white mangrove. Mangrove vegetation colonized the levee banks, leaving abundant roots in the peaty deposits. Indications of agricultural activity are absent at San Andres, although settlement begins at the neighboring sites of Isla Yucateca and Isla Alor. The San Andres branch of the braided Río Bari lost capacity either through flow capture by another branch upstream or a return to drier conditions similar to those at Cenote San José Chulchaca.

Zone IV is transitional, with a retreat of mangroves followed by brackish (sedges, Chenopodiaceae–Amaranthaceae pollen types, and leather fern) and then freshwater marsh taxa (grasses, composites, cattails). Maize is again present. This zone corresponds to the Late Bari period from 1400 to 1150 B.C. The return of over-bank flow and rapid deposition of sandy clay alluvium indicates a reactivated levee setting. The regional sea level appears to have

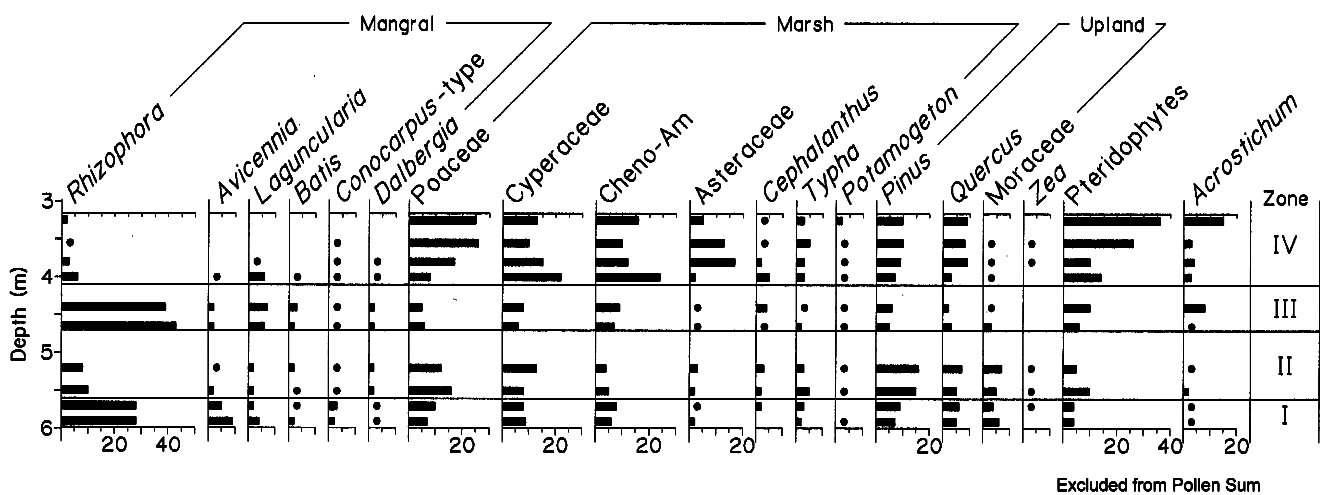


Figure II. San Andres pollen percentage diagram. Circles represent values less than 2%. Taxa are grouped by dominant plant association. Cheno-Am, Chenopodiaceae–Amaranthaceae pollen type. The ferns were excluded from the pollen sum. Pollen zones are shown to the right of the figure. Zones I and II span the early Preclassic Early Bari period (ca. 2250 to 1750 B.C.) (Rust and Leyden 1994; Rust and Sharer 1988); Zone III dates from the Middle Bari period (ca. 1750 to 1400 B.C.); Zone IV corresponds to the Late Bari period (1400 to 1150 B.C.).

been lower at this time (Pohl et al. 1996), which would have steepened the stream gradient. Alternatively, the cyclical nature of these alternating conditions between pollen zones may reflect an extension of the 200-year drought cycle on the Yucatan Peninsula (Hodell et al. 2001), and precipitation may have increased again. Increasing percentages of unidentifiable pollen and, finally, the near-absence of pollen at the top of the zone are evidence of pollen degradation caused by greater aeration of the upper sediments. Maize cultivation continued nearby and contributed to the herbaceous representation in the pollen record. Both white mangrove and leather fern can become dominant in disturbed areas, which may explain their increased representation. The later decline of white mangrove may be related to its preference as a source of charcoal (Thom 1967).

SUMMARY

Today, we can rely on written and instrumental records as well as computer models to understand the workings of our world and our impact on it. However, what we have experienced in historical times does not encompass the full range of what happened in the past. Paleoenvironmental studies can provide a glimpse into that past. There are many paleoenvironmental proxies, each with strengths and limitations. Pollen analysis is one proxy for vegetational and climatic change that is widely applicable. When climate is the dominant force, such as during the last glacial period, pollen

percentages and influx clearly reflect changing environments. But other forces, such as eustatic sea-level rise and humans, can also affect vegetation and the deposition of pollen. The relative importance of multiple forces can be difficult to discern when effects are comparable. In these situations, the use of multiple proxies provides a more robust interpretation of events.

The history of the Maya Lowlands is an excellent record to examine both for its intrinsic value and for the insight it can provide into managing our future. Environmental forces were the dominant mechanism for change until the last 3,000 to 4,000 years, and pollen analysis provides a good record of changing conditions. The Maya became the dominant environmental engineer after they entered the Lowlands. The results of their actions, as seen in the pollen record, clearly demonstrate the capacity of humans to change the world, but the ability of pollen analysts to discern climatic fluctuations is severely limited. Some of these fluctuations may have had a greater impact on cultural systems than on the vegetation associations, which would mask the event in the pollen record further. Was it arrogance with respect to this power over nature that ultimately led to the collapse of Maya civilization? Perhaps. Glimpses of climatic change remain in the pollen record and indicate that the late Holocene climate was not static. Some questions have been answered, but more remain. Pollen analysis will continue to be an important component of multi-disciplinary paleoenvironmental studies.

RESUMEN

El análisis de polen en núcleos de sedimentos lacustres se aplica al estudio de los cambios paleoambientales en las tierras bajas de los mayas. Los principios son sencillos. Sin embargo, hay limitaciones asociadas al método. Por ejemplo, la interpretación es problemática cuando la paleovegetación inferida no tiene un análogo moderno. También, estudios multidisciplinarios son necesarios cuando las influencias culturales sobre la selva dominan. Varios estudios han discutido los cambios climáticos, los impactos antropogénicos sobre el paisaje, y otros temas paleoecológicos en la región de las tierras bajas de los mayas. El clima ejerció el control mayor sobre la vegetación durante el Pleistoceno tardío y la selva tropical se ausentaba hasta ~10,000 años C-14 a.P. Entre 36,000 y 24,000 años C-14 a.P., el clima en el Petén (Guatemala) era menos húmedo y aproximadamente 4.7–6.5°C más frío que el clima actual. Un bosque húmedo-templado ocupó las áreas húmedas mientras que el género *Juniperus* existió en los lugares más secos. Durante el período entre 24,000 y 14,000 años C-14 a.P., la vegetación en el Petén era dominada por hierbas (gramíneas) y matorral escaso. Las condiciones climáticas fueron más secas y unos 6.5–8°C más frías que la actual. El clima mejoró entre 14,000 y 10,000 años C-14 a.P. y un bosque tipo húmedo-templado creció de nuevo. Durante el Younger Dryas (~12,500 años a.P.), la expansión de la selva se paró como una consecuencia de condiciones más frías pero no más áridas. En el Petén, la selva del Holoceno temprano estaba caracterizada por especies que reflejan condiciones más húmedas y la familia Moraceae subió de predominancia rápidamente. Esta vegetación, documentada por los registros palinológicos, no tiene ningún equivalente moderno. La selva tropical

subperennifolia estaba bien establecida ~8,000 años a.C. Las condiciones húmedas y calurosas predominaban entre los 8,000 y 6,000 años a.C. Esta época fue el período más húmedo de los últimos ~36,000 años. En el norte de la península de Yucatán, la vegetación siempre estaba bajo el control de las condiciones edáficas, y los lagos empezaron a llenarse sólo después de ~6,400 años a.C., en parte como una respuesta a los niveles crecientes del mar. La distribución geográfica moderna de las formaciones vegetales en la península de Yucatán fue establecida hacia el final del Holoceno temprano (~6,000 años a.C.), sugiriendo que las condiciones climáticas (temperatura y precipitación) modernas también fueron establecidas. El norte de la península de Yucatán nunca sostuvo el pino (*Pinus*) (como sí se encuentra en Belice), ni la selva subperennifolia, que caracteriza el Petén en el presente. Los mayas fueron la fuerza motriz de los cambios medioambientales en el Holoceno tardío durante la época cuando sus poblaciones llegaron a densidades altas. Sus impactos sobre la vegetación son claramente visibles en los registros del polen. Existe evidencia que el clima del Holoceno no era invariable en la región maya. Por ejemplo, es posible que el clima pudo haber contribuido al resurgimiento de la selva en el Holoceno tardío después del colapso de la civilización maya en el siglo nueve d.C. Sin embargo, parece que los registros del polen no pueden percibir sequías cíclicas, detectadas por el uso de isótopos estables de oxígeno en conchas de invertebrados, preservado en los depósitos lacustres. Es probable que la vegetación natural de la parte norte de la península de Yucatán es bien adaptada a las condiciones secas y puede persistir, aún durante las sequías prolongadas.

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