# Climatic and Environmental Variability in the Rise of Maya Civilization: A Preliminary Perspective from Northern Peten

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# CLIMATIC AND ENVIRONMENTAL VARIABILITY IN THE RISE OF MAYA CIVILIZATION

## *A preliminary perspective from northern Peten*

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## Abstract

Archaeological and ecological investigations in the Mirador Basin of northern Guatemala have recovered archaeological, phytolith, palynological, and pedological data relevant to the early occupation and development of Maya civilization in a specific environmental matrix. Fluctuation in vegetation types as evident in cores and archaeological profiles suggest that the seasonally wet, forested *bajo* environment currently found in the northern Peten was anciently more of a perennially wet marsh system that may have been heavily used and influenced by large Preclassic occupations. Data suggest that climatic and environmental factors correspond with the cultural process in the Mirador Basin, and research in progress is oriented to further elucidating these issues.

Recent archaeological investigations in the northern Peten, Guatemala, have identified a large and unusual Middle and Late Preclassic occupation in a circumscribed, geographically defined, elevated area known as the Mirador Basin. This geographic feature is located in northern Guatemala and extends into extreme southern Campeche, Mexico (Figure 1). Settlements of unusual size and organizational complexity have been found to date to the Middle Preclassic (1000 B.C.–350 B.C.) and Late Preclassic (350 B.C.–A.D. 150) periods, with a much more modest occupation during the Late Classic period (A.D. 600–840; Hansen 1998, 2001). The unusual density of ancient populations is suggested by the concentration of sites that are large and early and that have architecture of monumental proportions. Current information indicates the presence of Middle and Late Preclassic monumental constructions at the sites of El Mirador, Nakbe, Wakna, Tintal, and Xulnal, which represent five of the largest sites within the Mirador Basin (Figures 2 and 3). The large site of Naachtun (Guatemala) and the site of Balakbal (Mexico), located in the northeastern corner of the Mirador Basin, have strong indications of monumental Preclassic architecture and site formats, but the known extensive Classic occupation and the absence of more comprehensive systematic study makes the Preclassic occupation of these sites poorly understood.

Archaeological data suggest that the precocious Preclassic development in the basin was the cumulative effect of a long sequence of occupation and settlement nucleation beginning at least by the early Middle Preclassic period and continuing until approximately A.D. 150. At that time, demographic densities appear to have been substantially reduced or entirely absent; major architectural construction programs were discontinued; and a forested environment appears to have returned to the area for approximately 550 years. It is clear from the Late Classic occupation at A.D. 700–A.D. 850 that the modest residential compounds nestled among the much larger Preclassic ruins were placed with little regard for ancient settlement organization or functional structure of the sites. This disregard is evident in the location of numerous Late Classic residences on the elevated Preclassic causeways, stone-robbing from Preclassic buildings, and the placement of Late Classic quarries on Preclassic causeways and platforms. Today, the contemporary Kek'chi and *mestizo* settlers near Carmelita consider the area an inhospitable zone because of the presence of the numerous *bajos*, or seasonal swamps in flat-bottomed depression areas. The *bajos* are formidable obstacles, because vegetation is difficult to remove due to the hard, thorny woods and the venomous nature of much of the vegetation (i.e., *Metopium brownii*, known as *Chechen negro*). Further challenges are the inundated surfaces during the wet season and extreme drought during the dry season, which transforms the clay soils into solid, cement-like consistencies that defy agricultural manipulation. The extraordinary quantity, density, and antiquity of early Maya remains in the Mirador Basin provide a paradox of prodigious growth and cultural sophistication in an area that should be limiting (and currently is) to population growth and development. If the environmental and geomorphologic landscape were the same in the past


**Figure 1.** Map of Mesoamerica showing area of the Mirador Basin.

as in the present, we ask, as did Peter Harrison (1977:477), how did such large-scale populations thrive and expand in areas with such limited well-drained soils?

Water supplies in particular are the most limiting feature of this environment. No perennial freshwater supplies exist near the major sites of Nakbe, El Mirador, Wakna, Naachtun, and Tintal, and the only surface water available during the dry season is found in natural water holes and ancient reservoirs called *aguadas*. These water sources highly fluctuate in any given year and are barely sufficient to supply a 150-person workforce for a two- to three-

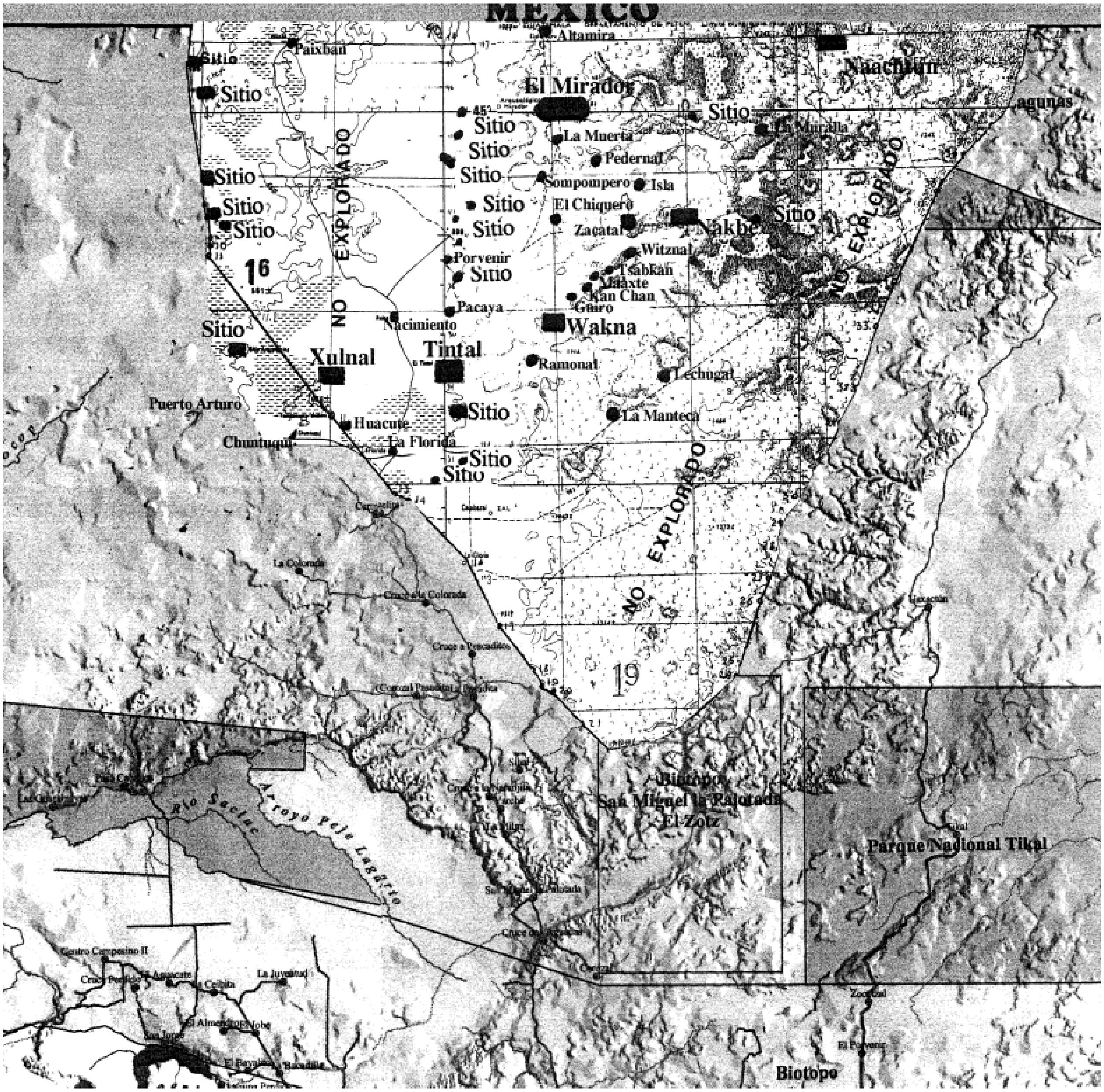


Figure 2. Map of the Mirador Basin.

month field season. As the water recedes during the dry periods, the concentrations of coliform and *Escherichia coli* become significant. In a water sample collected in 1998 from the Zacatal aguada by James Woods (CSI), the fecal bacteria tested 0, but the total coliform bacteria tested greater than 1,000 colonies per 100/mL, and *E. coli* concentrations also tested greater than 1,000 colonies per 100 mL (Stukenholtz Laboratory 1998, no. 13703). Furthermore, fluctuations of water supplies within the same general region demonstrate wide variations. For example, in 1996, water was found in the Camarrones and Zacatal aguadas, located 4 km to the east and west of Nakbe, respectively. In 1998, Camarrones was completely dry and only Zacatal had water. Similar fluctuations throughout the entirety of the basin are common annually. It is difficult to imagine how dense urban centers suggested by the massive sites in the Mirador Basin could have flourished in this area. Even the sophisticated water-harvesting techniques used by the Maya at Tikal (e.g., Scarborough 1993, 1998; Scarborough and Gallopin 1991) would seem to provide little more than subsistence rations and hardly enough to sustain a major thriving metropolis.

Another fascinating paradox is the fact that permanent, perennial lakes such as Chuntuqui, Paixban, and Puerto Arturo, are located slightly to the west of the Mirador Basin, yet the major settlements avoided these natural lacustrine resources. The emphasis for settlement seems to have been in more hydrologically difficult areas, requiring the construction of artificial *aguadas*.

To understand how environmental factors may have dictated settlement behavior during the Preclassic and Classic periods in

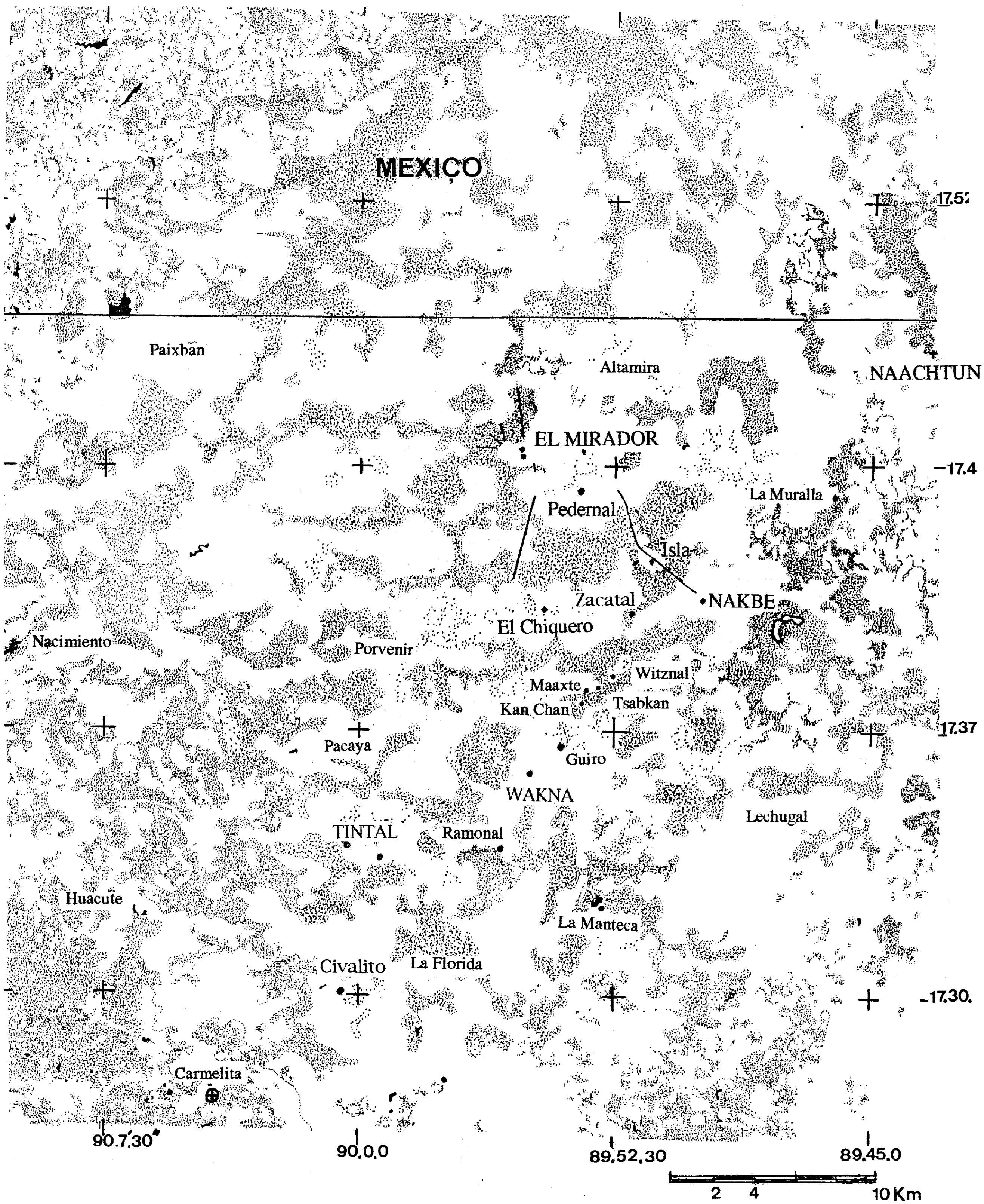


**Figure 3.** Map of a portion of the Mirador Basin showing concentration of *bajos*.

the Mirador Basin and to examine the potential variations of climate and human-induced ecological change, the UCLA and FARES (Foundation for Anthropological Research and Environmental Studies) Regional Archaeological Investigation of the North Peten (RAINPEG)–Mirador Basin project has conducted a series of investigations oriented to reconstruct environmental conditions that prevailed during the distinct periods of human occupation and abandonment of the area. The results of these preliminary studies by a number of specialists from various institutions in the United States, Mexico, and Guatemala have enabled fresh consideration of the nature and extent of the ancient environmental impact of incipient populations in the Mirador Basin and the role of potential variations in climate in the overall history of the basin. Although the distribution of major sites in the Mirador Basin may in part have resulted from ideological and economic factors, this paper provides preliminary results that demonstrate that settlement distribution was closely associated with the lowland depressions and swamps and that a different environment profile existed during the Preclassic periods in the Mirador Basin.

The northern Peten is a limestone karst environment with no defined integrated drainage. Sink holes are present but are less common than farther north in the Yucatan shelf. Distinct river channels are present, but these flow only in the rainy season. Large, flat-bottomed *bajos* from 50 to more than 100 $km^2$ in size characterize the drainage of this area. The *bajos* in the Mirador Basin occupy approximately 70% of the surface area (Figure 4). Some of these *bajos* are immense, exceeding 5 km in width and more than twice that in length (Figure 5). These *bajos* are forested (described in more detail later), with vegetation dominated by inkwood (logwood) or *palo tinto* trees (*Haematoxylum campechianum*); in general, the vegetation is much lower in height than the forest in the contiguous upland areas.

Satellite and aerial observations indicate that numerous *bajos* within the Mirador Basin contain features known locally as *civales* (Figure 6)—treeless, wet areas of herbaceous vegetation (Figure 7). These features are distinct from the dry savannas found in the southern and central Peten. *Civales* are much less extensive than *bajos* and are almost always located within or adjacent to *bajos*. The *bajos* flood in the rainy season (May to October) and remain inundated for as long as two months. The marshy *civales* usually stay wet throughout the dry season in most years, and many of the natural water holes are found in these *civales*.

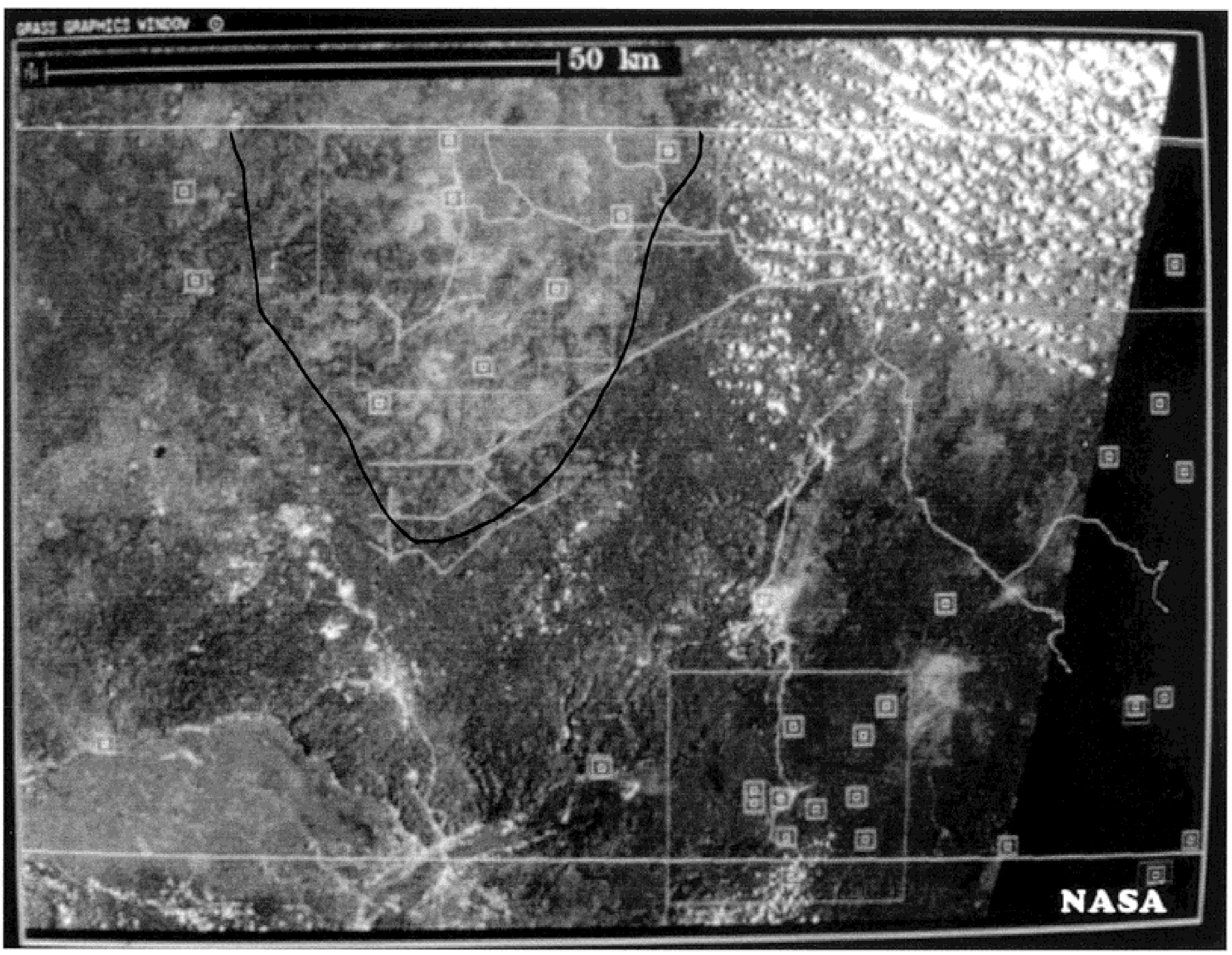


**Figure 4.** Satellite photo of the Mirador Basin in an infrared spectrum showing the concentration of *bajos* relative to upland forest (courtesy Tom Sever, NASA).

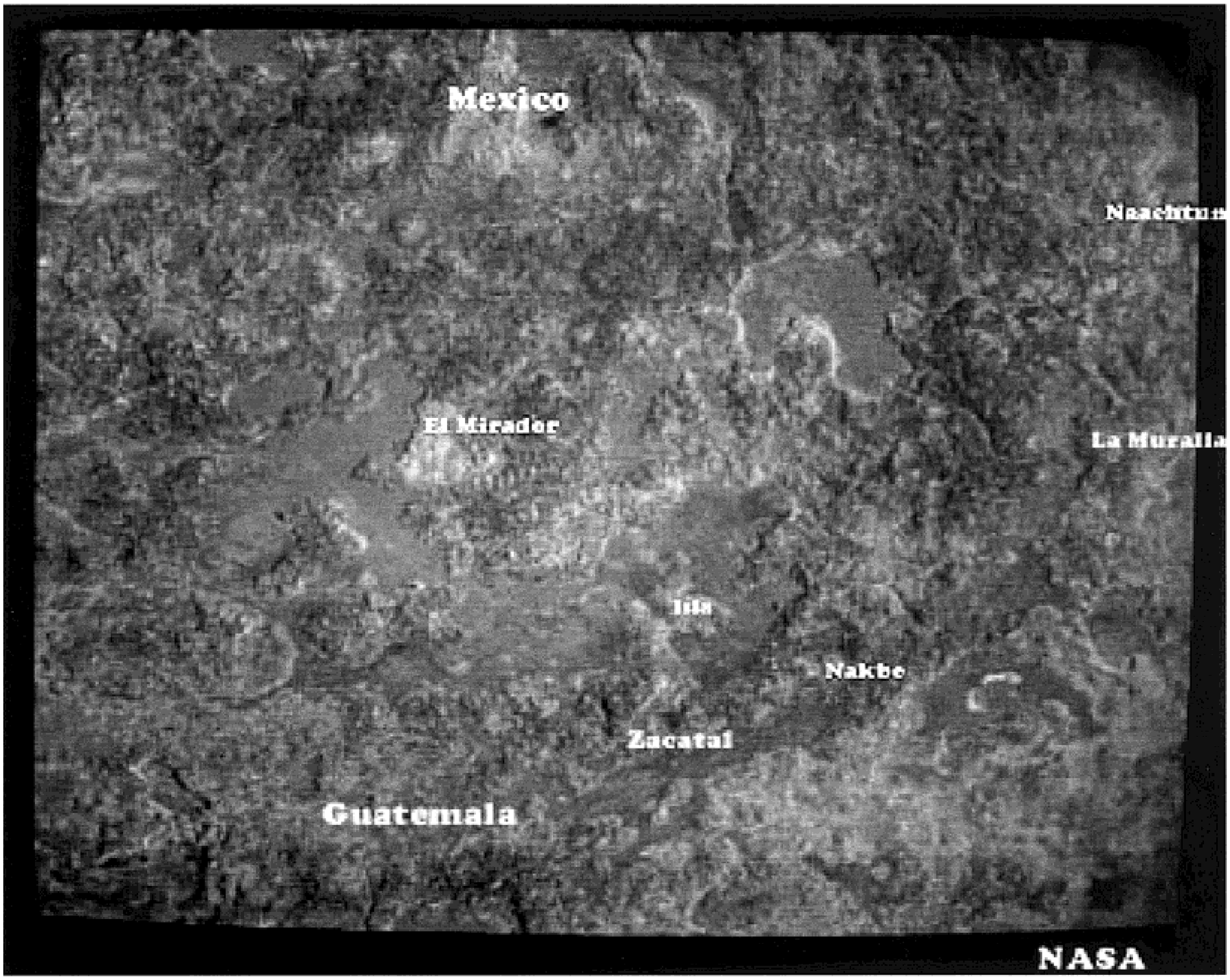


**Figure 5.** Satellite photo of the northern section of the Mirador Basin showing a closer perspective of the *bajos* surrounding the major sites (courtesy Tom Sever, NASA).

The argument that *bajos* may have been lakes during the periods of Maya occupation (Cooke 1931; Madeira 1931) lacks evidence (e.g., Cowgill and Hutchinson 1963:39, 41; Culbert et al. 1990; Dahlin et al. 1980; Harrison 1977). Other investigators (e.g., Pope and Dahlin 1989) argue that the *bajos* were essentially the same during the periods of Maya occupation as today. Our data tentatively suggest that neither of these previously postulated positions is accurate, and we suggest that the primary attraction for large-scale demographic densities in the Mirador Basin was the result of humid, perennially wet marshlands that provided numerous resources of strategic importance for the major urban centers of the northern Peten. In addition to a more reliable or permanent source of water, the vast marshlands would have been an incredibly productive environment in terms of wildlife, fiber resources, and organic soils. The marshes possibly also would have provided defensive functions for the emerging centers during the Middle and Late Preclassic periods, a point well taken when one attempts to traverse a *cival*-type marsh such as the *aguada* at Zacatal or the Cival Madre to the east of Nakbe.

Surface studies of the *civales* within the *bajos* of the Mirador Basin by the geomorphologist Gilberto Alvarado of the Universidad de San Carlos; the botanical specialists César and César Castañeda of the Universidad de San Carlos; and systematic excavations in *bajos* by John Jacob of Texas A&M indicate that the past environment in the basin was radically different. Indeed, observations suggest that present-day vegetation in the forested *bajos* is encroaching on contemporary *civales*, suggesting an evolutionary sequence of change from marsh to forest as the *civales* become filled by sediments (Figure 8; see also Siemens 1978:143). These observations are verified by detailed pollen studies now being conducted and by preliminary pollen and botanical studies that have already been undertaken on the project (Castañeda 1995; Castañeda and Castañeda 1994; Hansen 1995; Jacob 1994, 1995b, 2000; Jones 1991; Leyden 1994; Wahl 2000a, 2000b, 2000c, 2001; Wahl et al. 2000, 2001; Weinstein 1994).

## *BAJO* VEGETATION

According to RAINPEG investigations with the tropical botanist Cesar Castañeda of San Carlos University in Guatemala, contemporary vegetation types could be of assistance in determining past ecological successions and the development of soils in land and

**Figure 6.** Aerial photo of the treeless grassland marshes known as *civales* found in the Mirador Basin, Guatemala.

aquatic systems. Castañeda and colleagues began a detailed listing of the botanical species in the immediate region of Nakbe as a complement to Cyrus Lundell's (1937) standard corpus of vegetation in the northern Peten. Within the eight diverse vegetative type communities found near Nakbe, Castañeda identified 55 of the most abundant botanical family species (see Wiseman 1978 for a similar study). Although Lundell noted 785 species in the botanical corpus of northern Peten (Lundell 1937:49), the Peten forest is

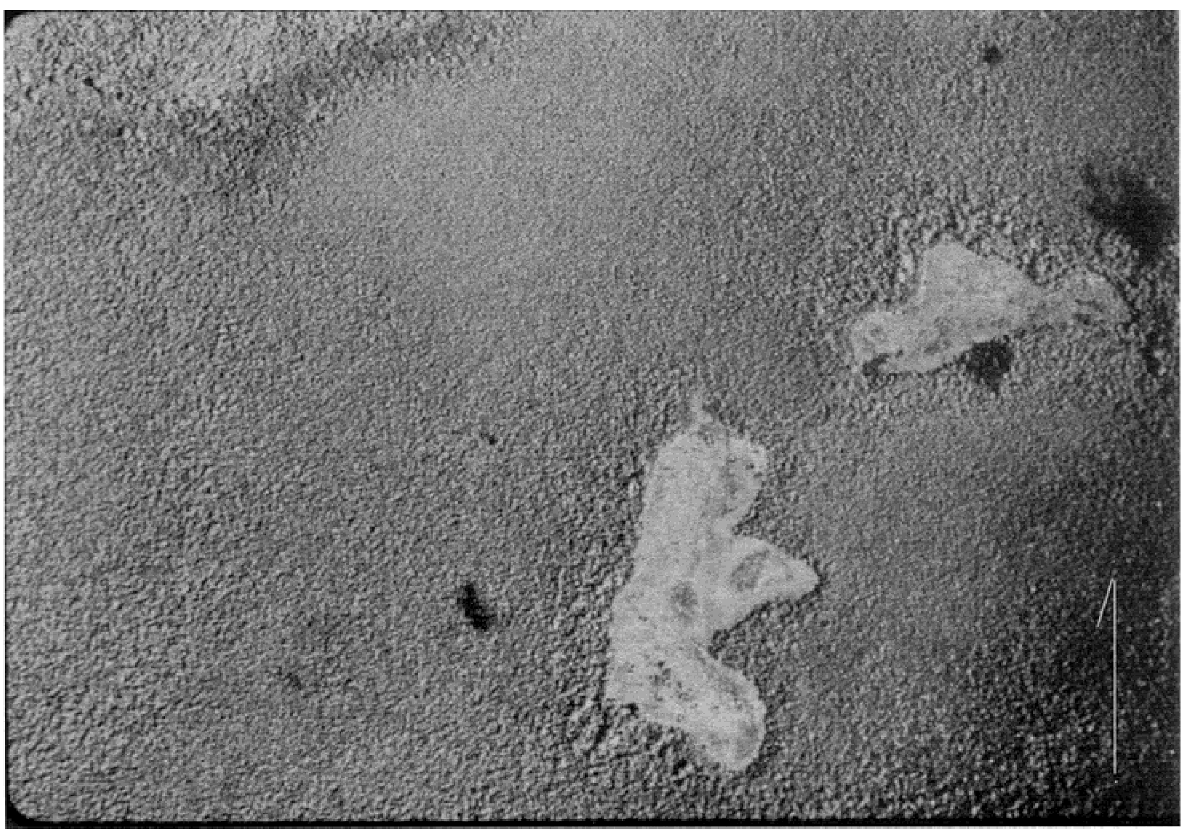

**Figure 7.** Aerial photo of the *cival* remnants in the large *bajo* to the immediate east of Nakbe.

**Figure 8.** Fossil remnant of a *cival* at Zacatal, Peten.

characterized by an average botanical diversity of approximately 80 species per hectare (Castañeda 1995; Castañeda and Castañeda 1994; see also Culbert et al. 1996:55; Romero Zetina and Schreiner 2000). In particular, Castañeda was convinced that the region was dominated in ancient times by a major, mature lacustrine system consisting of wetland marshes because of the presence, in the most humid area of the *bajos*, of *julubal* groves (*Bravaisia tubiflora)* and a species known as *cachazo* (taxonomy not determined by the lack of flower in the sample). These species represent a stage in the vegetative succession from a lacustrine to a forest system. In addition, Castañeda located an abundance of trees known as *zapoton* or *zapote bobo* (*Pachira aquatica*) near the Camarrones *aguada* on the edge of the *bajo* on the eastern side of Nakbe. These trees are usually associated with large lacustrine or riverine systems and seldom with small aquatic systems (Castañeda and Castañeda 1994:143). These vegetative types suggest perhaps a fossil remnant of the ancient system, providing a somewhat tenuous but visually verifiable argument for ecological succession with transitional vegetation along the major *bajos* in the region (Castañeda 1995:74). Such transitions in the *bajos* and *aguadas* have been noted by other scholars (i.e., Seimens 1978:143).

## *BAJO* SOIL COMPOSITION

The nature and formation of the *bajos* and the use of associated wetland agriculture, particularly in Tabasco, Campeche, northern Guatemala, and Belize, have attracted the attention of numerous scholars (Cowgill and Hutchinson 1963; Dahlin et al. 1980; Dominguez 1993; Fedick 1988, 1996; Harrison 1978, 1996; Jacob 1995a, 1995b; Matheny 1982; Culbert et al. 1989; Miller et al. 1991; Pohl 1990; Pohl and Bloom 1996; Pope and Dahlin 1989; Pope et al. 1996; Ricketson and Ricketson 1937; Siemens 1978, 1982; Siemens and Puleston 1972) with widely varying results. Previous soil descriptions from the Peten (i.e., Fomentos y Desarrollo del Petén 1968; Simmons et al. 1959; Stevens 1964) have identified a high percentage of soil types called Macanche (Ma), Yaloch (Ya), and Uaxactun (Ua) in the area of the Mirador Basin. Although the presence of these soils (Ma, Ya, Ua) is in part due to the greater predominance of *bajos* with poorly drained clay soils, they sharply define the Mirador Basin from the surrounding areas of the northern Peten, particularly to the west and east, which have predominantly distinct soil types called Yaxha (Yx), Sacluc (Sc), or Sacpuy (Sp) of low to moderate fertility. The western Peten is currently an area of more extensive perennial marshlands and swamps, so the variation in soil types does not simply seem to be a product of the *bajos*. Varying perspectives on the agricultural capability of the Mirador Basin soils range from "low to moderate fertility" (Fomentos y Desarrollo del Petén 1968) to "potentially the most productive soils of El Peten" (Stevens 1964:300). These variations suggest either that more studies on agricultural capability are needed on a regional basis or that the soils are more heterogeneous than previously thought. Nevertheless, contemporary farmers consistently avoid the *bajo* areas in spite of production potential.

## *BAJO* STRATIGRAPHY

RAINPEG investigations under the supervision of John Jacob were conducted in the large *bajos* and associated *civales* to the north and south of Nakbe. The northern *bajo* has been studied more intensively than the southern *bajo*, and additional studies will be continued in the southern *bajo*. A total of twenty-two excavations, ranging in size from 1.5 × 2 m to trenches more than 8 m long were placed in both the northern and southern *bajos*. These excavations focused on the stratigraphic sequences and morphological composition of the soils. Samples were collected by Richard Hansen Jacob, Gustavo Martinez, Juan Luis Velasquez, and David Wahl for chemical and physical analyses, pollen collection, fertility evaluations, and other detailed pedological information. RAINPEG studies indicate that, because of the high clay content of the soils, they are subject to radical fluctuations of contraction and expansion. These soils are classified as Vertisols (Soil Taxomony). The cycles of contraction and expansion form a surficial pattern of microhighs and microlows known as *gilgai*. Internally, the shrinking–swelling action of these soils results in sheer planes known as slickensides. Archaeologically, slickensides represent miniature faults in the clay matrix that allow for vertical and some horizontal movements of the soil during dry or wet periods (Figures 9 and 10). Microtopography of the *bajo* surface with Total Station mapping equipment demonstrates the distorted and convoluted surface of *bajos* (Figure 11). As can be expected, the radical movements of expansion and contraction of these soils has resulted in a disturbed stratigraphic context that has defied adequate stratigraphic interpretations. Nevertheless, Jacob's excavations revealed two primary stratigraphic features in the *bajos*: (1) the presence of a buried layer in both the north and south *bajos* forming what is believed to be a buried A-horizon; and (2) an upper sedimentary level known as Maya Clay. This Maya Clay layer extends approximately 80 cm to 1 m below the contemporary surface level. The buried soil layer below the clay was identified on the basis of a darker color of the level versus the overlying material (Figure 12). As explained earlier, the severe movements of the soils and sediments have modified the vertical stratigraphy of the feature, but the buried A-horizon has proved consistent in all *bajo* excavations. As we argue here, the discovery of a possible buried A-horizon with similar color, textures, phytoliths, and isotope compositions comparable to existent marshlands suggests that it was formed in a more humid, marshy environment. Several profiles were examined for morphological comparison in the *civales* surrounding Nakbe, and the profiles were similar with the exception that superficial topsoil was thicker in the *civales* than in the *bajos*. The subsoil strata were similar in all cases.

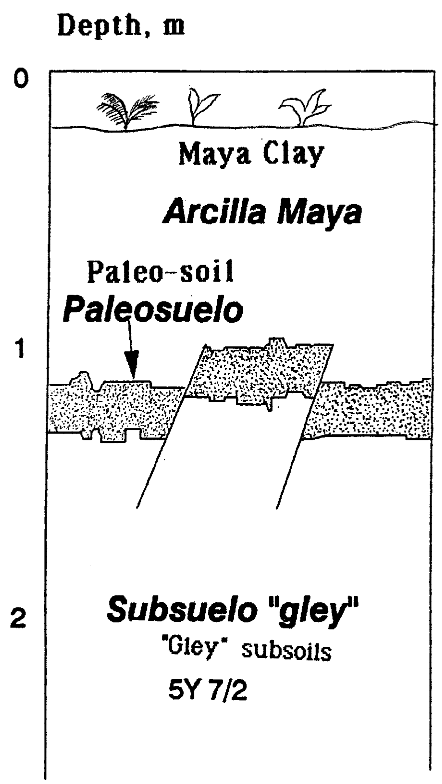


**Figure 9.** Schematic drawing of soil movements in *bajo* clay strata due to hydration or drying (after Jacob 1994).

Ursula Cowgill and G. E. Hutchinson (1963:39) suggested that in the *Bajo* de Santa Fe at Tikal, the sedimentation rate in the *bajo* was approximately 40 cm per millennium. If a similar sediment rate occurred in the *bajos* in the northern Mirador Basin, the buried A-horizon between 80 cm and 1 m below the surface would place the exposure of the deposit between A.D. 0 and 500 B.C., which correlates well with the apogee of civilization in the Mirador Basin. However, sediment accumulation from specific isolated phenomena, such as Hurricane Mitch that recently devastated Honduras, Guatemala, and parts of Belize also could have been responsible for radical sedimentation in the *bajos*, although this should have influenced both areas fairly equally. Further excavations and detailed examinations are necessary to define and refine these possibilities.

## ISOTOPE DATA

Isotope analyses (C-13) of the organic material from the buried A-horizon also suggest that there has been an environmental change in the Mirador Basin (Figure 13; Jacob 1994, 1995b). Jacob discovered that the buried A-horizon, located between 80 cm and 1 m deep, had a higher percentage of C-4 plants (grasses and possibly corn) than those of the overlying soil horizons. The surface sediments that had been deposited above the buried layer indicated an abundance of C-3 plants, an isotopic signature similar to that of the contemporary forest. Therefore, the contemporary surface of the *bajos* appears not to have been the primary agricultural surface for the ancient Maya, a concept that is also argued by Mary Pohl and Paul Bloom (1996:164). These data suggest that the original surface layer of the *bajos*, which we believe may be represented in the buried A-horizon, might have been created when the *bajos* were wetland marsh, while the overlying intrusive sediments were associated with a period of intense sedimentation followed by an abandonment of the area and part of the succession to contemporary forest species.

## POLLEN AT ZACATAL

Recent fieldwork by Juan Romero Zetina, Thomas Schreiner, and David Wahl the *cival* reservoir of Zacatal, located in a *bajo* 4 km west of Nakbe, have determined that the *aguada* was formed by the excavation and construction of a circular berm nearly 100 m in diameter (Figure 14; Schreiner and Wahl 2000). The Zacatal reservoir has proved to be of extreme importance in understanding the ecological sequence of the Mirador Basin. Previous pollen samples collected by Jacob and examined by Eri Weinstein of Texas A&M University and Barbara Leyden of the University of South Florida, Tampa (Figure 15) determined that pollen preservation in the sediment of the *aguada* was fair to excellent as a result of the permanently wet, anoxic environment. Schreiner and Wahl subsequently recovered a 3.35 m core at the center of the reservoir, and recent analyses by Wahl and Roger Byrne of the

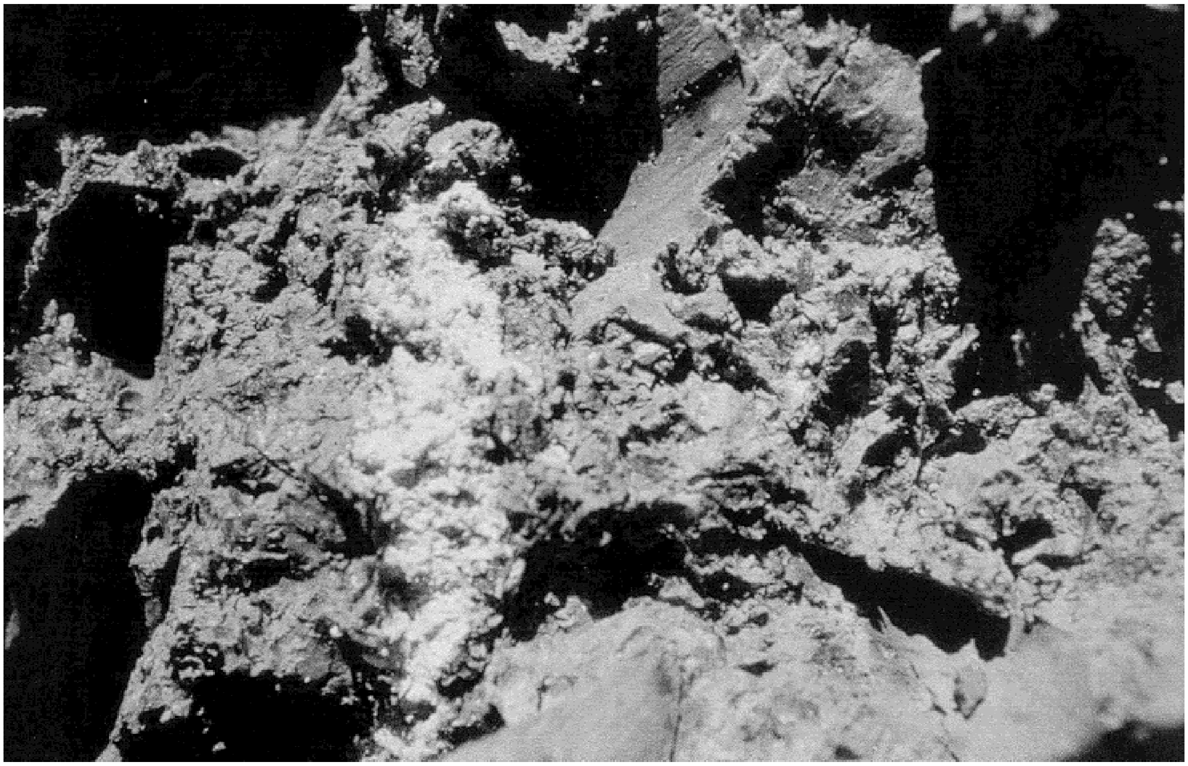

**Figure 10.** Photo of slickensides in gilgai formations in the Nakbe *bajos*.

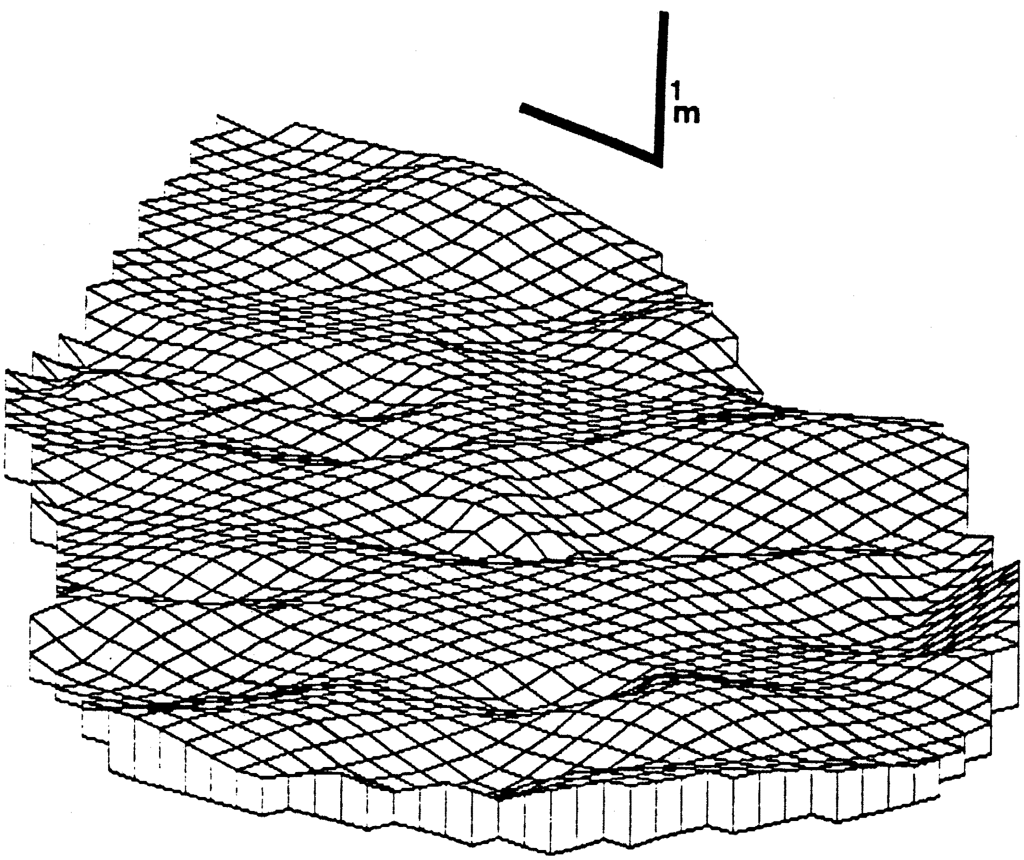


**Figure 11.** Microtopography with Total Station technology of a small section of *bajo* surface, showing the argilloturbation of the soils due to expansion and contraction of clay according to moisture (after Jacob 1994).

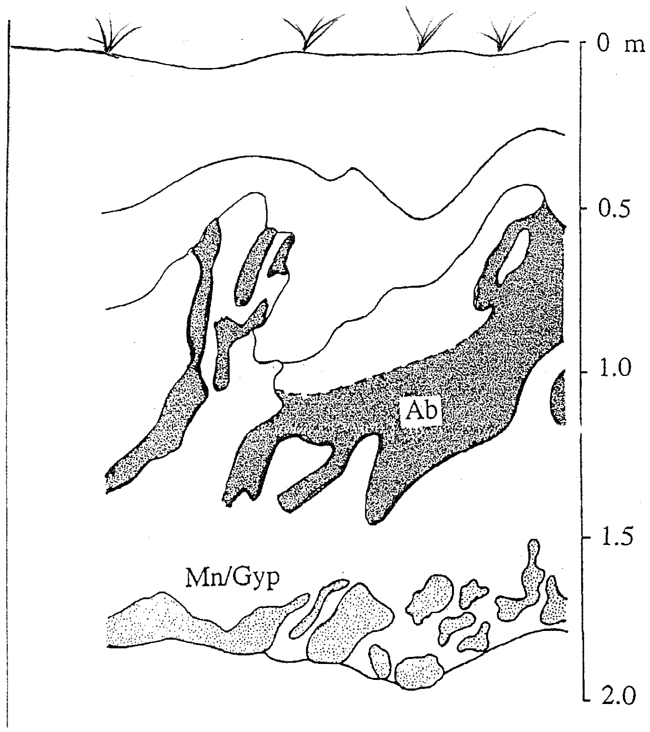


**Figure 12.** Stratigraphic profile of a *bajo* excavation showing the dark brown layer that horizontal formation disrupted by gilgai formations (after Jacob 1994).

University of California, Berkeley, have determined that the upper 1.15 m of the sediment core had the best preserved microfossils. The organic content of the sediments increased markedly closer to the surface, providing darker strata and suggesting a possible correlate for the fossil buried A-horizon found in the *bajo* excavations surrounding Nakbe.

The pollen assemblages directly above the artificial floor of the reservoir indicate that there were relatively few forest plants in the immediate vicinity of the feature, but the presence of *Zea* pollen in nearly all lower levels, as well as abundant *Poaceae* (grasses), suggests nearby forest clearance and cultivation between A.D. 680 and 840 (Table 1). This corresponds well with the settlement of the small Late Classic site of Zacatal, found in the vicinity of the *aguada*. The pollen record shows a distinct change above 55 cm, indicating a marked increase in aquatic species, ferns, and a recovery of surrounding forest species. This sequence indicates an abrupt abandonment of the area and a cessation of human disturbance, which, according to radiometric dating, occurred at about A.D. 840 (Table 1; see Brenner et al. 1990 for data on post-abandonment pollen patterns associated with depopulation). The distinct change in pollen that corresponds so well with the beginning and cessation of occupation in the Late Classic period has led to more intensive paleoecological work, specifically with deep lakes lining the western edge of the Mirador Basin, with the purpose of isolating the periods of incipient occupation in the Preclassic and the collapse that occurred at the close of the Late Preclassic period. Recent pollen-laden cores by Wahl and Schreiner from the lakes of Chuntuqui and Puerto Arturo will provide an unprecedented chronological perspective of environmental change and agricultural activities that took place in the Mirador Basin. Because the prevailing winds are from the east, the samples from the western edge of the basin should provide an accurate account of the ecological events within the basin. Studies in other areas of Mesoamerica have demonstrated that human disturbance and climatic factors are visible in cylindrical cores (i.e., Metcalfe et al. 1990). These studies are now under way at the Quaternary Paleoecology lab in the Department of Geography at the University of California, Berkeley.

## PHYTOLITHS

Steven Bozarth of the University of Kansas analyzed two phytolith (microscopic opaline plant remains with distinct forms) samples taken from an artificial garden terrace system discovered in Group 18 in the Western Group at Nakbe (Figures 16 and 17). This garden terrace system consisted of a 20 m × 120 m terrace located immediately adjacent to what is believed to be a residential palace complex dating to the Middle and Late Preclassic period. The most unusual aspect of this terrace was that it was constructed of imported mud, matching the color and general texture of the level previously discovered by Jacob in the *bajos* surrounding the site. Both samples analyzed by Bozarth contained well-preserved phytoliths, including a corn (*Zea mays*) cob phytolith and gourds (*Lagenaria)* from a level associated with an ancient garden (a fossil field) discovered on the terrace (Bozarth and Hansen 2001; Hansen et al. 2000; Martinez et al. 1999; Figure 18). In addition, phytoliths of palms were recovered in the sample. Although we believe that palms were grown on the terrace constructions, it is possible that these samples were imported initially with the mud. The presence of statospores (spherical cells with silicate walls produced in golden algae) provide additional clues of the imported nature of the mud from probable *bajo* contexts. This concept is not particularly new as Bruce Turner (1978:170) noted that in terrace soils near Cubietas Viejas, Belize, "the terraces may have been filled or at least fertilized with alluvial soils." Ray Matheny (1976, 1978:204) noted that, if the canals and reservoirs of Edzna were cleaned occasionally (as they appear to have been), the resultant muck could have been an important addition to surrounding agricultural systems. Therefore, soil transport may have been common on terrace constructions of ancient Maya populations.

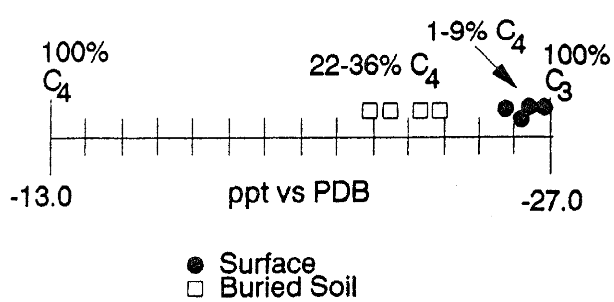


**Figure 13.** Delta C-13 isotope analysis of organic materials in the *bajos* at Nakbe. The buried A-horizon levels show a consistent C-4 isotope profile (grasses, corn), while the sediments that inundated the buried A-horizon are C-3 plants, consistent with present forest species (after Jacob 1995b: Figure 4-16). ppt vs PPD, parts per thousand versus Pee Dee Belemnite.

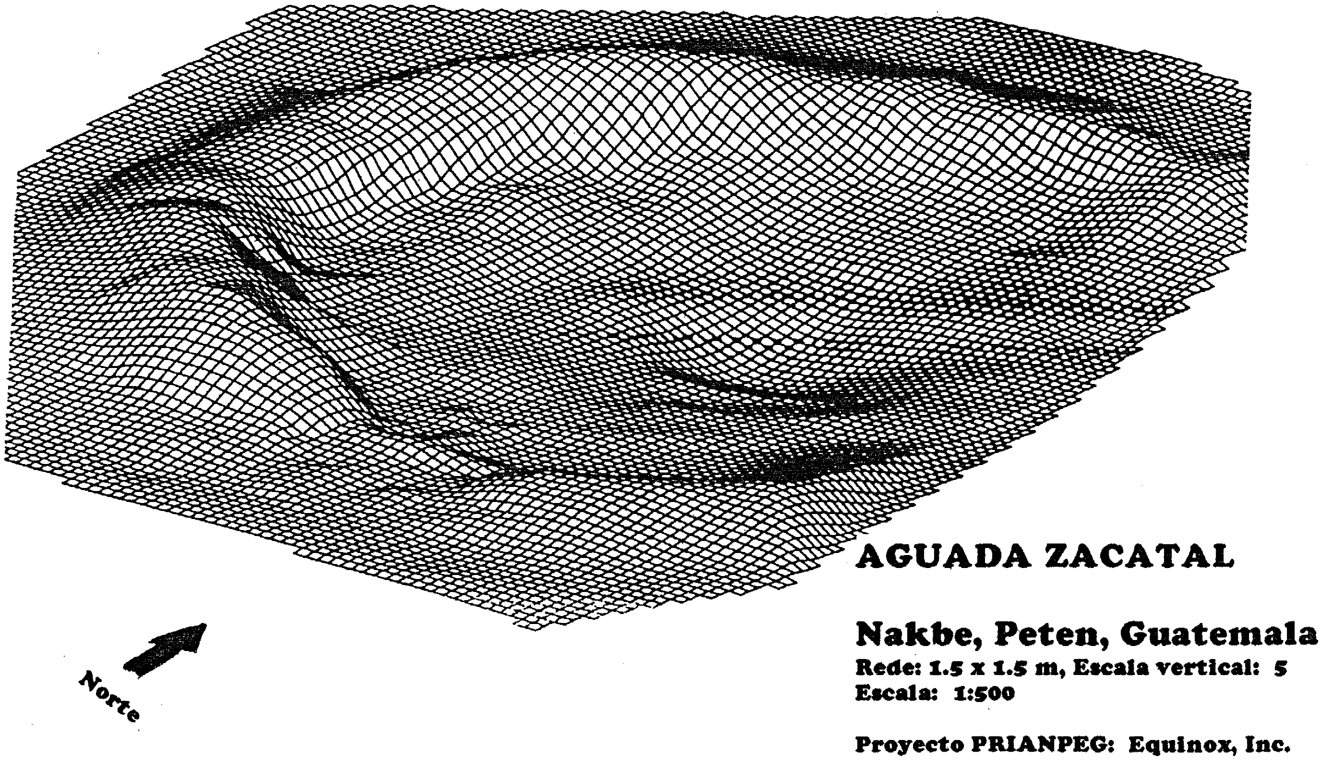


Figure 14. Aguada Zacatal, Peten, showing circular berm that surrounds the water source (after Schreiner and Wahl 2000:537).

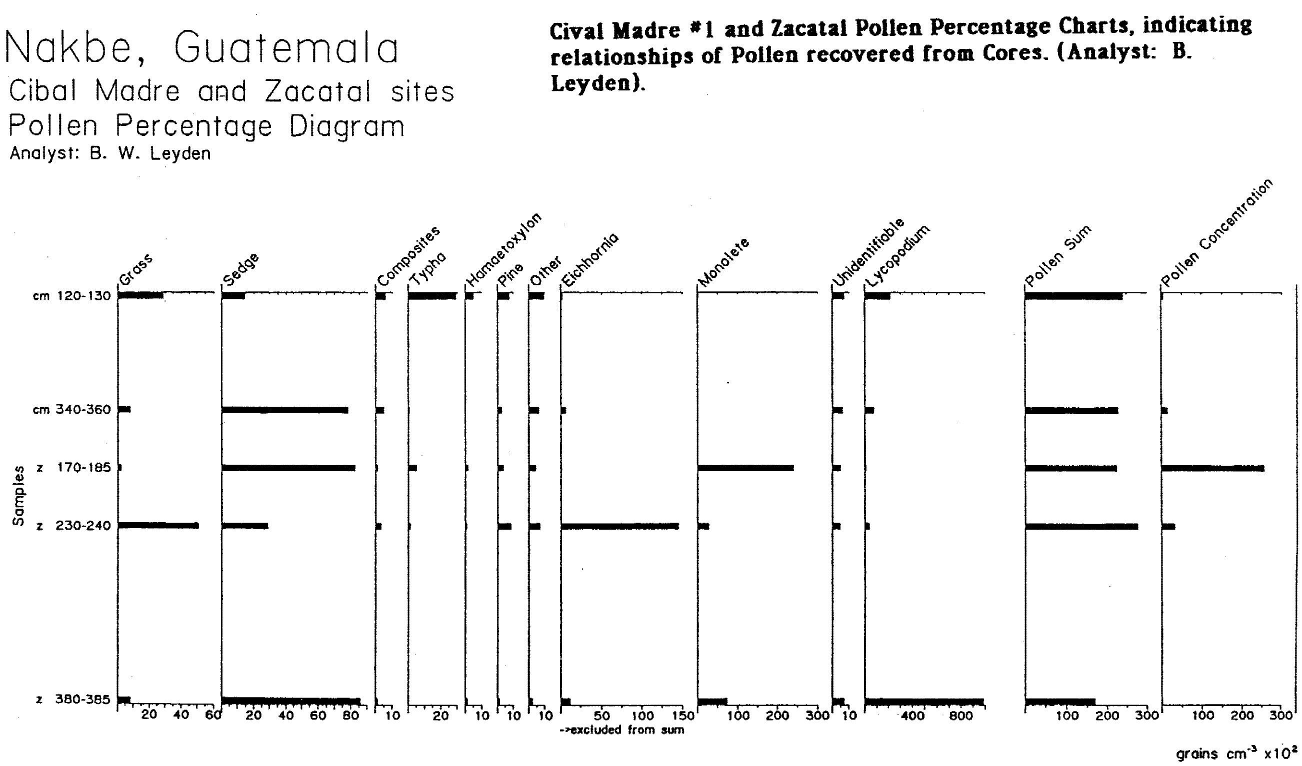


Figure 15. Previous preliminary pollen from Zacatal *aguada* with concentrations of grasses and sedges of wetland marsh formation.

Table 1. Radiocarbon dates for the strata from Aguada Zacatal

| Depth (m) | Uncalibrated Date | Calibrated Date, 1 sigma | Probability | Laboratory No. |
|---|---|---|---|---|
| .56 | 1180 ± 40 B.P. | 783–890 A.D. | 1.000 | CAMS-63813 |
| 1.06 | 1320 ± 40 B.P. | 663–714 A.D. | .860 | CAMS-63814 |
| | | 751–762 A.D. | .140 | |

*Source:* Wahl (2000a:29).

Subsequent excavations in the same area of Operation 18 at Nakbe provided twelve additional sediment samples that were collected and analyzed for phytoliths. Bozarth's detailed analyses, which will be elaborated elsewhere (Bozarth 2000), have provided strong evidence of post-abandonment vegetation near the surface but much higher frequencies of grass phytoliths in lower levels. Statospores were present in all samples from this zone and are presumed to be typical of the vegetation growing in *civales*. These data indicate that the soil at depths from 27 cm to 75 cm was imported from a foreign source and provide direct evidence of Maya agricultural practices.

The lower zone of the terrace had the highest frequency of grass phytoliths (88%) of any of the samples analyzed. The presence of algae statospores in this level indicate that the soils were from a wet marshland environment. The high frequencies of crosses and bilobates show that these grasses were in the *Panicoid* subfamily, which match the perennially wet marshlands still in existence in parts of the Mirador Basin. In addition, several corn phytoliths were recovered in the lower levels of the terrace and particularly on the undulating surface of the fossil garden (Figure 18) . Other phytoliths identified from these levels include squash, palms, and gourds (Bozarth and Hansen 2001).

The undulating surface of the fossil field has modern, ethnographic correlates (Folan and Gallegos 1992), described in more detail elsewhere. However, the presence of lime on the undulating surface in Operation 18 at Nakbe prompted Maya workmen to suggest that the ancient field may have been subject to ants and other insects, which could be deterred by the placement of lime on the surface, as is done by the current Kek'chi inhabitants near Carmelita. However, there is also a slight possibility that the lime

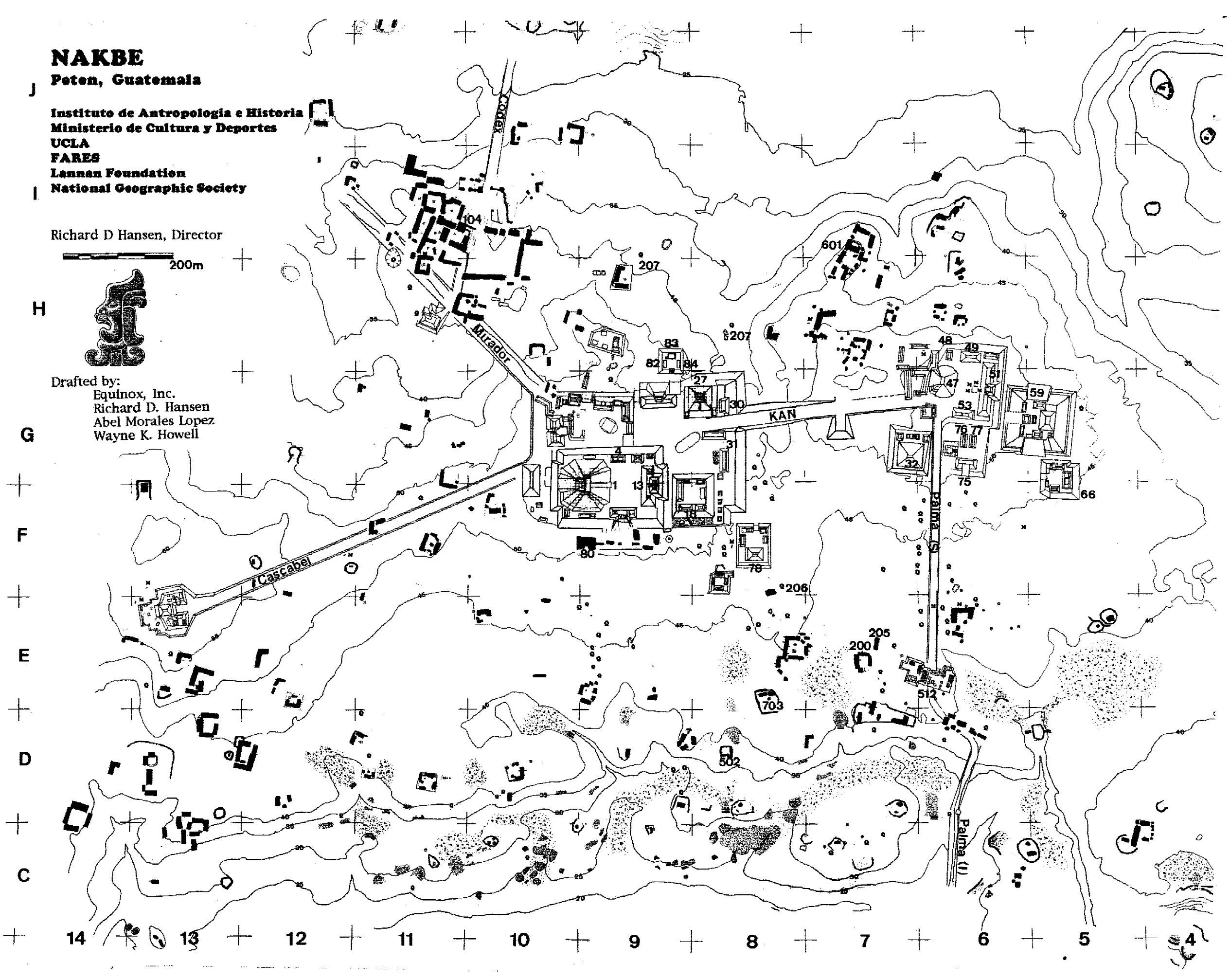


Figure 16. Map of Nakbe showing the West and East Groups of major architecture with associated causeways. The stippled area along the southern portion of the site are identified as ancient terrace constructions (darker stipple) and fields of imported *bajo* mud (lighter stipple).

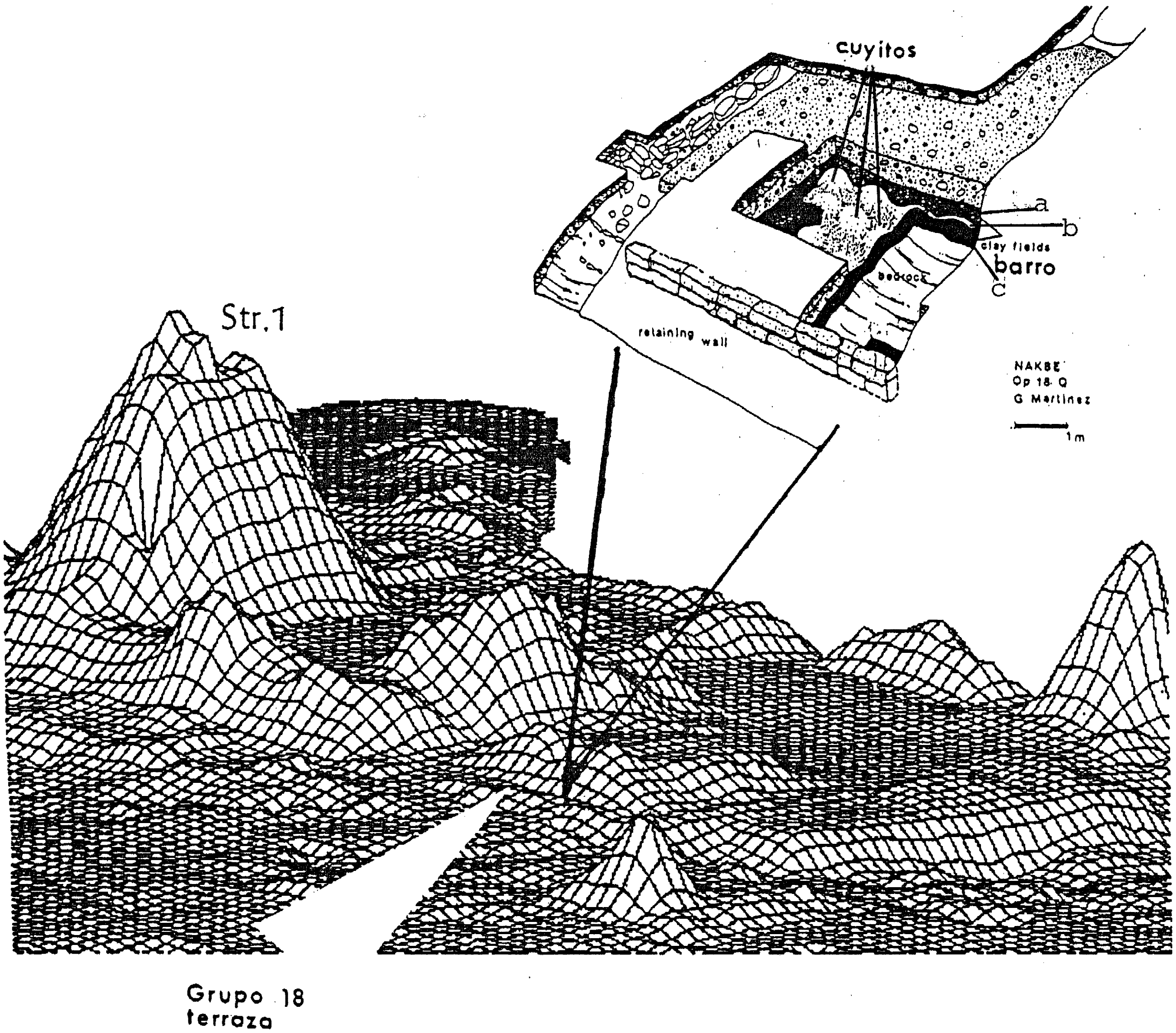


Figure 17. Portion of the West Group at Nakbe showing the garden-terrace system located along the southern edge of the Group 18.

may have been added to decrease the acidity of the *bajo* soils (see Dahlin et al. 1980:49), depending on the amount of rotting vegetation, suggesting that a possible sedentary and complex agricultural technology may have been employed by the Middle and Late Preclassic periods.

Additional corroborative evidence for the dramatic importation of exotic soils was initially discovered in another area of the West Group at Nakbe, where more than 2.5 vertical meters of imported mud were located in another terrace construction (Operation 31X; Figures 19 and 20). These imported dark brown clay levels, with Munsell colors of 5 YR 3/1, 10 YR 3/1, and 10 YR 3/2, match the upper peat and organic levels of Zacatal *aguada* and the buried A-horizon found in the *bajos*. More than 2 m of dark brown mud were successively added directly over a *sascab* (a powdery, friable, weathered limestone layer usually found above the parent material and frequently mined by the Maya) floor level containing Middle Preclassic ceramics (Figure 20). This floor had been placed over earlier levels, which were also of imported mud, and provides a testament to the antiquity and duration of the agricultural systems employed in Preclassic economic dynamics. These samples are currently undergoing analysis at the University of Kansas laboratories.

The identification of what appears to be imported mud in garden terrace formations in the civic centers provides some evidence for its origin in a wetland-marsh environment such as that in present-day *civales*. Subsequent surveys have located additional areas of the imported mud throughout the site of Nakbe, particularly in arroyos with check dams (Figure 21) and near escarpments. The locations of artificial terrace constructions and imported mud fields have now been defined primarily on the southern side of the site (Figure 16; Hansen et al. 2000). These features date to the Middle and Late Preclassic periods according to ceramics incorporated in the fill, and Preclassic domestic structures were located directly on the fields. The stippled areas along the


**Figure 18.** Undulating field surface of Group 18 at Nakbe showing the artificial basins and elevations that form *cuyitos* of contemporary fields in Campeche.

southern portion of the site (Figure 16) are identified terraces (darker stipple), fields of imported mud (lighter stipple), and check dams (dark, short lines). The predominance of such massive importations of dark mud indicates that the ancient Maya practiced an intensive form of agriculture capable of supporting large sedentary populations, a concept long argued by Oliver G. and Edith Bayles Ricketson (1937:11–12; see also Culbert et al. 1989). As long as the marsh environment was available, fields could be rejuvenated with a simple addition of more nutrient-laden mud, thus perpetuating indefinitely the agricultural production of the major centers in the Preclassic periods (see also Pohl et al. 1990:235). The precise source of the mud is probably still conjecture, according to Jacob, because thin sections and chemical analyses are not complete. However, RAINPEG excavations placed in the sites of Zacatal, Isla, Pedernal, El Mirador, Nakbe, La Florida, Tintal, La Muerta, Tsabkan, Witznal, Maaxte, Kan Chan, Guiro, and Wakna have not located these soils in a natural state. Further, several stratigraphic profiles in our excavations (Operations 510A, 511A, 511B, 31X) demonstrated that the mud (with artifacts) was placed over existing A-horizon soils and floors, thus confirming the intrusive nature of the deposit. The Palma causeway at Nakbe extends to the south from the East Group and ends precisely in the southern *bajo*, which suggests that the causeway may have facilitated transportation of *bajo* muck, among other resources, into the civic center. Similar parallels for causeway use for stone transportation are based on the fact that a large number of quarries are adjacent to the causeways.

## ECOLOGY AND SOCIETAL COLLAPSE

The evidence for intensive agriculture, sustained and expanding growth, and large-scale development during the Preclassic period is evident from both synchronic and diachronic perspectives in the Mirador Basin. This model of reasonably moderate stability begs a question: What were the factors that led to the demise and ultimate collapse of the social, political, and economic systems that had maintained the society? Some scholars have attempted to explain such collapse phenomena as the result of an overbearing or top-heavy elite or of endemic warfare. However, a survey of world cultures suggests that there is no evidence that bureaucratic bungling or warfare have ever created large-scale abandonment that persisted for centuries. The only models that can attest reliably to large-scale abandonment are ecological and/or climatic in nature. The causes of the particular environmental degradation in the Mirador Basin are varied, complex, and beyond the scope of this paper, but it will suffice to note that RAINPEG investigations have identified data suggesting that massive sedimentation of wetland marshes occurred at the close of the Late Preclassic period (ca. A.D. 150), in much the same fashion that C. Wythe Cooke (1931) proposed for the supposed *bajo* lakes. As Ricketson and Ricketson (1937:11) suggested,

> [T]he erosion of loam and surface soil . . . should receive great emphasis. . . . But in the erosion of the surface soil, a civilization dependent upon agriculture would be starved to death irrespective of any secondary causes, though these secondary

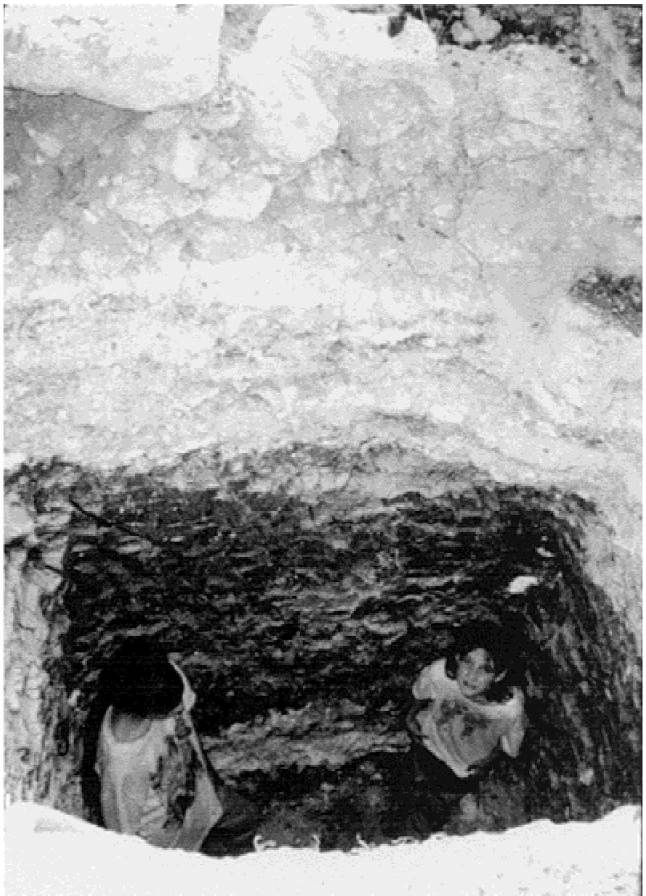

**Figure 19.** Operation 31X at Nakbe, showing 2.5 vertical meters of imported dark brown clay adjacent to Structure 31, West Group, Nakbe.

> causes may well have accelerated the impending doom. The theory has certain features which render it more plausible than others to the writer.

However, the loss of surface soil (see Paine and Freter 1996; Jacobs 1995a) may not have been as crucial as the sedimentation and depositional burial of the source of renewable agricultural soils—the marsh mucks in the swamps surrounding the sites. Evidence suggests that lime and stucco production are very likely to have contributed to, and may have been responsible for, the extensive deforestation that accompanied the loss of upland soils and clays (Hansen 1995; E. Hansen 2000; Schreiner 2001, 2002). The environmental degradation of the wetland marshes, combined with an additional external stress such as drought or extreme moisture, brought long-term and devastating results to the complex societies in the Mirador Basin.

## CLIMATE DATA AND EVIDENCE OF CHANGES

The evidence for climate changes in the Mirador Basin is much more tenuous, and major investigative research is now under way using large core samples obtained from permanent lakes near the edge of the basin. Although periods of drought and abundant precipitation have sporadically confronted almost every major society, there is limited evidence for climatic change in the Maya Lowlands that may have provided a strong external stress for the Lowland Maya during the latter part of the Late Preclassic period (A.D. 150–A.D. 250) (Brenner et al. 2000; Dahlin 1983, 1993; Dahlin et al. 1991, 1992; Leyden et al. 1996; Whitmore et al. 1996). A similar situation may also have confronted the terminal Late Classic Maya (see Dahlin 1995; Gill 2000; Leyden et al. 1998). This possible drought phenomena may have affected riverine discharge rates and provided a climate stress in the dynamics of complex society in the Mirador Basin. Because of the lack of adequate surface exploration in southern Campeche, there has been some confusion about whether the northern Peten is associated with the Hondo River drainage system (Xmoscha River) (Tamayo and West 1964:Figure 2), or the Candelaria drainage to the northwest (Shupe 1989). RAINPEG surface explorations, observations of water flow in the *bajos* during wet periods, and aerial observations of water channels suggest that the primary water flow is to the northwest, via the Paixban River and into the Candelaria system. The Candelaria is probably the primary drainage system for the Mirador Basin, although stream flows near sites along the western fringe of the basin suggest at least some flow into the San Pedro–Usumacinta drainage. Recent research on the discharge rates of the Candelaria River from 1958 to 1984 and the associated global temperature patterns as determined by a Global Energy Balance show interesting correlations of climate, global temperature, and quantity of rainfall (Gunn et al. 1994). According to the model, the lower the global temperature, the smaller the amount of precipitation that falls in the tropical lowlands of Mesoamerica. The extrapolation of the pluvial discharge and associated temperatures during the Holocene period by Gunn and colleagues (Gunn 1985; Gunn et al. 1994:184–185) indicates that the maximum periods of global cooling, ca. A.D. 100 and A.D. 815, were also associated with minimum discharge rates in the Candelaria River system. Similar evidence for a cooling and desiccation period for the Late Classic period was suggested independently in Folan et al. (1983). This suggests that minimal precipitation would have been falling during major periods of abandonment (terminal Late Preclassic, Terminal Classic) in the lowlands and correlates with evidence for a period of desiccation in the Yucatan at the close of the Late Preclassic period (Brenner et al. 2000; Dahlin 1983, 1993; Dahlin et al. 1991, 1992; see also Gill 2000).

Pohl notes that the opposite effect may have occurred in the terminal Preclassic and perhaps the Early Classic period in Belize, where she notes a "rise in water level along the lower courses of rivers . . . perhaps in response to sea level rise" (Pohl 1990:189). This apparent paradox is worthy of more analysis, particularly in light of evidence that the marshlands in the Mirador Basin were inundated by a dense layer of clay from upland areas. If intense sedimentation occurred because of extensive deforestation, the case for too much moisture may prove to be more applicable. Even if drought conditions were to occur, the ever pervasive opportunity for a major storm, such as a hurricane, could have created the massive sedimentation implicated, as was the case with Hurricane Mitch in Honduras and Guatemala. Such a possibility can be tested archaeologically. The buried A-horizon, which was the source of imported mucks and other agricultural manipulations, would have been much more difficult to acquire and thus rendered the area incapable of maintaining large-scale populations that had thrived in the Preclassic periods in the basin.

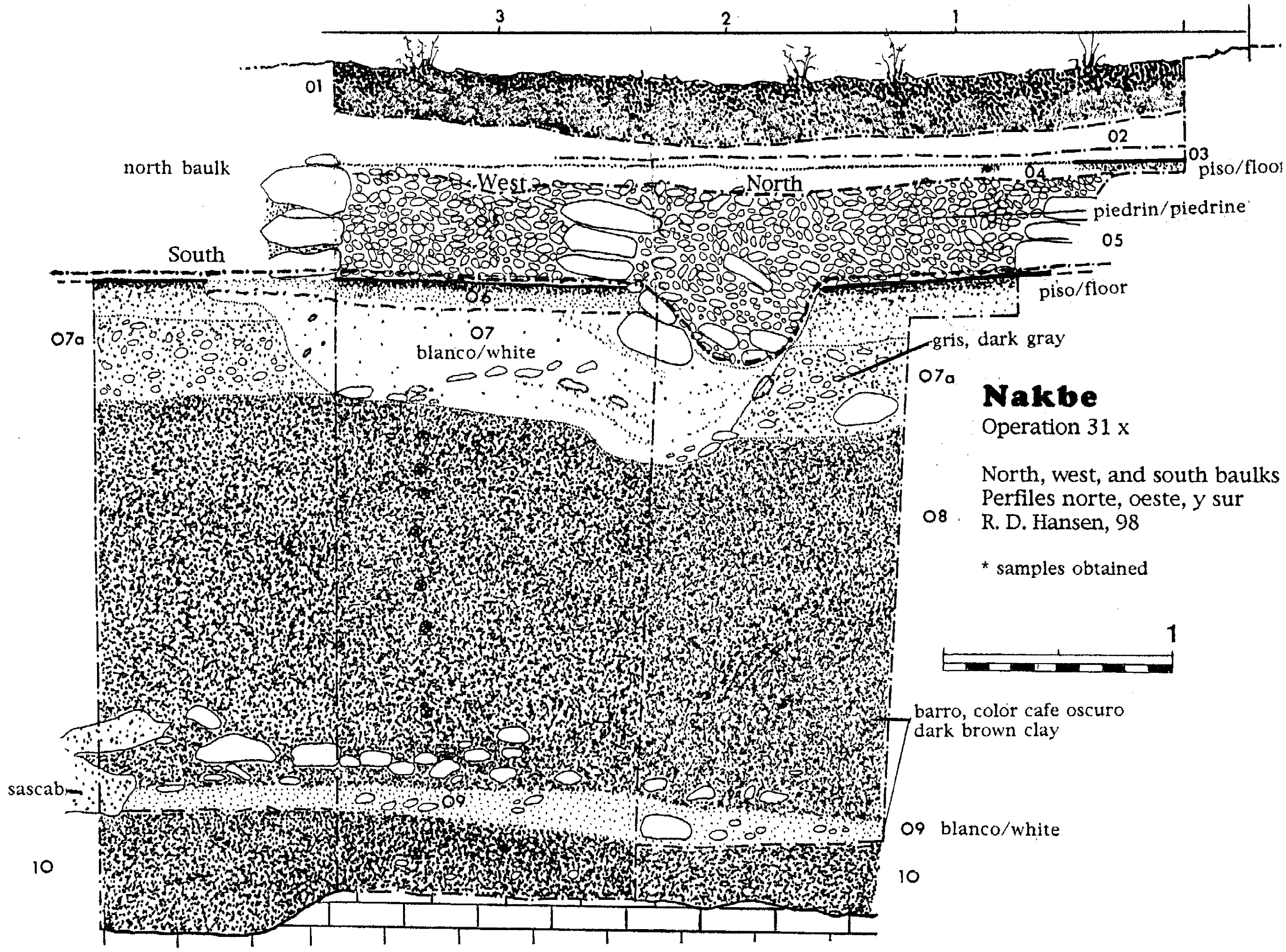


**Figure 20.** Drawing of western profile of Operation 31X at Nakbe, showing the dark brown imported clays above a lime and *sascab* Middle Preclassic floor (after Hansen 2000).

Independent studies of the composition, pollen, and influx rates for dated sediment zones in cores from the more distant lakes Yaxha and Sacnab indicate a substantial decrease in the percentages of arboreal pollen at the close of the Late Preclassic (compatible with deforestation models) and beginning of the Early Classic period, as well as at the close of the Late Classic period (Deevey et al. 1979:302; Rice et al. 1985; Figure 22). This suggests that large-scale deforestation, whether by artificial means or by environmental restriction, had occurred in the region by the Early Classic period, with “sharply accelerated slopewash and colluviation, amplified in the Yaxha sub-basin by urban construction, transferred nutrients plus calcareous, silty clay to both lakes” (Deevey et al. 1979:298; this is compatible with excessive moisture models). In addition, limnological, palynological, and paleolimnological work at several *aguadas* in the Peten savannas have indicated that a reforestation had occurred at the demise of the Late Classic period and at the period of European contact (Brenner et al. 1990). These data, combined with the material from the Yaxha region, suggest that deforestation in the Late Classic period was associated proportionately with population growth (see Abrams and Rue 1988), and may have been accompanied by some sort of climatic stress manifest in the form of increased influxes of sediments and colluviation in lakes, basins, and *bajos*. These factors apparently formed an external stress facing Late Classic inhabitants in the Yaxha–Sacnab area and the Peten savanna region, and it is our contention that similar factors were in place at the close of the Late Preclassic period nearly 700 years earlier.

Cowgill and Hutchinson derived the proposal that a climatic oscillation occurred somewhere in the first millennium B.C. on the basis of the maximum presence of chloride, when there was a “temporary increase in rainfall, perhaps followed by a decrease below the modern level” (Cowgill and Hutchinson 1963:39). The increase in rainfall “might have occurred when the surface of the *bajo* lay about 100 centimeters lower than it does today” (Cowgill and Hutchinson 1963:39), which would place the maximum rainfall around 500 B.C., followed by a drying period that, on the basis of sedimentation levels in the *bajos* surrounding Nakbe, could have occurred shortly after the turn of the millennium.

**Figure 21.** Excavations of check dams in arroyos at Nakbe have revealed dramatic variations between imported mud soils (background) and the naturally accruing soils in the foreground. These dams were used to contain soils in areas most receptive to water flows.

## CONCLUSIONS

These data provide working hypotheses that the *bajos* surrounding the dominant Preclassic sites of the Mirador Basin were, at the time of prime Preclassic occupation, tropical wetland marshes capable of providing a wide range of resources that were attractive to the early pioneers of the basin in about 1000 B.C., if not earlier. Archaeological data indicate that the wetland marshes were of prime importance in the development of agricultural systems at Nakbe, because imported soils were crucial to the agricultural success of civic-center terrace-garden systems. This system ultimately was challenged by an environmental stress wrought in part by the demand for lime and stucco manufacture. Additional data from the Mirador Basin, as well as from other areas of the Maya Lowlands, suggest that climate stress may have further challenged the strained ecosystem because of increased sedimentation of marshland environments.

We suggest that the processual evolution from lakes to tropical marshlands or *civales*, then into *bajos*, is a process that is in motion in the tropical forests of the northern Peten today. Further, the fact that the northwestern Peten is now the zone of greater *cival* areas raises the intriguing possibility that, if the Maya occupants of the great Preclassic centers were surveying their ecological landscape today, they would be more inclined to establish settlements in the marshy northwestern area than in the inhospitable *bajos* of the north-central Peten. Although information on the sites and settlement distribution in northwestern Peten is still inadequate, available information suggests that settlements were smaller, with less Preclassic presence, and more dispersed (Leal Rodas et al. 1988), which is compatible with the more lacustrine environment that would have been present at that time. This has potential implications for the large groups of contemporary Maya who are currently seeking settlement zones by cutting and clearing vast tracts of tropical forest (see Wilk 1985). Settlement in the wet marshland areas of the northwestern Peten may substantially reduce the amount of deforestation currently taking place in northern Guatemala and may provide more adequate agricultural production through use of the marshland systems, in much the same way that ancient inhabitants exploited wetland marshes. Experiments to this effect have begun in Carmelita, where a series of elevated terraces have been built with imported mud from an adjacent wetland marsh. Preliminary results demonstrate the agricultural superiority of this system in terms of productivity and longevity of production.

As multiple avenues of investigation have proceeded in the Mirador Basin, new perspectives have emerged about role of environmental change in the rise and demise of complex societies. Additional data on climate change and the adaptive response of the early Maya are currently being processed. However, there is no doubt that the great *bajos* and wetland marshes of the northern Peten are crucial to understanding the rise of sociopolitical and economic complexity of the great ancient centers of the Mirador Basin.

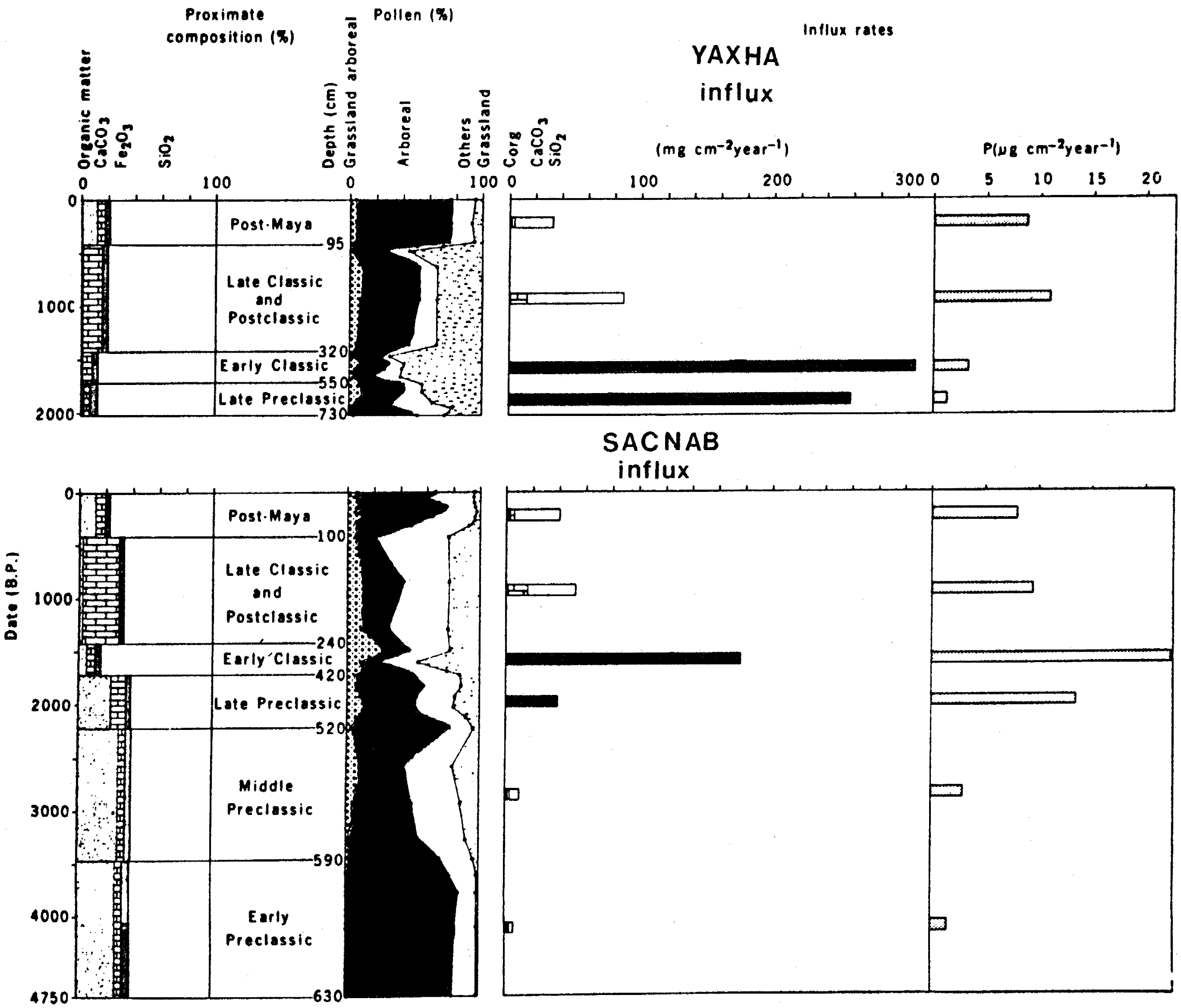


**Figure 22.** Drawing of soil-influx rates and pollen correlations into the lakes of Yaxha and Sacnab (from Deevey et al. 1979).

## RESUMEN

Recientes investigaciones en la Cuenca Mirador en el norte del Petén, Guatemala, han revelado los restos arqueológicos que muestran un alto grado de complejidad cultural en los períodos Preclásico Medio y Preclásico Tardío (1000–350 a.C., 350 a.C–150 d.C). Esta complejidad es evidente en la densidad y tamaño de los sitios, evidencia de sistemas de intercambio, arquitectura mayor y monumentos de piedra tallados y estucados. Lo irónico de estos asentamientos tan grandes es que se encuentran circundados por una alta cantidad de bajos. Los bajos actuales impiden asentamientos modernos por causa de suelos inadecuados, inundaciones, sequias, y bosques dificiles de cortar.

Nuestros datos sugieren que hubo un cambio ambiental en la Cuenca Mirador. En los períodos preclásicos, parece que los bajos eran pantanos húmedos. Estos pantanos eran sistemas lacustres agónicos que formaban los recursos naturales y agrícolas necesarios. Los restos fósiles de estos pantanos húmedos, llamados civales, todavía se encuentran en los bajos de la Cuenca Mirador. Excavaciones e investigaciones en los bajos, con análisis de suelos, botánicos, isótopos, fitolitos, polen, secuencia botánica, y perfiles estratigráficos, demuestran que los primeros Mayas aprovecharon los ricos recursos lacustres de los pantanos para abastecer estos sitios tan grandes. En particular, los Mayas transportaron enormes cantidades de lodo desde los pantanos para establecer terrazas agrícolas en los centros cívicos. Estos sistemas agrícolas intensivos se encuentran identificados en Nakbe y la cantidad de terrazas y campos agrícolas indican la importancia del lodo importado en el desarrollo de los sitios preclásicos. Sin embargo, la pérdida de bosque y la inundación de estas fuentes de lodo por sedimentos de barro desde los terrenos más altos coinciden con el abandono de los sitios a finales del Preclásico Tardío (ca. 150 d.C.).

Proponemos que los pantanos húmedos servían como una atracción para los pioneros Mayas y que el desarrollo cultural en la Cuenca Mirador fue en base de sistemas agrícolas. El cambio ambiental de los bajos está relacionado con el abandono de sitios en el Preclásico Tardío en la Cuenca Mirador. El estrés climatológico y la degradación ambiental por parte de la ocupación humana, pudieron haber sido responsables por un colapso sociopolítico y económico. La inundación de las fuentes de lodo en los pantanos húmedos posiblemente fue un factor en el abandono de los sitios preclásicos mayores. Los estudios actuales están enfocados en el entendimiento de los sistemas ambientales que existieron en el preclásico y la relación del impacto humano y climático en la historia del desarrollo cultural en la Cuenca Mirador.

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## REFERENCES

Abrams, Eliot, and David Rue
1988 The Causes and Consequences of Deforestation among the Prehistoric Maya. *Human Ecology* 16:377–395.

Bozarth, Steven
2000 Análisis de fitolitas de opalo en un jardín de la realeza de Nakbe, sitio Maya preclásico, Guatemala. In *Investigaciones arqueológicas y ecológicas en la Cuenca Mirador, 1998: Informe de la temporada de campo*, edited by Richard D. Hansen and Judith Valle, pp. 567–598. Proyecto Regional de Investigaciones Arqueológicas del Norte del Peten, Guatemala (PRIANPEG). Report on file, Instituto de Antropología e Historia de Guatemala, Monumentos Prehispánicos, Guatemala.

Bozarth, Steven, and Richard D. Hansen
2001 Estudios paleo-botánicos de Nakbe: Evidencias preliminares de ambiente y cultivos en el preclásico. In *XIV Simposio de Investigaciones Arqueológicas en Guatemala*, edited by Juan Pedro Laporte, Ana C. de Suasnavar, and Barbara Arroyo, pp. 419–436. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal.

Brenner, Mark, Barbara Leyden, and Michael W. Binford
1990 Recent Sedimentary Histories of Shallow Lakes in the Guatemalan Savannas. *Journal of Paleolimnology* 4:239–252.

Brenner, Mark, Barbara W. Leyden, Jason H. Curtis, Bruce H. Dahlin, and Rosa M. Medina Gonzalez
2000 Un registro de 8000 años del paleoclima del noroeste de Yucatan, Mexico. *Revista de la Universidad Autónoma de Yucatan* 15(213):53–65.

Castañeda, César, and César Castañeda Cerna
1994 Evidencias floristicas de la dinámica Lacustre (Pantanosa) en el area de Nakbe, Peten. In *Investigaciones arqueológicas en Nakbe, Peten: El resumen de la temporada de Campo de 1993*, edited by Richard D. Hansen, pp. 139–151. Report filed with the Instituto de Antropología e Historia de Guatemala, Monumentos Prehispánicos, Guatemala.

Castañeda Salguero, César
1995 *Sistemas lacustres de Guatemala: Recursos que mueren*. Editorial Universitaria, Universidad de San Carlos, Guatemala.

Cooke, C. Wythe
1931 Why the Mayan Cities of the Peten District, Guatemala, Were Abandoned. *Journal of the Washington Academy of Sciences* 21(13): 283–287.

Cowgill, Ursula M., and G.E. Hutchinson
1963 El Bajo de Santa Fe. *Transactions of the American Philosophical Society* 53(7):1–51.

Culbert, T. Patrick, Laura J. Levi, and Luis Cruz
1989 The Rio Azul Agronomy Program, 1986 Season. In *Rio Azul Reports Number 4, the 1986 Season*, edited by R.E.W. Adams, pp. 189–214. University of Texas, San Antonio.
1990 Lowland Maya Wetland Agriculture. In *Vision and Revision in Maya Studies*, edited by Flora Clancy and Peter D. Harrison, pp. 115–124. University of New Mexico Press, Albuquerque.

Culbert, T. Patrick, Laura J. Levi, Brian McKee, and Julie Kunen
1996 Investigaciones arqueológicas en el Bajo La Justa, entre Yaxha y Nakum. In *IX Simposio de Investigaciones Arqueológicas en Guatemala, 1995*, edited by Juan Pedro Laporte and Hector L. Escobedo, pp. 51–57. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal.

Dahlin, Bruce H.
1983 Climate and Prehistory on the Yucatan Peninsula. *Journal of Climate Change* 5:245–263.
1993 Climate and the Collapse of Preclassic Maya Civilization. Paper presented at the 65th Annual Meeting of the American Association for the Advancement of Science, San Francisco.
1995 Climate and the Collapse of Late Classic Maya Civilization. Paper presented at the 65th Annual Meeting of the American Anthropological Association, Washington, DC.

Dahlin, Bruce H., Mark Brenner, Barbara Leyden, and Jason H. Curtis
1992 Preclassic and Early Classic Period Climate Change at San Jose Chulchaca, N.W. Yucatan. Paper presented at the 58th Annual Meeting of the Society for American Archaeology, Pittsburgh.

Dahlin, Bruce H., John E. Foss, and Mary Elizabeth Chambers
1980 Project Acalches: Reconstructing the Natural and Cultural History of a Seasonal Swamp at El Mirador, Guatemala: Preliminary

Results. In *El Mirador, Peten, Guatemala: An Interim Report*, edited by Ray T. Matheny, pp. 37–57. Papers of the New World Archaeological Foundation No. 45. Provo, UT.

Dahlin, Bruce H., Barbara Leyden, Mark Brenner, and Jason H. Curtis.
1991 Climate Change at San Jose Chulchaca during the Preclassic and Early Classic Periods. Paper presented at the Conference on Ancient Maya Agriculture and Biological Resource Management, University of California, Riverside.

Deevey, Edward. S. Jr., Don S. Rice, Prudence M. Rice, H.H. Vaughan, Mark Brenner, and M.S. Flannery
1979 Mayan Urbanism: Impact on a Tropical Karst Environment. *Science* 206:298–306.

Dominguez, Maria del Rosario
1993 Calakmul, Campeche y su sistema hidraúlico. In *Los investigadores de la cultura Maya*, edited by William J. Folan, pp. 42–46. Universidad Autónoma de Campeche, Mexico.

Fedick, Scott L.
1988 *Prehistoric Maya Settlement and Land Use Patterns in the Upper Belize River Area, Belize, Central America.* Ph.D. dissertation, Arizona State University, Tempe. University Microfilms, Ann Arbor.

Fedick, Scott L. (editor)
1996 *The Managed Mosaic: Ancient Maya Agriculture and Resource Use*. University of Utah Press, Salt Lake City.

Folan, William J., and Silverio Gallegos
1992 Uso prehispánico del suelo. *Programa de manejo reserva de la biósfera Calakmul, Campeche*, edited by William J. Folan, J. García Ortega, and M. Sánchez. Universidad Nacional Autónoma de México.

Folan, William J., Joel D. Gunn, Jack D. Eaton, and Robert W. Patch
1983 Paleoclimatological Patterning in Southern Mesoamerica. *Journal of Field Archaeology* 10:453–468.

Fomentos y Desarrollo del Petén
1968 *Mapa de los suelos de El Peten*. Proyecto de Evaluación Forestal, FAO-FYDEP. Fomentos y Desarrollo del Petén, Instituto Geográfico Nacional, Guatemala City.

Gill, Richardson B.
2000 *The Great Maya Droughts: Water, Life, and Death*. University of New Mexico Press, Albuquerque.

Gunn, Joel D.
1985 *Climod, Version 3.02: Modeling Climate/Culture Change, User's Guide.* BCS Corporation, San Antonio, TX.

Gunn, Joel D., William J. Folan, and Hubert R. Robichaux
1994 Un análisis informativo sobre la descarga del sistema del Rio Candelaria en Campeche, Mexico: Reflexiones acerca de los paleoclimas que afectaron los antiguos sistemas Mayas en los sitios de Calakmul y El Mirador. In *Campeche Maya colonial*, edited by William J. Folan, pp. 174–197. Universidad Autónoma de Campeche, Mexico.

Hansen, Eric F.
2000 *Ancient Maya Burnt-Lime Technology: Cultural Implications of Technological Styles.* Ph.D. dissertation, Department of Archaeology, University of California, Los Angeles.

Hansen, Richard D.
1995 *Early Environmental Impact: The Ecological Consequences of Incipient Maya Settlement.* Report submitted to the National Geographic Society, NGS 4984-93.
1998 Continuity and Disjunction: Preclassic Antecedents of Classic Maya Architecture. In *Function and Meaning in Classic Maya Architecture*, edited by Stephen D. Houston, pp. 49–122. Dumbarton Oaks, Washington, DC.
2000 Una nota de la excavación de Campos Agricolas: La Operación 31X. In *Investigaciones arqueológicas y ecológicas en la Cuenca Mirador, 1998: Informe de la temporada de Campo*, edited by Richard D. Hansen and Judith Valle, pp. 235–246. PRIANPEG, UCLA RAINPEG, FARES, Rupert, ID.
2001 The First Cities—The Beginnings of Urbanization and State Formation in the Maya Lowlands. In *Maya: Divine Kings of the Rain Forest*, edited by Nikolai Grube, pp. 50–65. Konemann-Verlag, Germany.

Hansen, Richard D., Gustavo Martinez, John Jacob, and Wayne K. Howell
2000 Cultivos intensivos: Sistemas agrícolas de Nakbe. In *Investigaciones arqueológicas y ecológicas en la Cuenca Mirador, 1998: Informe de la temporada de Campo*, edited by Richard D. Hansen and Judith Valle, pp. 687–700. PRIANPEG. Report on file, Instituto de Antropología e Historia de Guatemala, Monumentos Prehispánicos, Guatemala.

Harrison, Peter D.
1977 The Rise of the Bajos and the Fall of the Maya. In *Social Process in Maya Prehistory: Studies in Honour of Sir Eric Thompson*, edited by Norman Hammond, pp. 469–508. Academic Press, London.
1978 Bajos Revisited: Visual Evidence for One System of Agriculture. In *Prehispanic Maya Agriculture*, edited by Peter D. Harrison and Bruce L. Turner, pp. 247–253. University of New Mexico Press, Albuquerque.
1996 Settlement and Land Use in the Pulltrouser Swamp Archaeological Zone, Northern Belize. In *The Managed Mosaic: Ancient Maya Agriculture and Resource Use*, edited by Scott L. Fedick, pp. 177–190. University of Utah Press, Salt Lake City.

Jacob, John
1994 Evidencias para cambio ambiental en Nakbe, Guatemala. In *VII Simposio Arqueológico de Guatemala*, edited by Juan Pedro Laporte, Hector L. Escobedo, and Sandra Villagran de Brady, pp. 275–280. Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Museo Nacional de Arqueología y Etnología.
1995a Ancient Maya Wetland Agricultural Fields in Cobweb Swamp, Belize: Construction, Chronology, and Function. *Journal of Field Archaeology* 22(2):175–190.
1995b Archaeological Pedology in the Maya Lowlands. *Pedological Perspectives in Archaeological Research*, edited by M. Collins, pp. 51–82. Soil Science Society of America Special Publications, Madison, WI.
2000 Informe de las Operaciones 801C, 801B, 801A, Nakbe: Temporada 1998. In *Investigaciones arqueológicas y ecológicas en la Cuenca Mirador, 1998: Informe de la temporada de Campo*, edited by Richard D. Hansen and Judith Valle, pp. 515–519. PRIANPEG. UCLA RAINPEG, FARES, Rupert, ID.

Jones, John G.
1991 *Preliminary Pollen Testing and Evaluation of Eight Samples, Nakbe, Peten, Guatemala.* Report on file, Department of Soil and Crop Sciences, Texas A&M University and FARES, Rupert, ID.

Leal Rodas, Marco Antonio, Salvador Lopez Aguilar, Maria Teresita Chinchilla, Jose Hector Paredes G., Jose Enrique Benitez, and Mario E. Zetina Aldana
1988 *Reconocimiento arqueológico en el noroccidente de Peten*. Instituto de Investigaciones Históricas, Antropológicas, y Arqueológicas, Vol. 1. Escuela de Historia, Universidad de San Carlos de Guatemala.

Leyden, Barbara
1994 *Nakbe, Cibal Madre, and Zacatal Sites, Pollen Analysis.* Report on file, FARES, Rupert, ID.

Leyden, Barbara W., Mark Brenner, Tom Whitmore, Jason H. Curtis, Dolores R. Piperno, and Bruce H. Dahlin
1996 A Record of Long- and Short-Term Climatic Variation from Northwest Yucatan: Cenote San Jose Chulchaca. In *The Managed Mosaic: Ancient Maya Agriculture and Resource Use*, edited by Scott L. Fedick, pp. 30–50. University of Utah Press, Salt Lake City.

Leyden, Barbara W., Mark Brenner, and Bruce H. Dahlin
1998 Cultural and Climatic History of Coba, a Lowland Maya City in Quintana Roo, Mexico. *Quaternary Research* 49:111–122.

Lundell, Cyrus Longworth
1937 *The Vegetation of Peten.* Carnegie Institution Publication No. 478. Carnegie Institution of Washington, Washington, DC.

Martinez Hidalgo, Gustavo, Richard D. Hansen, John Jacob, and Wayne K. Howell
1999 Nuevas evidencias de los sistemas de cultivo del preclásico en la Cuenca El Mirador. *XII Simposio de Investigaciones Arqueológicas en Guatemala*, edited by Juan Pedro Laporte, Hector L. Escobedo, and Ana Claudia M. de Suasnavar, pp. 327–336. Museo Nacional de Arqueología y Etnología, Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal.

Madeira, Percy C., Jr.
1931 An Aerial Expedition to Central America. *Museum Journal* 22(2):93–153. Museum of the University of Pennsylvania, Philadelphia.

Matheny, Ray T.
1976 Maya Lowland Hydraulic Systems. *Science* 193:639–646.

1978 Northern Maya Lowland Water-Control Systems. In *Pre-Hispanic Maya Agriculture*, edited by Peter D. Harrison and Bruce L. Turner, pp. 185–210. University of New Mexico Press, Albuquerque.
1982 Ancient Lowland and Highland Maya Water and Soil Conservation Strategies. In *Maya Subsistence: Studies in Memory of Dennis E. Puleston*, edited by Kent V. Flannery, pp. 157–178. Academic Press, New York.

Metcalfe, Sara Elizabeth, Roy Bernard Brown, Phillet E. Hales, Robert Alaine Perrott, F.M. Steininger, and Francis Alaine Street-Perrott
1990 Arqueología de cuencas lacustres: El impacto human en Guanajuato y Michoacan. *Arqueologia* 4:3–14.

Miller, W. Frank, Thomas L. Sever, and Daniel Lee
1991 Applications of Ecological Concepts and Remote Sensing Technologies in Archaeological Site Reconnaissance. In *Applications of Space Age Technology in Anthropology: November 28, 1990 Conference Proceedings*, edited by C.A. Behrens and Thomas L. Sever, pp. 121–136. National Aeronautics and Space Administration Science and Technology Laboratory, John C. Stennis Space Center, New Orleans, MS.

Paine, Richard R., and AnnCorinne Freter
1996 Environmental Degradation and the Classic Maya Collapse at Copan, Honduras (A.D. 600–1250). *Ancient Mesoamerica* 7:37–47.

Pohl, Mary DeLand (editor)
1990 *Ancient Maya Wetland Agriculture: Excavations on Albion Island, Northern Belize.*. Westview Press, Boulder, CO.

Pohl, Mary, and Paul Bloom
1996 Prehistoric Maya Farming in the Wetlands of Northern Belize: More Data from Albion Island and Beyond. In *The Managed Mosaic: Ancient Maya Agriculture and Resource Use*, edited by Scott L. Fedick, pp. 145–164. University of Utah Press, Salt Lake City.

Pohl, Mary DeLand, Paul R. Bloom, and Kevin O. Pope
1990 Interpretation of Wetland Farming in Northern Belize: Excavations at San Antonio Rio Hondo. In *Ancient Maya Wetland Agriculture: Excavations on Albion Island, Northern Belize*, edited by Mary DeLand Pohl, pp. 187–254. Westview Press, Boulder, CO.

Pope, Kevin D., and Bruce H. Dahlin
1989 Ancient Maya Wetland Agriculture: New Insights from Ecological and Remote Sensing Research. *Journal of Field Archaeology* 16(1):87–106.

Pope, Kevin O., Mary D. Pohl, and John S. Jacob
1996 Formation of Ancient Maya Wetland Fields: Natural and Anthropogenic Processes. In *The Managed Mosaic: Ancient Maya Agriculture and Resource Use*, edited by Scott L. Fedick, pp. 165–176. University of Utah Press, Salt Lake City.

Rice, Don S., Prudence M. Rice, and Edward S. Deevey, Jr.
1985 Paradise Lost: Classic Maya Impact on a Lacustrine Environment. In *Prehistoric Lowland Maya Environment and Subsistence Economy*, edited by Mary Pohl, pp. 91–105. Papers of the Peabody Museum of Archaeology and Ethnology, Vol. 77. Harvard University, Cambridge, MA.

Ricketson, Oliver G., Jr., and Edith Bayles Ricketson
1937 *Uaxactun, Guatemala: Group E-1926–1931*. Carnegie Institution of Washington Publication No. 477. Washington, DC.

Romero Zetina, Juan L., and Thomas Schreiner
2000 Estudios de las zonas ecológicas de Zacatal, Aguada Maya, Nakbe, Peten, Guatemala. In *Investigaciones arqueológicas y ecológicas en la Cuenca Mirador, 1998: Informe de la temporada de Campo*, edited by Richard D. Hansen and Judith Valle, pp. 520–530. PRIANPEG). UCLA RAINPEG, FARES, Rupert, ID.

Scarborough, Vernon L.
1993 Water Management Systems in the Southern Maya Lowlands: An Accretive Model for the Engineered Landscape. In *Economic Aspects of Water Management in the Prehispanic New World*, edited by Vernon L. Scarborough and B.L. Isaac, pp. 17–69. Research in Economic Anthropology, Supplement 7. JAI Press, Greenwich, CT.
1998 Ecology and Ritual: Water Management and the Maya. *Latin American Antiquity* 9(2):135–159.

Scarborough, Vernon L., and Gary G. Gallopin
1991 A Water Storage Adaptation in the Maya Lowlands. *Science* 251:658–662.

Schreiner, Thomas
2001 Fabricación de cal en Mesoamérica: Implicaciones para los Mayas del preclásico en Nakbe, Peten. In *XIV Simposio de Investigaciones Arqueológicas en Guatemala*, edited by Juan Pedro Laporte, Ana Claudia de Suasnavar, and Barbara Arroyo, pp. 405–418. Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Museo Nacional de Arqueología y Etnología, Guatemala.
2002 *Traditional Maya Lime Production: Environmental and Cultural Implications of a Native American Technology.* Ph.D. dissertation, Department of Architecture, University of California, Berkeley.

Schreiner, Thomas, and David Wahl
2000 Muestras sedimentarias y investigaciones arqueológicas y botánicas en la Aguada Zacatal, Nakbe, Peten, Guatemala: Operación 900. In *Investigaciones arqueológicas y ecológicas en la Cuenca Mirador, 1998: Informe de la temporada de campo*, edited by Richard D. Hansen and Judith Valle, pp. 531–544. PRIANPEG. UCLA RAINPEG, FARES, Rupert, ID.

Shupe, John F.
1989 *Land of the Maya: A Traveler's Map*. National Geographic Society, Washington, DC.

Siemens, Alfred H.
1978 Karst and the Pre-Hispanic Maya in the Southern Lowlands. In *Pre-Hispanic Maya Agriculture*, edited by Peter D. Harrison and Bruce H. Turner, pp. 117–143. University of New Mexico Press, Albuquerque.
1982 Prehispanic Agricultural Use of the Wetlands of Northern Belize. In *Maya Subsistence: Studies in Memory of Dennis E. Puleston*, edited by Kent V. Flannery, pp. 205–225. Academic Press, New York.

Siemens, Alfred H., and Dennis E. Puleston
1972 Ridged Fields and Associated Features in Southern Campeche: New Perspectives on the Lowland Maya. *American Antiquity* 37:228–239.

Simmons, C., S. Tarano, and J. Pinto
1959 *Clasificación de reconocimiento de los suelos de la República de Guatemala*. Editorial del Ministerio de Educación Pública, Guatemala City.

Stevens, Rayfred L.
1964 The Soils of Middle America and their Relation to Indian Peoples and Cultures. In *Natural Environment and Early Cultures*, edited by R.C. West, pp. 265–315. Handbook of Middle American Indians, Vol. 1. University of Texas Press, Austin.

Tamayo, Jorge L., and Robert C. West
1964 The Hydrography of Middle America. In *Natural Environment and Early Cultures*, edited by R.C. West, pp. 84–121. Handbook of Middle American Indians, Vol. 1. University of Texas Press, Austin.

Turner, Bruce L., II
1978 Ancient Agricultural Land Use in the Central Maya Lowlands. In *Pre-Hispanic Maya Agriculture*, edited by Peter D. Harrison and Bruce L. Turner, pp. 163–183. University of New Mexico Press, Albuquerque.

Wahl, David Brent
2000a *A Stratigraphic Record of Environmental Change from a Maya Reservoir in the Northern Peten, Guatemala.* M.A. thesis, Geography Department, University of California, Berkeley.
2000b Evidencia de polen de la caída de la cultura Maya de una represa en el norte del Peten, Guatemala (abstract). *GEOS, Unión Geofísica Mexicana, A.C.: Estudios del Cuaternario* 20(3).
2000c Pollen Evidence of the Classic Maya Collapse from a Bajo Reservoir in the Northern Peten, Guatemala. *Abstracts of the 65th Annual Meeting of the Association of Pacific Coast Geographers, September 19–23, 2000*, p. 206.
2001 Pollen Evidence of the Classic Maya Collapse from a Bajo Reservoir in the Northern Peten, Guatemala. Poster presented at the 21st Symposium in Plant Biology, University of California, Riverside, January 18–20.

Wahl, David, Thomas Schreiner, and Roger Byrne
2000 A Stratigraphic Record of Environmental Change from a Maya Reservoir in the Northern Peten, Guatemala. In *Program Abstracts from Archaeometry: 32nd International Symposium, May 15–19, 2000*, p. 64. Conaculta–Instituto Nacional de Antropología e Historia, Universidad Nacional Autónoma de México, Mexico City.
2001 La secuencia ecológica de la Cuenca Mirador: La evidencia de polen. In *Abstractos del XV Simposio de Investigaciones Arqueológicas en Guatemala 16–20 July, 2001*, p. 28. Ministerio de Cultura y Deportes, Dirección General del Patrimonio Cultural y Natural, Instituto de Antropología e Historia, Museo Nacional de Arqueología y Etnología.

Weinstein, Eri
1994 Presence/Absence Analysis of Pollen Recovered from Nakbe, Guatemala Sediment Samples. In *Investigaciones arqueológicas en Nakbe, Peten: El resumen de la temporada de campo de 1993*, edited by Richard D. Hansen, pp. 346–348. Report filed with the Instituto de Antropología e Historia de Guatemala, Monumentos Prehispánicos.

Whitmore, Thomas H., Mark Brenner, Jason H. Curtis, Bruce H. Dahlin, and Barbara W. Leyden
1996 Holocene Climatic and Human Influences on Lakes of the Yucatan Peninsula, Mexico: An Interdisciplinary Approach. *The Holocene* 6(3):273–287.

Wilk, Richard R.
1985 Dry Season Agriculture among the Kekchi Maya and Its Implications for Prehistory. In *Prehistoric Lowland Maya Environment and Subsistence Economy*, edited by Mary Pohl, pp. 47–57. Papers of the Peabody Museum of Archaeology and Ethnology, No. 77. Harvard University, Cambridge, MA.

Wiseman, Frederick M.
1978 Agricultural and Historical Ecology of the Maya Lowlands. In *Pre-Hispanic Maya Agriculture*, edited by Peter D. Harrison and Bruce L. Turner, pp. 63–115. University of New Mexico Press, Albuquerque.