As scientists collect more paleoclimatic data from the Maya lowlands, two important facts have emerged: there has been significant regional variation in the paleoclimate of the Maya lowlands, and a long-lasting phase of decreased rainfall began around AD 800 in many areas of the lowlands. Archaeological research has proven that the social and political transformations that we usually call the Classic Maya collapse were also regionally variable in their timing and nature. Despite this variability, most areas of the Maya lowlands experienced changes of great magnitude between AD 750 and 950—changes that included significant demographic decline, shifts in settlement location, new trade patterns, political decentralization, and new political ideologies. The transformations of the ninth and tenth centuries changed the sociopolitical organization of the Maya lowlands in fundamental ways, and scholars have proposed many different models to explain them.

One factor that has received renewed attention is the role of climatic change. In this paper, we evaluate the archaeological evidence for the social and political transformations at the end of the Late Classic and Terminal Classic periods (ca. AD 700–1000) and the paleoclimatic data for that same period. We compare and contrast the data within and between the northern, central, and southern lowlands of the Yucatan Peninsula. The collapse was undoubtedly a complex process structured by many different factors, of which climatic change was important in many regions of the Maya lowlands. Demographic and environmental transformations such as population increase, deforestation, and topsoil erosion also influenced the collapse.

To understand the role that climatic and environmental change might have had, however, we must assess how such changes would have shaped people’s options and decision-making in the Classic Period. Thus, we discuss paleoclimatic data in light of environmental effects, and we evaluate the archaeological data for social and political transformations. In so doing, we explore the complex interactions among paleoclimate, environment, and culture that...
could have led to the collapse, and critically evaluate the difficulties of synthesizing data sets that are based on three different chronological frameworks (radiocarbon, ceramic chronology, and calendrical texts).

Pre-Columbian Maya civilization of the central and southern lowlands reached its apogee of social complexity during the Late Classic Period (AD 600–800). Scores of political centers, the capitals of rival polities, crowded a landscape marked by high population densities and were supported by a mosaic of intensive and extensive agricultural strategies. Inside these centers, members of the ruling elite lived in elaborate palaces and were laid to rest in sumptuous tombs deep in the hearts of funerary pyramids. With their unprecedented wealth and power, the divine kings or k’uhul ajawə’ of Maya polities sponsored skilled artisans who crafted elaborate objects for personal adornment and ceremonial use and gifted artists who carved hundreds of stone monuments depicting the political and ceremonial activities of the rulers and their elite peers and clients. Most of these monuments include hieroglyphic texts that describe these important events, recount the genealogies of the royal houses, and extol the legitimacy of the rulers as the leaders of their people.

Late in the eighth century AD, however, these polities began to undergo a series of radical changes that would transform Maya society in fundamental ways over the course of the next two centuries. These changes entailed a substantial demographic decline, the abandonment of most large centers, and the apparent disappearance of the ruling elite who are so salient in the archaeological record of the Classic Period. Although they occurred first in the central and southern lowlands, many regions in the northern lowlands underwent broadly parallel changes approximately fifty or seventy-five years later.

These pan-lowland changes are often termed the collapse of Classic Maya civilization or the Maya collapse, phrases that are useful shorthand references, but which also mask the complexity of the processes involved (see also Cowgill 1988). As new data have proven the existence of strong continuities from the Classic to Postclassic periods (Chase and Rice 1984; Sabloff and Andrews 1986), many scholars feel uncomfortable with the term collapse, given its connotations of disjunctive change and degeneration. Furthermore, it is now clear that different regions and sites went through very different trajectories in the ninth and tenth centuries, and some did not collapse at all (Demarest et al. 2004; Marcus 1995). This variability underscores the futility of trying to impose a unitary or eventlike model of collapse on the Maya lowlands. Recognizing this, we will use the term collapse advisedly to refer in a general way to the complex sets of processes that restructured Maya civilization in the lowlands in the two centuries following the Late Classic Period.

Scholars have proposed many different models to explain the collapse. In 1995, David Hodell and his colleagues (1995) reported the first physical evidence for a drought during the Terminal Classic Period in sediments from Lake Chichancanab in the north-central Yucatan Peninsula. The Chichancanab record indicated that this drought was one of the most severe of the last 7,000 years, leading to speculation that drought may have been a causal factor in the collapse. Since that time, the role of climatic change in the collapse has received renewed attention. Additional paleoclimatic records from the Maya lowlands have revealed important differences in the climatic histories of subregions of the Yucatan Peninsula during the Terminal Classic Period.

In this chapter, we review the archaeological evidence from the end of the Late Classic Period through the Terminal Classic Period (AD 800–1000) and the paleoclimatic data for that same period. We critically evaluate the drought hypothesis by comparing the timing, magnitude, and spatial extent of paleoclimatic and paleoenvironmental change with the social and political transformations in three regions of the Maya lowlands during the eighth through tenth centuries AD. This evidence suggests that the collapse was a complex process structured by many different factors, of which climatic change was important in many regions of the Maya lowlands.

THE CLASSIC MAYA COLLAPSE

The collapse has long been a topic of scholarly and popular debate, eliciting scores of explanations. Early models tended to focus on single causal factors, often events that were catastrophic in nature and timing (Sabloff 1992:102), such as a widespread peasant revolt (Thompson 1966), earthquakes (MacKie 1966), and epidemics. In contrast, other scholars argued that the collapse was the result of declining crop yields caused by gradual processes of environmental degradation such as the silting up of productive wetlands (Rickerson and Rickerson 1977) and savanna encroachment (Cooke 1991).

The 1970 Advanced Seminar at the School of American Research punctuated a shift in views of the collapse, as is evident from the contributions in the resulting publication, The Classic Maya Collapse (Culbert 1973). An expanding body of archaeological data suggested the collapse was best understood not as an abrupt event, but instead as a transformative process that took generations to play out. Consequently, the models postulated in the publication eschewed unicausal, prime-mover theories in favor of complex, multicausal explanations (e.g., Willey and Shimkin 1973). Most gave weight to social, political, and historical factors rather than environmental or climatic explanations, with few exceptions (e.g., Sanders 1972).

In the thirty years since the advanced seminar, studies of the collapse have largely followed the trajectory set forth therein, and most scholars continue to favor multicausal models that emphasize the social and political aspects of the collapse (Demarest et al. 2004). Although environmental changes—especially environmental degradation and soil exhaustion—continue to be invoked, these changes are often framed as the anthropogenic results of population growth and short-sighted, politically motivated managerial choices (e.g., Culbert 1988; cf. Turner 1990). In the last decade, however, scholars have begun to consider the role played by climatic change.
Climatic Change and the Collapse

Two factors have encouraged scholars to reassess the role of climatic change, especially decreased rainfall, in the ninth- and tenth-century transformations in the Maya lowlands. Perhaps the most important stimulus has been the accumulation since the 1980s of a great deal of paleoenvironmental data, including paleoclimatic data, discussed below. Maya archaeologists have begun to incorporate this information into their explanations of the collapse.

The other factor relates to the social context in which Maya archaeology is practiced. As Richard Wilk (1987) has noted, the factors that scholars invoke to explain the collapse correlate closely with the concerns that those researchers face in their daily lives. In the last decade, global warming and El Niño have become household phrases, and the United Nations Environment Programme (2002) found that weather-related natural disasters in the 1990s had doubled in frequency compared to the 1970s, costing some trillions of dollars. Within this context, it is not surprising that scholars are increasingly interested in understanding the role of climatic change and climatic fluctuations in social and cultural change across the globe (e.g., Brenner et al. 2002; deMenocal 2001; Diamond 2005; Fagan 1999; Weiss and Bradley 2001).

In the Maya area, Richard E. W. Adams (1997), William Folan (Folan et al. 1985a, 2000), Richardson Gill (2000), Joel Gunn (Gunn and Adams 1981; Gunn et al. 2002) and others (Dahlin 1985; Lucero 2002) have argued more specifically that long-lasting pan-lowland droughts were a primary stimulus or trigger for the collapse of the complex Classic sociopolitical system. As Brian Fagan (1999:158) evocatively states, many of these scholars believe that climatic change “delivered the coup de grâce to rulers no longer able to control their own destinies because they had exhausted their environmental options in an endless quest for power and prestige.” Unfortunately, some of these accounts are simple recapitulations of earlier mono-causal, catastrophic models of the collapse (e.g., Gill 2000), which we believe obscure more than they explain. The irrefutable evidence of dramatic regional differences in the cultural transformations of the Terminal Classic Period across the Maya lowlands (e.g., Demarest et al. 2004), coupled with increasing evidence of the complexity of the climatic changes that occurred during that same period, demands more complex understandings of the relationship between Maya society and culture, climate, and the natural environment.

The Collapse in the Archaeological Record

All models that attempt to explain the collapse must be judged ultimately against the same set of archaeological data, which several scholars have laid out in some detail (Adams 1973; Sabloff 1971a; Sharer 1977, 1994; Webster 2002). Most agree that the following general empirical trends mark the collapse:

1. Abandonment of palaces and temples and cessation of the construction of monumental architecture;
2. Reduction or cessation of the creation of public sculpture;
3. Substantial decline in the use of hieroglyphic writing on stone media and disappearance of Long Count calendar;
4. Reduction in the production of sumptuary or “luxury” items, like polychrome pottery and carved shell and jade objects;
5. Significant decline in investment in mortuary architecture and grave goods;
6. Significant decline in population and population density.

These six empirical factors must be understood as generalizations, however, and when examined in more detail, the data prove more complex, demonstrating variability at three different scales. First, there is significant variability between the different regions of the lowlands in the timing and nature of the changes that are routinely grouped together under the term collapse. Second, even within regions we find significant differences among sites: some did not decline as rapidly as others, and some, such as Lamanai, continued to be occupied until the Spanish Conquest (Pendergast 1997). Some, such as Chichen Itza in the northern lowlands, even flourished during the Terminal Classic Period (Andrews and Robles 1986; Cobos 2004). Finally, within specific polities, the processes that caused the collapse affected different groups in different ways. Although decline and abandonment are the general trends, settlement survey and household archaeology data from the Petexbatun region, Copan, and upper Belize River valley demonstrate that some families and villages survived for decades if not generations longer than their neighbors (Palka 1997; Webster and Freter 1990; Yaeger 2003). We mention this complexity not to downplay the scope of the changes of the Terminal Classic Period, but to emphasize that the collapse was neither a unitary nor an eventlike phenomenon; it was a complex set of processes spanning generations that played out quite differently at sites across the lowlands (see also Demarest et al. 2004; Marcus 1999).

The three primary data sources we use to understand the social and cultural changes of the Terminal Classic Period are archaeological, epigraphic, and art-historical, the former two being employed most frequently. Hieroglyphic inscriptions provide detailed histories of those sites that possess a large corpus of inscriptions, but synthesizing the epigraphic and the archaeological data is a complex task (Fash and Sharer 1991; Houston 1989; Stuart 1992). The histories of many sites contain lacunae that can be attributed to gaps in the creation of texts, the later destruction of text-bearing monuments, and, in some cases, a relative lack of fieldwork. Furthermore, Classic-Period hieroglyphic texts are restricted almost exclusively to accounts of the activities of the rulers and nobles of Maya polities: raids against neighboring polities, the births of royal heirs, the consecration of new temples, the deaths and burials of powerful nobles, for example (Marcus 1993; Martin and Grube 2000). They do not speak to demographic trends, population movements, or agricultural productivity, and they bear only indirect witness to many other topics pertinent to understanding the collapse, such as the production of luxury goods. Archaeological data can provide information with which to understand these topics, but chronologically coordinating these two kinds of data is problematic. Often the trends that can be documented by the much finer-grained hieroglyphic chronologies are given priority in interpretations, and the other trends are assumed to follow suit.
Dating the Collapse

Many early studies of the collapse focused on determining when the collapse occurred or when a particular site or region was abandoned. This approach was driven by the culture-historical framework employed by most Maya archaeologists in the first half of the twentieth century and was informed by an implicit understanding of the collapse as a panregional event or a series of collapses of individual sites. It was further encouraged by the nature of early Maya epigraphy. The glyphs relating to the Maya calendar were deciphered decades before other aspects of the writing system, so early scholars could identify the last recorded dates at sites before they could understand the events recorded for those dates and, with few exceptions, hieroglyphic texts constituted the only data set for inferring the timing of the abandonment of many lowland sites (e.g., Morley 1946).

As scholars have reconceptualized the collapse in terms of culture processes and historically contingent transformations instead of a one-time catastrophic event at the site or regional levels, their interests in chronology necessarily have shifted from determining the terminal date of a site’s occupation to charting changes in Maya society during the eighth through tenth centuries. This requires a firm chronological control of the timing and pace of different social and political transformations, which at most sites is obtained by combining calendrical information from hieroglyphic inscriptions, ceramic sequences, and radiocarbon dates.

Hieroglyphic texts are almost ubiquitous on Classic-Period Maya monuments, and they usually contain calendrical information that allows epigraphers to assign the events described in the texts to the Gregorian date on which they occurred. Many studies of the collapse have charted regional patterns in the final hieroglyphic dates at sites across the lowlands, using the last inscribed date at a site as a proxy for the date of abandonment or political decentralization of that site (Gill 2000; Haug et al. 2003; Lowe 1985). Although the cessation of creation of stone monuments and hieroglyphic texts is a central symptom of the collapse, it does not reliably correlate with other aspects of the collapse. At some sites, the last dated stone monument predates, in some cases significantly, the center’s final abandonment (Harrison 1999; Pendergast 1997); at others, it is followed by politically charged stone sculpture lacking hieroglyphic texts (Martin and Grube 2000).

Other studies, however, have looked for patterns in the events described in the inscriptions of the later Late Classic and Terminal Classic periods. They have found evidence for increasing political competition as reflected in the number of people and offices mentioned in the texts, increasing frequency of warfare, and decentralization in the larger polities as reflected in the proliferation of sites whose rulers use their own emblem glyphs and the title k’uhul ajaw or divine king (Houston 1993; Marcus 1976, 1992; Martin and Grube 2000; Stuart 1993).

Most of the deposits studied by archaeologists in the Maya lowlands lack associated calendrical texts, and the principal tool archaeologists use in dating these deposits is the associated ceramic vessels, following the groundbreaking work of Robert E. Smith (1965) at Uaxactun. Smith defined ceramic complexes by the co-occurrence of distinct vessel forms and decorative modes, and then dated the sequence of complexes using associations between diagnostic vessel types and hieroglyphic texts. Even after the development of radiocarbon dating provided archaeologists with another tool for assigning absolute dates to the ceramic sequences, the range of error was often so great that cross-ties to the ceramic sequences of Uaxactun and other sites, together with the local association of ceramic material with hieroglyphic dates, have remained critical for assigning chronological dates to ceramic sequences (e.g., Chase 1994).

Ceramic phases tend to be relatively long, on the order of seventy-five to two hundred years in the Late and Terminal Classic periods, although some scholars have established finer-grained chronologies (e.g., Taschek and Ball 1999). Consequently, the temporal resolution in the archaeological record at most sites is between three and eight generations. This gross chronology seriously compromises efforts to tightly correlate archaeologically visible changes—shifts in demography or household economy, for example—with the political events that we can follow from year to year in the hieroglyphic inscriptions. Further, because of the palimpsest nature of the archaeological record, many archaeological deposits are actually cumulative products of years or even generations of human behavior, and short-term changes can be lost or aggregated and averaged out.

Further clouding the picture, the absolute dates for ceramic phases that correspond with the Terminal Classic Period are often less secure than those for earlier phases. At most sites, the Terminal Classic Period is marked by reduced occupation and fewer monuments. The consequent paucity of associations between Terminal-Classic ceramic vessels and radiocarbon dates or hieroglyphic texts makes it difficult to accumulate enough dates to define the boundaries of the phase with much precision. Consequently, there is a risk of using ceramic cross-ties to date these phases, making them essentially contemporaneous, and masking significant variability between regions. It is especially difficult to ascertain the ending date for the Terminal Classic phase, a significant empirical fact, given that it is likely that most sites continued to be occupied after their rulers ceased to commission texts with hieroglyphic dates. In these cases, the only way to date the end of the Terminal Classic phase independently is through radiocarbon dating, and the lack of later occupation makes it impossible to bracket the radiocarbon dates to more precisely define the last use of the assemblage. This is unfortunate, as this date would serve as a much more accurate proxy for the abandonment of a site than does its last hieroglyphic date.

The third dating technique that Mayanists use frequently is radiocarbon dating. Although radiocarbon dates are often presented as Gregorian calendar dates, they are more accurately thought of as time spans, not exact points in time. The probabilistic nature of radiocarbon decay, the fluctuations in atmospheric radiocarbon frequencies, and the nature of organic preservation all introduce an inherent multidecadal fuzziness in the precision of radiocarbon
The error range of samples dated with accelerated mass spectrometry (AMS) techniques is often ±30–50 years and two to three times that for samples dated with standard procedures. Consequently, dating events or contexts in the archaeological record, even when it involves combining dates from multiple independent samples, is subject to a decadal or generational precision that is much fuzzier than the temporal precision that pertains for events recorded in hieroglyphic texts, which can often be dated to the day they occurred.

Further complicating the precision of a date is the need to calibrate a radiocarbon date to correct for fluctuations in the frequency of radiocarbon isotopes in the atmosphere. Calibration curves have improved markedly in the past twenty years (Stuiver et al. 1998), but portions of the curve are inherently problematic because the rate of change in the amount of radiocarbon in the atmosphere was such that a given radiocarbon date can have multiple intercepts. Unfortunately, these “flat” zones on the calibration curve include three periods during the eighth through tenth centuries (AD 680–760, 790–880, and 900–950). Samples dating to these time periods are likely to return probability curves with long spans of time in which multiple dates are equally likely. For example, a sample with a radiocarbon date of 1195±45 14C BP yields seven equally probable intercepts between AD 780 and 857, a one-sigma range of AD 774–889, and a probability curve that is essentially flat from AD 785–885—the century of greatest interest to those trying to understand the Maya collapse.

Finally, because of the hot, humid conditions in much of the Maya lowlands, plant remains are rarely preserved unless carbonized, charcoal is rarely preserved, and most preserved carbonized material derives from long-lived deciduous trees. Because it is usually impossible to determine how much time passed between the point at which a segment of a tree became heartwood and thus removed from active carbon-exchange and the point at which people cut down the tree and used it, an additional level of uncertainty—decadal in many cases—is introduced into many carbon dates, save those that derive from preserved seeds, endocarps, tubers, twigs, and other short-lived or annual vegetative elements.

Despite these limitations, significant strides have been made in refining the regional chronological frameworks used by Maya archaeologists in the decades since the 1970 symposium on the collapse. Although the advent of AMS radiocarbon dating was one factor in these advances, basic empirical data collection was much more important. The establishment of refined ceramic sequences at many sites and the related ability to determine the temporal relationships between different regional ceramic traditions have allowed archaeologists to recognize two important facts regarding the timing of the collapse.

First, the collapse of many Maya polities in the central and southern lowlands in the ninth century was roughly contemporaneous with the growth in size and political power of sites in the northern lowlands (fig. 1). Many have argued that the decline of the southern polities and rise of the northern polities
were related (Erasmus 1968; Lowe 1986). Some have argued that changing political economies and regional exchange networks refocused trade along circum-Peninsular routes that were controlled by Peten, Izta, and other Mexicanized groups and bypassed inland polities (Ball 1977; Braswell 2003; Freidel 1986; Sabloff 1973b; Sabloff and Ratliff 1977); others have suggested that the disruptions in the south led to significant immigration to northern cities, increasing their size and economic might (Carmean et al. 2004). Although many northern polities underwent a decline and abandonment in the tenth century, data from the north, discussed below, demonstrate that the collapse did not affect that region uniformly.

The second important fact arose from a chronological reevaluation of Chichen Itza, the largest site and clear regional power center in the Early Postclassic northern lowlands. Scholars had argued that Chichen Itza and its associated Soruta ceramic complex largely postdated the decline of other northern sites like Coba and Uxmal, the latter associated with the Cehpech ceramic complex (e.g., Smith 1977). New chronological data indicate that there is considerable temporal overlap between the Soruta and Cehpech complexes, and that the Chichen Itza polity was contemporaneous with Coba and the Puuc polities like Uxmal (Anderson 1998; Cobos 2004; Keeke 1998; Ringle et al. 1998). Many researchers now conclude that Chichen Itza played a central role in the decline and abandonment of other northern sites during the tenth century:

The rise and fall of the Coba state in the northern Maya lowlands of the Yucatan peninsula, Mexico, during the Terminal Classic and Early Postclassic times, was probably the single most important process in late Maya history (Andrews 1990: 258).1

This new understanding of the Chichen Itza chronology has led many Maya archaeologists, especially those working in the northern lowlands, to reconsider the dating of the Terminal Classic Period. In the central and southern lowlands, most scholars use the term Terminal Classic in two senses. Chronologically, it refers to ceramic complexes roughly contemporaneous with Smith’s Tepeu III complex at Uaxactun, usually dated to AD 800–ca. 900, although sometimes adjusted to begin in AD 850, corresponding to the Long Count date 10.0.0.0.0 (see Rice and Foy 2004 for a detailed discussion of Terminal Classic ceramic chronologies). Culturally, scholars use the term to refer to the period of social and political transformations that comprise the collapse. Because data from Uxmal and other sites indicated continued tenth-century occupation, many archaeologists working in the northern lowlands used a somewhat expanded range of AD 800–900–1000 (Andrews and Andrews 1980; Smith 1971), but they lacked many firm absolute dates for Terminal Classic ceramic complexes (Andrews and Sabloff 1986).

More recently, however, scholars have argued that the dates of the Terminal Classic must be revised if the term is to refer to sociopolitical transformations. George J. Bey and colleagues (1997: 218) suggest that the Terminal Classic in the northern lowlands be used to refer to a period that postdates the end of monumental construction at Uxmal and other Puuc sites, AD 925–1000. Charles Suhler and colleagues (1998) broaden the period to AD 730–1100 so that it encompasses the rise and fall of the Puuc centers and the later apogee of Chichen Itza. In contrast, Kelli Carmean and colleagues (2004) prefer a narrower date range of AD 770–950 for the Puuc Hills region of the northern lowlands, one that encompasses the florescence and decline of the Puuc polities and is more in line with the dates used for that period in the southern and central lowlands.

For our discussion, we define the Terminal Classic as AD 800–1000. This date range is widely used in the paleoclimatic literature and, to a lesser extent, among archaeologists. These dates correspond with the strongest evidence for drier climatic conditions, and they encompass the abandonment of most large polities in the central and southern lowlands and in the Puuc region of the northern lowlands. We would point out, though, that using the same dates for the Terminal Classic period for all parts of the lowlands can generate confusion and obscure important differences at the local and regional scales, as processes and events that can be distinguished temporally become grouped under the broader rubric of Terminal Classic.

CLIMATE AND ENVIRONMENT

Modern Hydrologic Setting

The spatial and seasonal distribution of rainfall is highly variable across the Yucatan Peninsula today and is affected by climatic variability of both Pacific and Atlantic origin (e.g., ENSO [El Nino/Southern Oscillation] and NAO [North Atlantic Oscillation], respectively). The northwest coast is the driest area with an annual rainfall of 450 mm/yr near Progreso, Yucatan, Mexico, but rainfall increases steadily to the south, reaching 1600 mm per year at Flores, Peten, Guatemala (fig. 2). This represents an increase of 1500 mm over a distance of 500 km, a gradient that is significantly greater than that of the drought-prone Sahel (1000 mm over 750 km).

Precipitation is highly seasonal, and most rain falls during a distinct rainy season from May to October (fig. 3), interrupted by the canícula or "little dry season" in July and August, when conditions are typically somewhat drier and less cloudy (Magaña et al. 1999). The rainy season coincides with the Northern Hemisphere summer, when the Intertropical Convergence Zone (ITCZ) and North Atlantic subtropical high-pressure system (also known as the Azores–Bermuda high) move northward (Fasenrath 1966, 1972, 1976, 1984, 1990). Tropical storms and hurricanes during this period can contribute greatly to rainfall averages for a single year (Gray 1987, 1991). The dry season occupies the Northern Hemisphere’s winter months of November through April. During this time, precipitation is suppressed as the ITCZ swings...
south of the equator and the North Atlantic subtropical high-pressure zone moves south and dominates in the Intra-Americas Sea (Gray 1993).

Interannual variability in rainfall is controlled by a mechanism similar to that of the annual cycle, involving competition between the North Atlantic high-pressure system and the eastern Pacific ITCZ (Giannini et al. 2000, 2001a, 2001c). The strength of the subtropical North Atlantic high is governed mainly by the NAO. A positive phase is associated with a stronger-than-usual subtropical high-pressure center, stronger trade winds, cooler SST (sea-surface temperature) in the tropical North Atlantic, and decreased rainfall in the Caribbean.

During the lifetime of an ENSO cycle, the Caribbean experiences both dry and wet extremes (Giannini et al. 2000, 2001a; see also Maasch, this volume). A warm El Niño phase is generally associated with drier-than-average conditions during the boreal summer of year (0) and wetter-than-average conditions during the spring of year (+1). However, the dry season that coincides with the mature phase of ENSO is wetter than average in the Yucatan. Following the strong El Niño of 1997–1998, much of Mexico and Central America experienced drought conditions that resulted in massive wildfires.

The relationship between ENSO and Mesoamerican precipitation is complex, however, because of interactions with conditions in the North Atlantic. The interaction of the NAO and ENSO can produce constructive interference that leads to anomalously dry or wet conditions in the Caribbean (Giannini et al. 2001a, 2001b). For example, summers following winters characterized by a positive phase of the NAO and a developing warm ENSO event (0) produce extremely dry conditions in the Caribbean. In contrast, winters characterized by a negative phase of the NAO and a warm ENSO event (+1) should result in anomalously wet conditions in the Caribbean. This is similar to the findings of Enfield and Alfaro (1999), who concluded...
that oppositely signed SST anomalies in the Pacific and tropical North Atlantic are associated with enhanced rainfall departures over the Caribbean and Central America. For example, when an El Niño event (associated with warm temperatures in the eastern tropical Pacific) is coupled with a cool tropical North Atlantic (positive NAO), the summer rainy season in the Caribbean tends to be anomalously dry.

Climate and the Classic Maya

The interannual variability in precipitation caused by the cycles described above would have had a significant impact on rainfall agriculture in the Yucatan Peninsula. As important as the total amount of rainfall, however, is intra-annual distribution of rain and the onset of the wet and dry seasons. In modern swidden agricultural systems, predicting the onset of the rainy season is especially important in the cycle of burning and planting of fields (Gunn et al. 1995). If the rainy season begins before farmers have burned the forest they felled to make their farming plots, they get an incomplete burn, resulting in a field full of half-burned trees and a loss of nutrients that derive from the burned plant matter. In contrast, if the rainy season begins late, weedy growth will spring up in a field before the planted maize has germinated, requiring extensive labor investment in weeding.

In the Classic Period, nonswidden farming practices were probably quite common, reducing some of the risk entailed by an unexpected onset of the rainy season, but the timing and distribution of rainfall over the course of the growing season would have been critical nonetheless. Shortages or excesses in water availability at certain key times in a crop’s life cycle—especially during germination, pollination, and fruit maturation—can affect yields substantially. In the northern lowlands where average annual rainfall is just sufficient for maize production and in areas where the Maya grew crops during the dry season using pot or canal irrigation, raised fields, or other strategies, slight reductions in precipitation could have had a disproportionate impact on agricultural productivity, especially if they occurred at the key times mentioned above. The risk of crop failure due to reduced rainfall could be abated by planting multiple kinds of crops, and multiple varieties of maize that had somewhat different maturation times. In contrast, in the central and southern lowlands, annual rainfall is several times greater than the amount needed to produce a full crop of maize. Because there is no linear relationship between rainfall and maize yields, the excess rainfall does not increase maize productivity, and thus a significant reduction in annual precipitation would have had little impact on maize yields, especially if the reduced rainfall affected the rainy season.

Both the NAO and ENSO can potentially affect the start and end dates of the rainy season. For example, the ITCZ tends to migrate more slowly to northern latitudes during El Niño years, thereby delaying the onset of the rainy season (Mesoamerica Climate Outlook Forum 1998). In southern Central America, Enfield and Alfaro (1999) found that a warm tropical North Atlantic favors an expansion of the rainy season at both ends (onset and end), while a cool North Atlantic leads to a contraction of the rainy season. In contrast, Pacific ENSO affects the rainy season end dates but not the onset date.

The Classic Maya required water for other purposes besides agriculture, including drinking, cooking, construction, and bathing (Polan et al. 2000; Lucero 2002), and it is likely that the Maya in many areas of the lowlands would have needed to store water in the rainy season in order to have sufficient supplies throughout the dry season. Water supply is influenced not only by precipitation, but also by access to groundwater. In the northern lowlands, rainfall quickly percolates into the porous limestone and surface drainage is negligible. The water table is close to the surface (e.g., ~28 m at Chichen Itza), however, and can be accessed through cenotes, the lakes reached by sinkholes that perforate the bedrock. Because of higher elevation caused by faulting along the Sierra de Ticul, the water table is significantly deeper in the Puuc region (Dunning 1992). There, the Maya built cisterns called chultuns in their houses to store rainwater for domestic use (McAnany 1990; Thompson 1897).

In the central and southern lowlands, surface waters are perched above the regional water table, which is more than a hundred meters below the surface (e.g., ~310 m at Tikal). The Maya of the central and southern lowlands were generally more reliant on surface water supplies for drinking water than was the case in the northern lowlands. These water supplies included lakes, rivers and streams, and springs, as well as reservoirs both in large cities (Lucero 2002; Scarborough 1996) and in hinterland residential areas (Weiss-Krejci and Sabbas 2002).

Climate, Environment, and the Maya

Under the direction of Edward S. Deevey from 1972 to 1988, the Central Peten Historical Ecology Project (CPHEP) advanced our understanding of the relationship between the prehistoric Maya and their environment by combining archaeological data on population density with paleolimnological information from several lake basins in the central lowlands (Rice 1998). The project demonstrated that a thick deposit of inorganic colluvium called Maya Clay underlies many Peten lakes. As the name implies, the researchers concluded that this sediment deposit was anthropogenic, the end result of growing Maya population densities, which caused deforestation, topsoil erosion, increased colluviation, and phosphorus sequestration in lake sediments. The CPHEP data led to a conceptual model, applied widely throughout the Maya lowlands, that the Maya were primary agents of environmental transformation and “stressors” of the natural ecosystem (Deevey et al. 1979), and that human-induced environmental degradation contributed significantly to the collapse.

A fundamental assumption of CPHEP was that climatic change was negligible during the period of Maya occupation, as explicitly expressed by Deevey and colleagues (1980: 420): “[c]limatic changes during and since Maya time were unimportant, and the major environmental perturbations arose from human settlement and technology.” Recent paleoclimatic evidence derived from analysis of sediment cores from the Yucatan Peninsula.
and circum-Caribbean region demonstrates that Holocene climate, and specifically rainfall, has not been constant throughout the period of Maya occupation (Hodell et al. 1991, 1995, 2001, 2005a; Curtis et al. 1996, 1998, 1999; Haug et al. 2000, 2003). Furthermore, the data show important differences in the climatic histories of subregions of the Yucatan Peninsula during the Terminal Classic Period, as we demonstrate below (see also Messenger 2002; Shaw 2003).

Charting Paleoclimatic Changes

In the Maya lowlands, instrumental records of climatic change are limited to the last century (e.g., 100-yr-long record of rainfall at Mérida), although colonial records and Maya chronicles such as the Books of Chilam Balam extend back to the fifteenth century (Folan and Hyde 1985; Craine and Rein-dorp 1979). Several approaches have been used to infer paleoclimatic change in Mesoamerica for earlier periods. Initially, climate-modeling studies were undertaken to retrodict climate in the Maya region on the basis of various forcing mechanisms, such as solar insolation and volcanic activity, and their correlations to global temperature trends (Gunn and Adams 1981; Messenger 1990; Sanchez and Kurzbach 1974; for review see Gunn et al. 2002). Other studies have relied on more detailed paleoclimatic records from other regions (mostly from the high-latitude Northern Hemisphere), employing models of telenconnective climatic linkages between regions to predict how climate would have changed in Maya lowlands (Folan et al. 1981a; Gill 2000; Gunn et al. 1995; cf Messenger 2002).

A more direct approach to climate reconstruction uses sediment cores taken from closed-basin lakes in the Maya lowlands (Curtis et al. 1996, 1998; Hodell et al. 1995, 2001, 2005a; Rosenmeier et al. 2002a, 2002b). Mark Brenner and colleagues (2002, 2003) have reviewed the use of sediment cores to reconstruct climate in the Maya lowlands elsewhere, but a brief summary of the use of oxygen isotope ratios and mineral concentrations as geochemical proxies for inferring changes in the ratio of evaporation to precipitation (E/P) is called for here.

In closed basin lakes, the volume, concentration of dissolved solutes, and $\delta^{18}O/\delta^{16}O$ ratio of the lake water are controlled by a balance between water lost by evaporation relative to water gained by precipitation and runoff:

$$d\text{Volume}_{lake} = \text{precipitation} (P) + \text{runoff} (R) + \text{groundwater} (G) - \text{evaporation} (E)$$

The amount of runoff and groundwater input is generally related to precipitation, so the hydrologic budget of a lake is essentially dependent on precipitation and evaporation. In some cases, however, runoff and groundwater input can be affected by human- or naturally induced vegetation changes. For example, deforestation reduces evapo-transpiration and soil moisture storage, thereby increasing surface and groundwater flow to the lake basins in a way that mimics increased rainfall (Rosenmeier et al. 2002b).

When water evaporates, water with the lighter isotope of oxygen ($H_{16}O$) evaporates at a faster rate than the heavier form ($H_{18}O$), thereby increasing the $\delta^{18}O/\delta^{16}O$ ratio of lake water. Furthermore, the dissolved salts in the lake water become more concentrated with increased evaporation. During a period of drier climate, a closed lake loses more water to evaporation than it receives from precipitation and, consequently, the lake volume decreases, dissolved solutes become more concentrated, and the $\delta^{18}O/\delta^{16}O$ ratio of lake water increases. The reverse occurs during wet periods, when the lake basin receives more water through precipitation and runoff than it loses to evaporation.

When organisms such as ostracods, gastropods, or bivalves precipitate shells of calcium carbonate (CaCO$_3$), the $\delta^{18}O/\delta^{16}O$ ratio of the carbonate-bound oxygen is related to the $\delta^{18}O/\delta^{16}O$ ratio of the water from which the carbonate precipitated. Temperature also affects the $\delta^{18}O/\delta^{16}O$ ratio of CaCO$_3$, but temperature changes in the Maya region during the late Holocene were small relative to changing E/P. Therefore, by measuring the changes in the $\delta^{18}O/\delta^{16}O$ ratio of shells down the length of a core, one can reconstruct the relative changes in the $\delta^{18}O/\delta^{16}O$ ratio of lake water and, consequently, E/P.

Many lakes in the Maya lowlands have sulfate as their dominant anion (e.g., Lakes Chichancanab, Salpeten, and Peten-Itza), because gypsum (CaSO$_4$) is a common mineral in evaporite deposits in the bedrock. When rainwater or groundwater comes into contact with gypsum, Ca$^+$ and SO$_4^{2-}$ ions are dissolved and are delivered to the lake. These ions build up until the lake water becomes supersaturated. In cases of a sudden reduction in lake volume from increased E/P, supersaturation can be exceeded and these ions precipitate out. The sulfur content of sediments, measured as wgt. %S, can be used as a qualitative proxy of E/P in those lakes, like Lake Chichancanab, that are at or near gypsum saturation.

Although both oxygen isotopes and sulfur concentrations are valuable proxy measures, the combined measurements of both on the same sample is an especially powerful tool for reconstructing changes in E/P. For example, if both $\delta^{18}O$ and wgt. %S increase simultaneously in a sediment profile, then one can eliminate a change in the $\delta^{18}O$ of the rainfall because this process would have no effect on gypsum saturation.

Dating Climatic Changes

Prior to the advent of the AMS dating technique, most radiocarbon dates in lake sediments from the Maya lowlands were measured on shell or bulk organic material using traditional analytical techniques (gas counting and liquid scintillation). These dates were subject to hard-water lake error because the weathering of limestone in a lake’s watershed produces dissolved inorganic carbon that is devoid of $^{14}C$ and thus dilutes $^{14}C$ in the lake (Deevey and Stuiver 1964). Consequently, the dates make the samples appear older than their true age. Although there are corrective algorithms, hard-water lake error has historically limited the accuracy of core chronologies on the Yucatan Peninsula. AMS $^{14}C$ analysis now permits the dating of milligram-sized terrestrial organic material preserved in sediment cores, such as wood,
seeds, twigs, and charcoal. This tool has improved tremendously the dating accuracy of lake sediment cores in the Maya region, but several factors still serve as obstacles to correlating paleoclimatic changes observed in different lake cores, and to correlating patterns observed in the cores with the archaeological record.

As is the case with radiocarbon dates from archaeological contexts, there are errors introduced by the probabilistic nature of radioactive decay and other factors. Similarly, preservation of charcoal or other organic matter is an important consideration. Because the age of sediment between dated horizons is usually interpolated by assuming a constant sedimentation rate between points or by fitting higher-order functions to age-depth pairs, the number and position of dated points in a core are critical. In some cores, terrestrial organic matter is sparse or not present in datable quantities during the time periods of greatest interest, leading to interpolated age estimates for sediments far from any secure reference points.

We clearly face challenges in precisely and accurately dating both the paleoclimatic and archaeological records, challenges that are amplified when trying to correlate the two data sets. First, there are very few cases in which horizons or events like volcanic tephra deposits left visible signs in sediment cores and the archaeological record that we could use as shared chronological reference points. Thus, our correlations are almost always subject to the uncertainties inherent in radiocarbon dating, making it difficult to achieve more than a fuzzy temporal correlation between paleoclimatic and archaeological data.

Second, observations in the archaeological record using ceramic information and slices from sediment cores can only provide temporal resolution on a multidecadal scale. Within these slices of time, rapid changes can be hidden or “averaged out,” making them indistinguishable from gradual ones. These two difficulties should be kept in mind when attempting to correlate the archaeological and paleoclimatic evidence for the Terminal Classic.

DATA FROM THREE REGIONS

There is indisputable evidence of regional diversity in the social and cultural transformations of the Terminal Classic Period, and the paleoclimatic sequences from sites across the lowlands also present distinct local pictures. These facts preclude a single monolithic summary of the relationship between climatic changes and the collapse. Consequently, we will discuss three different regions that have rich archaeological and paleoclimatic records for the eighth through tenth centuries. We feel that it is important to begin our case studies in the early eighth century, during the heart of the Late Classic Period, and continue into the eleventh century wherever possible. In this way, we span the entire range of time that encompasses the collapse. These regions are the central, the north-central to northeast, and northwest sectors of the lowlands.

The Paleoclimatic Record. One of the more striking geological features of the central lowlands is an east-west chain of lakes known as the Peten Lakes that follows a geological fault in the limestone bedrock (Deevey et al. 1979, 1980). Of all areas of the lowlands, this region has been subjected to the most extensive paleoclimatic research, thanks largely to Deevey’s CPHEP project. As described above, CPHEP was more interested in human–environment interactions than climatic change. Consequently, Mark Brenner, David Hodell, and Jason Curtis have been directing more recent coring projects in Lake Peten-Itza and Lake Salpeten to recover paleoclimatic proxy records (fig. 2).

Two facts affect the interpretation of these records. First, because the central lowlands were the most densely populated region in the Classic Period, the oxygen isotope records must be interpreted with caution. Anthropogenic landscape changes such as human deforestation can alter a lake’s hydrologic budget by changing surface runoff and groundwater inflow in ways that mimic climatic change (Rosenmeier et al. 2002a, 2002b).

Second, the rate and nature of sediment deposition in Lake Peten-Itza and Lake Salpeten have resulted in proxy records with a multidecadal temporal resolution. Consequently, we complement them with a brief discussion of new paleoclimatic data from the Carriaco Basin of Venezuela, which has an extraordinarily fine temporal resolution.

Lake Peten-Itza. Lake Peten-Itza is the largest lake in the Maya lowlands, with a surface area of 100 km$^2$ and maximum depth of 165 m. Its large area buffers its hydrologic budget from human activities such as deforestation, but at the same time renders it relatively insensitive to changes in E/P compared to smaller lakes. As a result, observed changes in the oxygen isotope record were small (<0.5‰) during the past two millennia (fig. 4). The lowest δ$^18$O values occurred during the Early Classic and Late Classic periods, followed by a step-like increase in the Terminal Classic Period (fig. 4). The Maya Clay in Lake Peten-Itza is represented by relatively high magnetic susceptibility that reflects increased erosion of clastic material from the watershed (Curtis et al. 1998).

The increase in δ$^18$O in the Terminal Classic Period coincides with a decrease in magnetic susceptibility, which is consistent with a reduction in the quantity of eroded, magnetic minerals in the sediment (fig. 4). At the same time, changes in pollen frequencies in the profile indicate a decline in disturbance taxa and an increase in lowland forest taxa (Islebe et al. 1996). Together these changes reflect the recovery of forests and stabilization of soils as the declining population density associated with the collapse reduced human pressures on the landscape. The δ$^18$O increase in the Terminal Classic Period may represent either an increase in E/P (i.e., drought) similar to Lakes Chichancanab and Punta Laguna to the north, or a decrease in runoff related to reforestation of the watershed.

Lake Salpeten. Lake Salpeten is located just east of the northern basin of Lake Peten-Itza. It measures only 2.6 km$^2$ in area, however, and its hydrologic budget is consequently more sensitive to changes in water input and
Evaporation. The lake’s depth reaches 32 m along the steep, fault-controlled northern shore, but the southern shore is shallow and shelving (fig. 6). This basin geometry has resulted in intense sediment focusing and the deposition of a thick sediment package in the deep basin. The Maya Clay is the thickest unit, representing erosion of catchment soils as a consequence of human-induced deforestation. The base of the Maya Clay in Salpeten core 80-1 was dated to 3,160±80 14C yrs BP by AMS-14C dating of terrestrial material, which converts to an age range of 1700–1100 BC, in the Early Pre-Classic Period (Rosenmeier et al. 2002a). The top of the Maya Clay corresponds to the Terminal Classic Period, when forests recovered and soils stabilized as human pressures on regional vegetation were reduced.

During the last two millennia, the oxygen isotopic record of Lake Salpeten was marked by low values between AD 1–150, followed by a series of step-like increases around AD 150, 550, 900, and 1400 (fig. 4). These events may have been caused by increases in E/P and/or decreased hydrologic input to the lake as a consequence of land-use change (Rosenmeier et al. 2002b). It is often difficult to differentiate the relative roles of climatic change and human landscapes modifications in creating the proxy records we study (see also Dunning and Beach 2000; Rice 1993: 44). Nonetheless, paleolimnological records from both Lakes Salpeten and Peten-Itza suggest that climatic and/or human-induced changes on the environment of the central lowlands were profound during the time of Maya occupation of the watersheds.

Caribbean Basin. Although not located in the Maya lowlands, paleoclimatic records from cores retrieved in the anoxic Cariaco Basin off northern Venezuela are highly relevant for reconstructing precipitation changes in the Maya lowlands. As discussed above, rainfall in both regions is related to the seasonal migration of the ITCZ, and southward displacement of the ITCZ during summer should result in lower rainfall in both northern Venezuela and the Maya lowlands. Gerald Haug and his colleagues (2003) used the concentration of titanium in annually laminated sediments to infer changes in precipitation at a temporal resolution that is unmatched by any other terrestrial or marine record in the Neotropics. Ti is a terrigenous element delivered to the Cariaco Basin by rivers, and therefore its concentration is related to runoff and precipitation.
Cariaco Ti concentration was low in the Terminal Classic Period (fig. 7), indicating generally drier conditions, consistent with findings from north-central Yucatan lakes discussed below (Curtis et al. 1996; Hodell et al. 1995, 2001, 2005). Superimposed upon this generally drier climate, however, were four periods of drought dated to approximately AD 760, 810, 860, and 910. These severe droughts lasted between three and nine years and were spaced forty to forty-seven years apart (fig. 7). If we accept that the teleconnective links between Cariaco and the Maya lowlands would create roughly parallel climatic changes, the extraordinary temporal resolution of the Cariaco record permits a comparison between paleoclimatic events of the Terminal Classic Period and the archaeological evidence of the collapse (Haug et al. 2003). Although the Cariaco chronology is based on varve counting, the absolute dates for the individual drought events "float" in time because the chronology is referenced to an assumed date of AD 930 for a rise in Ti that marks the local onset of Medieval Warm conditions. Nonetheless, the pattern and relative timing of events in the Cariaco Ti signal should be robust.

The Archaeological Record. Throughout the central and southern lowlands, the last half of the eighth century was a remarkable time. Different polities had distinct historical trajectories, but Tikal, located in the middle of the central lowlands (fig. 8), provides a good example. The kingdom's k'uhul ajaw, Yax Nuun Ayiin II, began his rule in AD 768 and ruled at least until AD 794 and perhaps through AD 810 (Valdés and Fahsen 2004: 143); he continued a program of growth and political revitalization that his great grandfather Nuun Bak Chak and grandfather Jasaw Chan K'awiil had initiated in the seventh century (Valdés and Fahsen 2004; Martin and Grube 2000). These powerful rulers built towering funerary monuments and added palace buildings to the royal court (Harrison 1999; Jones 1991; Martin and Grube 2000; Schele and Mathews 1998). The polity's population densities reached new highs (Culbert et al. 1990; Ford 1986; Puleston 1983), presumably creating an unprecedented pool of labor tribute and staple surplus. Consequently, the divine kings who occupied the apex of Tikal's political economy reached a zenith of wealth and power, as reflected in their building projects and the craft goods and public art they commissioned.

Across the region, rulers at more sites than ever before erected new carved monuments during this period, a trend that culminated around AD 790 (Martin and Grube 2000: 226; Morley 1977–78). Although sometimes interpreted as a sign of great prosperity and cultural florescence, this proliferation of monuments is probably better understood as a sign of political decentralization and intensified competition between the rulers of the largest polities and their allies and vassals. Nowhere is this clearer than in the Petexbatun region, where competition turned to chronic warfare that wracked the entire region in the late eighth century (Demarest 2004; Demarest et al. 1997). After the fall of the ruler of Dos Pilas, K'awiil Chan K'inich, in AD 761, the region's polities, no longer subject to Dos Pilas, entered a period of endemic conflict and competition. There is little evidence of environmental degradation in the region (Dunning et al. 1997), and the frequency of indicators of dietary stress, malnutrition, and disease change little from the Early Classic through the Terminal Classic (Wright 1997). The end product of this fierce competition was the destruction and abandonment of most cities by AD 800 (Demarest 1997), and the last hieroglyphic monument in this area dates to AD 807 (Martin and Grube 2000). Although it is especially noteworthy in the Petexbatun, epigraphic evidence of increasing warfare during the later eighth century is found in many regions of the southern and central lowlands in polities like Naranjo, Yaxchilan, Piedras Negras, and Tonina. Warfare continued to be common across the region into the ninth century.

The next fifty years mark perhaps the period of greatest political change during the collapse in the central and southern lowlands. Many important sites—Palenque, Yaxchilan, Piedras Negras, Aguateca, Dos Pilas, Quirigua—have yielded no firmly dated monuments that postdate the k'atun-ending celebration of AD 810 (Martin and Grube 2000), suggesting
the end of the centralized political organization based on divine kingship in those polities, a system that had been pervasive in the Classic-Period Maya lowlands (Sharer and Golden 2004). At Tikal, the frequency of monument dedication decreases significantly in the ninth century, and there is no evidence of a long-reigned ruler after Yax Nuun Ayiin II’s reign. There is a sixty-year hiatus in monument dedication at Tikal beginning in AD 810, although inscriptions at other sites mention Tikal rulers during this time. This hiatus spans the completion of the important tenth bak’tun in AD 810, which went uncelebrated at Tikal, although the ruler of Zacpeten, a former Tikal subordinate, erected a monument to record the date (Marrin and Grube 2000). Taken together, these facts suggest an extended period of political turmoil and reduced control of labor and resources by Tikal’s rulers.

This fragmentation of larger regional polities was a widespread pattern (Marcus 1998). As Calakmul’s rural population declined significantly in the Terminal Classic (Braswell et al. 2004), the rulers of once-subordinate sites such as Oxpemul, Nadzcaan, and La Muñeca began commissioning their own stele, dating to the ninth century (Marcus 1976; Martin and Grube 2000). Copan had begun to undergo increasing political decentralization after AD 763, as reflected by the proliferation of carved monuments and hieroglyphic texts in nonroyal compounds and other trends in the art and architecture of the site’s epicenter (Fash et al. 2004); the site’s last monument dates to AD 822 (Stuart 1993). By AD 830, the royal lines of kings who had ruled the Late Classic period were gone, and construction ceased at Calakmul’s main plaza, where the last monument dates to AD 830 (Marcus 1998). The city grew to its maximum population (Tourtellot 1988), and additional monuments were added in the decades following, though the site’s last monument dates to AD 871. A few undated monuments that are probably later (Martin and Grube 2000: 227).

This decentralization was not universal, however. At Caracol, K’inich Joy Kawiil II, a strong and successful ruler who had ruled the Late Classic polities had disappeared from most sites of the central and southern lowlands (Martin and Grube 2000: 227). Caracol’s last monument dates to AD 821 (Stuart 1993). By AD 830, the local elites had taken back control of their domain, and the city continued to flourish as a regional power until its decline in the ninth century (Marcus 1998; Seigfried 1993). Caracol’s last monument dates to AD 871, and its population continued to grow until the city was abandoned around AD 890.

Seibal, adjacent to the Petexbatun region, presents an even more remarkable case. Following the region’s devastating wars of the later eighth century, a new royal dynasty was established in AD 830 and presided over a remarkable florescence. The city grew to its maximum population (Tourtellot 1988), and its rulers commissioned seventeen stele between AD 830 and 889, and several undated monuments that are probably later (Martin and Grube 2000: 227). Recent research does not support earlier reconstructions that Seibal was conquered by foreigners (Tourtellot and González 2004), but the presence of certain ceramic types, hairstyles, costume elements, writing conventions, and architectural styles at Seibal does indicate close ties between the polity’s elite and groups who were culturally affiliated with societies in the Gulf Coast region, presumably Irza and/or Putun Maya (Sabloff 1973b). These contacts likely linked Seibal, strategically located on the Pasión River, into the expanding circum-Caribbean canoe-trade networks. Several of the polities that maintain some degree of centralization during the ninth century, including Caracol, show similar connections (Chase 1985; Chase et al. 1991; Sabloff 1973b), and groups affiliated with northern polities apparently immigrated into the Peten Lakes region in the ninth and tenth century (Rice and Rice 2004). The general trends of political fragmentation and decentralization in the early eighth century correspond roughly with marked population declines in much of the southern and central lowlands (Culbert 1988). Tikal is typical of many large sites, in that its population after AD 830 was reduced to around fifteen percent of its Late Classic apogee in the city itself and twenty percent in the city’s sustaining hinterland (Culbert et al. 1990). Unfortunately, most of the region’s Late and Terminal Classic ceramic phases are a century or more in length (Rice and Forsyth 2004), a fact that precludes precisely correlating the political transformations of the early ninth century with trends in Maya demography or economy. At Tikal, the Imix complex dates to AD 700–830 and the Elzab complex to AD 830–910, making it impossible to assess empirically demographic changes between AD 775 and 825, for example.

During the second half of the ninth century, most of the remaining large cities were essentially abandoned. At a few of the old capitals, including Tikal and Calakmul, rulers erected a few monuments during this time, but most show only a few decades of monument dedication. Tikal’s ruler, Jasaw Chan Kawiil II, has his name evoking the great k’uhul ajaw who rebuilt Tikal’s political prestige and might nearly two centuries earlier, dedicated the site’s last carved monument, Stela 15, to celebrate the k’atun-ending date 10.2.0.0.0 (AD 869). The fall of the royal dynasty was followed by the movement of people into abandoned palaces and plazas, where they made makeshift houses in the crumbling city. Near Tikal, the rulers of Ixlu, Xultun, and Jimbal—polities that had once been Tikal’s subjects—erected monuments in the four decades following the last monument at Tikal, in the texts they name themselves k’uhul ajaw and, using the Tikal emblem glyph, indicate either their autonomy or the extension of that title to noble vassals beyond the Tikal sovereign (Valdés and Fashen 2004). The rulers of Jimbal and Uaxactun continued to exercise the royal prerogative to commission stelae after the last monument at Tikal, celebrating the k’atun ending in AD 889, but they were also much reduced in power.

Seibal, with its apparently strong ties to trade routes along the Gulf Coast, continued to thrive during the late ninth century (Tourtellot and González 2004), as did Quirigua, where the old site center was recouped by what appears to be a population from the Caribbean coast (Sharer 1988). Whatever their bases, these polities were relatively short-lived, apparently abandoned by the early tenth century. A few other larger sites showed continued occupation into the tenth century. Rulers at Calakmul and Tonina commissioned the region’s last Long Count dates to celebrate the k’atun ending on 10.2.0.0.0 (AD 909), and a few undated monuments at Seibal and Calakmul are likely somewhat later (Folan et al. 1995; Martin and Grube 2000).

By the early tenth century, however, over a century of political competition and
warfare, political fragmentation, and depopulation had radically changed the region, reducing the area’s once-great cities into crumbling ruins and transforming its once densely populated countryside into dispersed hamlets and farmsteads.

Discussion. The growing evidence of temporal correlations—albeit imprecise—between changes in the environment of the central lowlands and the tumultuous political and social changes of the eighth through tenth centuries must be incorporated into our understandings of the collapse. Although we must repeat that the evidence from Peten lake cores is ambiguous and we cannot single out climatic change as responsible for the proxy data there, the data do indicate that the natural environment in the central Peten changed dramatically over the course of the Late Classic Period. Toward the end of this period, Maya populations in this region were probably confronted by declining crop yields due to soil erosion, perhaps exacerbated by decreasing rainfall coupled with maximum population densities. It is important to note, however, that the multiple lines of evidence suggest that the Petexbatun region did not suffer similar environmental degradation during the eighth or ninth centuries (Dunning et al. 1997; Emery et al. 2000).

The Caracol record suggests that the Terminal Classic Period was marked by somewhat reduced rainfall, punctuated by drought events of three to nine years in length roughly every fifty years that began in the Late Classic Period (AD 760) and continued into the Terminal Classic Period (ca. AD 860, 960, and 970). Although scholars have cited these droughts as explanations for regional demographic trends (Haug et al. 2003, following Gill 2000), they seem to correspond better to documented political changes: increasing warfare and political destabilization in some areas after AD 760; the absence of monuments in many large cities after AD 860; and increasing political decentralization of many regional states in the early ninth century; and the cessation of dated hieroglyphic monuments at many sites over the second half of the ninth century, culminating with the last Long Count dates in AD 909. The Caracol record suggests that the impact of any climatic changes cannot be meaningfully isolated from environmental degradation, nor from the peak eighth- and early ninth-century population densities, nor the unprecedented demands on farmers’ surplus and labor by polity rulers, nor from the cultural constructs by which the Maya themselves interpreted and expected these changes (Friedel and Shaw 2000; Puleston [1979; Rice 2004]). Fine-grained archaeological and paleoenvironmental data now available for many regions in the southern and central lowlands show considerable variation in these factors (Demarest et al. 2004), which likely account for much of the variability in the sociopolitical changes that occurred in different polities across the southern and central lowlands during the eighth and ninth centuries. In some regions, droughts and drier conditions do not appear to have played a significant role. For example, one of the first areas to be abandoned was the Petexbatun, despite the region’s high annual precipitation rates, many large rivers, and the absence of significant environmental degradation. Caracol provides a counter example. Despite the polity’s high population densities and a scarcity of water that continues to be a limiting factor at the site today, K’inch Joy K’awil oversaw a renaissance that does not appear to have been significantly affected by the droughts hypothesized for ca. AD 860 and 880.

Beyond the central and southern lowlands, however, the ninth century is a period of Maya geopolitical recentering, as most of the large polities in the south declined and powerful polities like Uxmal, Coba, and Chichen Itza in the northern lowlands grew. These two phenomena are almost certainly related, and some have suggested that the disruptions in the south led to significant immigration to northern cities. Convincing empirical evidence of this remains lacking to date, although strontium isotope studies now offer the possibility of evaluating this hypothesis (Hodell et al. 2003; Price et al. 2000).

North-central and Northeastern Lowlands

The Paleoclimatic Record. Lake Chichancanab. The strongest physical evidence for a drought during the Terminal Classic Period comes from Lake Chichancanab in the north-central part of the Yucatan Peninsula (fig. 2; Hodell et al. 1995, 2001, 2002, 2005). Chichancanab means “little sea” in Yucatec Maya, which accurately describes its relatively high-salinity (4200 mg l-1) waters. Lake Chichancanab’s water is saturated for gypsum (CaSO4) and celestite (SrSO4), and therefore the S content of the sediment provides a qualitative proxy of E/P. Because sediment containing gypsum is denser than shell-bearing organic matter, sediment density can be used as an indicator of gypsum precipitation. One advantage of using sediment density over weight-percent sulfur (wt. % S) as a gypsum proxy is that density can be measured nondestructively at a high spatial resolution of every 0.5 cm by gamma ray attenuation while the sediment is still in polycarbonate core tubes. Measurement of wt. %S requires that the core be extruded or split so that discrete samples can be taken for geochemical analysis.

In 1993, David Hodell, Jason Curtis, and Mark Brenner (1995) retrieved a 4.9 m core in 0.9 m of water from Chichancanab’s central basin. This core provided the first physical evidence for a profound drought during the Terminal Classic Period, among the most severe in the last 7000 years. The δ18O of gastropod and ostracod shells and the wgt. % S record showed a pronounced increase at a depth of ~65 cm in the core. Hodell and colleagues (1995) dated this event by AMS-14C analysis of a seed that was extracted from the portion of the core that showed peak signals for δ18O and wgt. %S. The age estimate spans a century, it strongly suggests that a major drought occurred during the Terminal Classic Period, among the most severe in the last 7000 years.

In 2000, Hodell and colleagues returned to Lake Chichancanab with the aim of retrieving new cores from deeper water that might possess higher sedimentation rates than the 1993 cores (~0.5 mm yr-1). They were successful in obtaining higher-resolution cores with an average sedentation rate of 0.7 mm yr-1 from ~11 m of water. The wt. %S record from the 2000 cores was very similar to the 1993 cores and contained a pronounced gypsum layer
in the Terminal Classic Period (fig. 9). This gypsum lens formed when the lake volume dropped because of drought; the lake water became supersaturated for CaSO₄, and gypsum precipitated. Two AMS-¹⁴C dates on terrestrial organic matter from just below the gypsum layer yielded identical dates of 1550±50 ¹⁴C yrs BP (fig. 10), which converted to a calibrated age range of AD 680–810 (95.4% probability). This range, encompassing the entire Late Classic Period, illustrates the limitations of temporal comparison between paleoclimatic data and Maya cultural periods. Nonetheless, the date indicates that the gypsum was first deposited after AD 760–810. This date, when combined with the AD 780–990 age of the seed from the 1993 core, supports reconstructions of drier conditions during the Terminal Classic Period. Sediment just above the gypsum layer was dated to 990±60 ¹⁴C yrs BP (fig. 10), which translates to a calibrated age range of AD 950–1000 (92.7% probability), dating to the Early Postclassic Period.

Spectral analysis of the density signal from the 2000 Chichancanab core demonstrated that drought has been a recurrent phenomenon on the Yucatan Peninsula with periods of dry conditions of about 208 and 50 years (fig. 10; Hodell et al. 2001, 2003). The 208-year period is believed to be related to solar forcing, and the 50-year period is consistent with the spacing of drought events inferred from the Cariaco Basin during the Terminal Classic (Haug et al. 2003).

In March 2004, a series of sediment cores were retrieved in Lake Chichancanab along a water-depth transect ranging from 4.3 m to ~14.7 m (relative to 2004 water levels), near the deepest point in the lake (Hodell et al. 2005a).

Results demonstrated that the Terminal Classic gypsum layer is condensed in shallow water and expanded in deeper-water sections where it consists of numerous interbedded gypsum and organic-rich strata (fig. 11). This indicates a series of dry events separated by intervening periods of relatively moister conditions. A radiocarbon date on wood was obtained within the interval of gypsum deposition in deep-water core CH1 08-III-04-MWI-2. The age was 1140±35 ¹⁴C yrs BP, resulting in a calibrated age range of AD 780–1000 (95.4% probability). This age is indistinguishable from the ¹⁴C date obtained on a seed from the gypsum horizon in the shallow-water core taken in 1993 (1400±35 ¹⁴C yrs BP), confirming that gypsum precipitation was occurring during the Terminal Classic Period. Hodell et al. (2004a) were able to correlate density records among cores and derive a fine-grained chronology for the deep-water reference section. Absolute dates on paleoclimatic events remain uncertain because of the inherent errors associated with radiocarbon dating, but the pattern and frequency of climatic variations are robust. The investigators found evidence for two phases of dry climate (ca. AD 770 to 870 and 920 to 1000) separated by an intervening 50-year period of relatively moister conditions (ca. AD 870 to 920). Within each of the dry phases, the climate was marked by alternating dry and moist conditions with an interval of drought recurrence of about fifty years.

In summary, Lake Chichancanab provides one of the most sensitive paleoclimatic records of the Maya lowlands because of its substantial water loss to evaporation, precipitation of gypsum (CaSO₄), and relatively low-density occupation of its watersheds. A low density of occupation, combined with the dry scrub vegetation surrounding the lake, diminished any significant human impact on lake hydrology, and therefore we believe that the observed changes in sediment geochemistry reflect paleoclimatic change.

Lake Punta Laguna. Lake Punta Laguna is located 145 km northeast of Lake Chichancanab and 20 km from the Maya site of Coba. It is in the wettest part of the northern lowlands, where annual rainfall is ~1400 mm/yr. The core recovered from Punta Laguna in 1993 provided a high-resolution paleoclimatic record because of the high sedimentation rates of 0.1–0.2 cm/yr (Curtis et al. 1996). Oxygen isotopes indicate that the Classic Period was
generally drier than the Pre-Classic or Post-Classic (fig. 11). Two increases in δ18O during the Terminal Classic Period coincided with the two density peaks in the Chichancanab cores, within the limits of chronological uncertainty (fig. 11). In the case of the δ18O record, the time of rapid δ18O increase (first derivative of the signal), rather than the peak δ18O value, indicates drier climate. The ages of the two δ18O increases in the Terminal Classic Period are centered on about AD 800 and 900, based on fitting six dates in the core with a second-order polynomial equation (fig. 14). Both Punta Laguna and Chichancanab cores indicate a relaxation of drought conditions by ca. AD 1100 in the Early Post-Classic, as does the Ti record from the Cariaco Basin (Haug et al. 2003). Drought conditions are not strongly reflected in the proxy records at nearby Lake Coba, an absence perhaps explained as the result of significant anthropogenic transformation of the circumlacustrine landscape (Leyden et al. 1998).

The Archaeological Record. The decades of the 1980s and 1990s witnessed significant archaeological research in the northeastern and north-central lowlands, with long-term research projects at Chichen Itza, Yaxuna, and Ek Balam (fig. 15). Most archaeologists now see long-term interaction between Chichen Itza and Coba—the region’s two largest cities—and with other neighboring polities as the central factor in their models of the decline and abandonment of northern sites during the tenth century (Andrews 1990; Andrews and Robles 1985; Ringle et al. 2004; Robles and Andrews 1986; Stanton and Gallareta 2001; Subler et al. 1998, 2004).

Coba was an urban metropolis located in the moister northeastern part of the Yucatan Peninsula (Folan et al. 1983b). The city grew to its greatest size during the Machucaani phase (AD 600–800), when it reached 70 km² and may have had as many as 55,000 inhabitants (Folan 1983a). The core of Coba consists of three large architectural groups built on a massive man-made terrace. A series of causeways or sacbes connect this nuclear zone to other architectural groups.
in the city’s urban core (Folan 1983). The rulers of Coba carved twenty-three stelae in the seventh through ninth centuries. These monuments glorify Coba’s k’íbal ajawob’ in image and text, and the leaders of Coba show clear connections to elite traditions of the central and southern lowlands in the architecture they commissioned and in the layout of their city.

The published data from Coba itself are equivocal as to the relationship between Coba and Chichen Itza. Folan argues that the city reached its peak during AD 600–800, subsequently experiencing a slight decline in AD 800–900 before undergoing a significant reduction in its political and economic importance around AD 900–1000 (Folan 1983c). Folan’s dates for Coba appear to follow traditional ceramic chronologies, and he did not postulate any significant role for Chichen Itza in Coba’s decline (Folan 1983c).

A recent revision of the ceramic sequence puts the site’s apogee during the period marked by the Oro ceramic complex (Robles 1990), which has significantly later dates (AD 750–1100). Based on this new chronology, Anthony Andrews and Fernando Robles (1981: 66) assert that Coba continued to grow well past the eleventh century. They envision a scenario in which Chichen Itza gradually surrounded and weakened Coba between AD 1000 and 1200, conquering its territory and establishing trading outposts along the eastern coast of the peninsula. Charles Suhler and colleagues (2004: 447) suggest that the appearance of the foreign Piza subcomplex at Coba may indicate that Chichen Itza conquered Coba sometime around AD 1000.

The other key city in this region was Chichen Itza. Before the Terminal Classic Period, long-distance trade probably along circumpeninsular canoe networks had become important to the elite of Chichen Itza, despite the city’s distance from the sea. Before AD 800 the site controlled the trade port of Isla Cerritos (Andrews and Gallareta 1986) and had established political control over a corridor to the coastal salt-making center of Emal (Kepecs 1998; Smith 2000). This focus on salt and canoe trade indicate that the political economy of Chichen Itza may have been organized differently than that of contemporaneous northern polities.

The same is true of the polity’s political organization. Based on hieroglyphic texts, iconography, the layout of elite residences and monumental architecture, and the plan of the causeway system at Chichen Itza, various scholars have argued that Chichen Itza was not ruled by divine kings, but rather by a council of elite leaders, a system called mul tepal in early colonial documents (Cobos and Winemiller 2001; Marcus 1999; Schele and Freidel 1990; Wren and Schmidt 1991). The art of Chichen Itza is replete with images of war and conflict (Kurjack and Robertson 1994), suggesting that the power of the polity’s leaders lay not only in their mercantile connections, but also in their abilities to control military force.

The site of Yaxuna, located just south of Chichen Itza, has a relatively long occupation history. Founded around 500 BC, the site experienced a burst of growth in the Yaxuna III phase (ca. AD 600–730; Suhler et al. 2004). During this period the polity grew significantly in population, and its rulers sponsored monumental construction in the North Acropolis. The site’s ties to Coba were marked materially by a 100 km long causeway built to connect the two sites during this phase (Suhler et al. 1998). Ceramic and architectural patterns indicate interaction between the people of Yaxuna and Early Puuc populations to the west, while central and southern lowland diagnostics are absent, signaling a shift from the Early Classic interactions with the Peten (Suhler et al. 1998, 2004; Stanton and Gallareta 2001).

The Yaxuna IVa (AD 750–900) and IVb (AD 900–1250) phases encompass the Terminal Classic Period of greatest interest in this paper. The first phase witnessed intense building activities at the site, including the construction of crude fortification walls near the end of the phase, much like those known from the Peten region (Stanton et al. 2004). Numerous buildings were destroyed and ritually terminated, suggesting that conflict and warfare were common during this period. Suhler and colleagues (1998: 180; also Suhler et al. 2004) argue that Yaxuna was an outpost by which Coba sought to contain the growing influence of Chichen Itza in the ninth century.

The Yaxuna IVb phase, marked by the presence of Sotuta ceramics, apparently corresponds with the site’s conquest by Chichen Itza (Suhler et al. 1998). A Puuc-style elite residential complex was razed and replaced by a large residential structure whose inhabitants used Soruta ceramics (Stanton and Gallareta 2001: 214), and a structure in the North Acropolis interpreted as a popol na council house was burned and torn down (Suhler et al. 2004: 475). The many whole and partial vessels found smashed on the building’s floor may be evidence of celebrations or ceremonial activities associated with the ritual destruction of the building following the site’s conquest (Stanton and Gallareta 2001: 215; Suhler et al. 2004: 475). Despite these events in the city’s center, there is relatively little new construction at Yaxuna during this phase, which led the excavators to conclude that the city was largely depopulated, perhaps converted into a staging point for the Itza conquest of Coba (Suhler et al. 1998: 178).

The site of Ek Balam, a large center located 51 km northeast of Chichen Itza, provides a contrasting case. Intensive investigations at Ek Balam have shown that the site witnessed a peak occupation during the Late Yumcbab phase (AD 700–1050; Bey et al. 1998: 185; Ringle et al. 2004). The Late Yumcbab is a long ceramic phase, which certainly clouds our understanding of sociopolitical changes during this important period, but the presence of distinct architectural styles—Florescent masonry with slab vaults and poor masonry covered by thick plaster, Florescent veneer masonry, and a later lower-quality masonry style—permit finer chronological resolution (Bey et al. 1998: 178). The latter, they argue, is coeval with post-monumental Uxmal (i.e., tenth century or later). This finer-grained chronology allows Ringle and colleagues (1998: 226) to marshal evidence that the rulers of Ek Balam continued the tradition of divine kinship until sometime around AD 900.

* Changes in the organization of the causeways that connected the elite residences at Chichen Itza have led Rafael Cobos and Teresa Winemiller (2001) to argue that the mul tepal political organization that existed at Chichen Itza in the ninth century was replaced by more centralized governance and economic structures around ca. AD 900.
DISCUSSION

Two periods of significantly decreased rainfall are indicated in the proxy records of Lakes Chichancanab and Punta Laguna for the ninth and tenth centuries and again in the twelfth century. The role that these climatic shifts might have played in the events of the northeastern and north-central lowlands is an interesting question. Unless the current ceramic chronologies are radically misdated, the polities of this region generally do not seem to witness a decline or collapse during this time of decreased precipitation, although demographic patterns must be tentative given the paucity of full-coverage settlement surveys. Chichen Itza, Ek Balam, and Coba all prospered during the peak drought conditions of the ninth century (there may have been a reprieve from drought conditions in the middle of the Terminal Classic, but the dating control is poor), albeit in a context of intense regional competition making it difficult to postulate that the collapse was a pan-lowland phenomenon (an observation echoed by Ringle et al. [2004: 606]). The fortunes of individual sites differ significantly, though, and the leaders of Chichen Itza were clearly the most successful at expanding their regional influence and power during this drier period, especially during the tenth century.3

What role did climatic change play in the success of Chichen Itza? William Folan and Joel Gunn (Folan et al. 1983a; Gunn and Adams 1986) made the first strong argument for the role of climatic change in the Terminal Classic northeastern lowlands, but few archaeologists followed their lead. Today, most archaeologists working in the northern lowlands stress the role of Chichen Itza and emphasize the political and economic differences between Chichen Itza and its neighbors: its multi-petal political organization and ideology (Dunning and Kowalski 1994; Ringle et al. 1998); its more efficient market economy, based on mercantile instead of staple production (Kepecs et al. 1994); and its privileged links to circum-Caribbean canoe trade routes (Andrews and Gallareta 1986; Kepecs et al. 1994).

These sociopolitical characteristics would have provided the leaders of Chichen Itza considerable advantages in times of drought-induced staple shortage, as Nicholas Dunning (1992) points out. Mercantile production of salt and presumably cotton would have provided high-value staple goods that could have been traded for staples from areas more conducive to agriculture and/or unaffected by drier climatic conditions, and their access to the canoe networks would have allowed them to import those bulky staple goods more efficiently than sites that relied on overland trade routes (Drennan 1984). A market-oriented economic system would have permitted the more efficient distribution of staple and nonstaple goods (Kepecs et al. 1994), and a decentralized political organization could have responded more effectively to local shortfalls (Dunning 1992). Finally, an ideology based more on secular rulership and multi-petal governance would not be as susceptible as divine kingship to being undermined by natural disasters (Dunning and Kowalski 1994).

The correspondence of Chichen Itza’s expansion with drier conditions in the proxy data from Lakes Chichancanab and Punta Laguna suggests that drier conditions were a factor in that polity’s success. The region’s other sites, however, do not experience the rapid decline and abandonment that many centers to the south witnessed, despite similarly high population densities, political authority based on divine kingship, and the lower average precipitation in this region compared to the southern and central lowlands. This regional variability demonstrates that the role of climatic change in the Terminal Classic Period must be understood in light of the sociopolitical and cultural aspects of Maya civilization.

The Northwestern Lowlands

The Paleoclimatic Record. The northwestern corner of the Yucatan Peninsula is the driest region of the entire peninsula and is highly suited to paleoclimatic study because of the steep rainfall gradient (fig. 2). Hodell and colleagues (Hodell et al. 2005b) studied a 5.1 m sediment core from a sinkhole lake named Aguada X’caamal. Unlike the Chichancanab and Punta Laguna records, the oxygen isotopic signal at X’caamal shows relatively little change during the Terminal Classic Period (fig. 4). The ninth- and tenth-century drought, which is so prominent in the north-central and northeastern lowlands, either had little effect on E/P in northwestern Yucatan or was not recorded in the sediments of Aguada X’caamal. Nyberg and colleagues (2002) found evidence of a warming in the northeastern Caribbean off Puerto Rico around AD 700–950 and suggested that the pattern may have resulted from exception-}

3 Even under the shorter chronology for Chichen Itza that some scholars advocate (e.g., Ringle et al. 1998; Scheller and Mathews 1998; cf. Shubler et al. 2004), the site clearly prospered in the tenth century.
but many sculptures without texts probably date to AD 850–950 based on their stylistic characteristics (Pablo 1991; García 1999). The city as a whole, though, witnessed much less architectural investment after ca. AD 850, a trend that culminated in the site’s abandonment by ca. AD 1000. Miguel Rivera Dorado (1991: 47) links this decline to the rise of Uxmal as a regional center of power.

Despite antecedents like Oxkintok, the Puuc region underwent a period of remarkable expansion of population densities in the late eighth and ninth centuries. This growth may have included some immigration from southern polities, although scholars working in the region find little evidence that this population growth was not largely autochthonous (Carmean et al. 2004). Regardless, by AD 800, the Puuc region was densely occupied, and closely spaced political centers were characterized by large palaces, pyramids, and broad plazas. As was the case in most of the central and southern lowlands in the eighth and ninth centuries, the population expansion in the Puuc brought increasing interpolity conflict: walls were built at many sites, including Uxmal, Chacchob, and Cuca (Kurjack and Andrews 1976; Webster 1979); murals at Mulchik show a battle scene; and stone sculptures depict rulers in military costume. The Puuc polities were also similar to their southern counterparts in that their rulers’ authority derived in part from an ideology of divine kingship (Carmean et al. 2004; Dunning 1992; Dunning and Kowalski 1994; Kowalski 1987, 1989, 1994; Kowalski and Dunning 1999). Rulers of powerful sites commissioned carved stone stelae depicting them wearing costume elements like K’wil headresses traditionally associated with divine rulership and inscribed with hieroglyphic texts naming them as k’uhul ajawob’.

Sayil is one of the Puuc sites that we know best, thanks to extensive mapping and excavation directed by Jeremy Sabloff (Sabloff and Tourtellot 1992). Survey around Sayil indicates that the city extended over 4.5 km2 and had between 7,000 and 10,000 inhabitants, a figure that reached perhaps 16,000 if the site’s hinterland is included (Dunning 1992). The city is a series of architectural complexes, including elite residential compounds, temple-pyramids, and a ball court. Raised sakes connect these major groups, which are surrounded by a mosaic of residential groups for people of various statuses (Carmean 1991, 1998). Based on two radiocarbon dates, architectural mosaic styles, and obsidian hydration dates, Tourtellot and Sabloff (1994: 87–88) argue that the site was occupied between AD 800 and 950, and that the site center and most of the hinterland were abandoned prior to AD 1000, thus following the boom-bust pattern found at many Puuc sites.

The largest of the Puuc cities was Uxmal, which grew in power and influence to eclipse neighboring cities and become the capital of a regional state in the eastern Puuc by ca. AD 850 (Dunning and Kowalski 1994). The ruler Chan Chak K’ak’nal Ahaw (“Lord Chac”) commissioned many of the largest structures at the heart of Uxmal, drawing on a large hinterland populace who built the most powerful statements of divine kingship known to the Puuc region (Kowalski 1987). The public monuments of Chan Chak K’ak’nal Ahaw’s reign also show more militaristic themes than do earlier monuments (Dunning and Kowalski 1994: 81), and they can be dated by hieroglyphic texts to between AD 895 and 907 (Kowalski 1994). Some of the artistic canons and symbols employed on Chan Chak K’ak’nal Ahaw’s art and architecture indicate influences from highland or Mexicanized Putun Maya peoples, as was also the case at Chichen Itza. Despite these “foreign” elements, the buildings and architectural sculpture of buildings of Chan Chak K’ak’nal Ahaw’s reign, like the House of the Governor and the Nunnery Quadrangle, show clear connections to traditional Classic Maya architectural design and ideology (Kowalski 1987, 1989, 1994). There is little evidence for monumental buildings later than the reign of this powerful ruler, suggesting that the site ceased to be a major political force sometime between AD 925 and 975 (Kowalski 1994).

Explanations for Uxmal’s fall from prominence tend to focus on either political or ecological factors. Political models generally emphasize the Terminal Classic growth of Chichen Itza, the increasing depictions of military themes at Puuc sites and Chichen Itza, and the appearance of the same personal names at both Chichen Itza and Uxmal (Kowalski 1985). Furthermore, excavators at Uxmal and other sites in the region have found some Soruta ceramics, usually associated with Chichen Itza (cf. Stanton and Gallareta 2001). Many scholars would argue that this evidence betokens a regional conflict between Uxmal and Chichen Itza, in which Chichen Itza eventually won, resulting in the rapid decline of Puuc sites in the early- to mid-twentieth century and the continued growth of Chichen Itza and its influence over the Puuc region (Carmean et al. 2004; Dunning and Kowalski 1994).

Nicholas Dunning suggested that the abandonment of many Puuc cities in the tenth century was due in part to environmental changes caused by a shift in climatic conditions. He viewed the ninth-century demographic explosion, political centralization, and artistic and architectural florescence in the Puuc region as an “adaptive response to a period of increasing rainfall and regional population growth” (Dunning 1992: 157) that could not be sustained when rainfall began to decrease in the tenth century. Dunning did not see climatic change occurring in a vacuum, however, but contextualized it within the environmental conditions and political structures of the northwestern lowlands. He argued that the precarious ecological balance between burgeoning populations and the carrying capacity of the Puuc region was especially risky. Furthermore, given the ideology of divine kingship and the place of the ruler as the intermediary between his subjects and the spiritual realm, crop failure was likely perceived as a failure of individual
rulers and, ultimately, of divine kingship itself. In contrast, he proposed, the mul tepal system of council government suggested for Chichen Itza entailed an ideology that was less susceptible to being undermined by agricultural downturns, thus helping explain the growth of that polity during the ninth through eleventh centuries.

North and east of the Puuc region, Dzibilchaltun went through a similar trajectory of Late Classic growth and Terminal Classic florescence, reaching a population maximum of perhaps 25,000, followed by a subsequent rapid population decline and cessation of monumental building activities (Andrews and Andrews 1980; Sharer 1994). During its heyday, the polity’s rulers commissioned twenty-five carved monuments, including one with a period-ending date corresponding to AD 849, and the rulers show themselves using emblems of Classic divine kingship, such as K’awiil scepters.

**Discussion.** Assigning climatic change a role in the ninth- and tenth-century history of the northwestern lowlands is complicated by the lack of direct evidence for any drought during this period in the Aguada X’caamal proxy data. Even if one wished to discount the X’caamal record as not recording climatic change, the next best proxy records, the cores from Chichancnab (fig. 11), indicate early (ca. AD 770–870) and late (ca. AD 920–1020) drought phases with an intervening period (ca. AD 870–920) of relatively moister conditions. The archaeological data for the Puuc region during this same period demonstrate the complex relationships between climatic, environmental, and sociocultural changes: the dry ninth century witnesses significant population growth and political florescence in the Puuc region, a trend that continues with increased political centralization of the region under Uxmal’s reign as rainfall increases in the later ninth century. The region’s sites undergo a decline subsequently in the tenth century after drier conditions resumed.²

The apparent paradox, though, between demographic growth and political centralization in the Puuc during drier conditions is even more striking at sites farther north. The area around Dzibilchaltun is the most arid part of the peninsula, and it receives significantly less precipitation than the Puuc region. One would expect that any lessening of rainfall would be felt most strongly here, given that even slight fluctuations in rainfall could limit maize agriculture. Dzibilchaltun, however, experiences roughly the same boom-bust trajectory as the Puuc region, including a ninth-century florescence during dry conditions.³

¹Dunning (1992:151) suggests that there was a tenth-century decrease in rainfall due to global climatic change, but instead to largely anthropogenic processes, the product of population growth across the peninsula, increased deforestation, and reduced evapotranspiration.⁴ Although the proxy data from Lake Chichancnab support Dunning’s hypothesis of drying in the tenth century, they do not support his suggestion that the ninth century was a period of increasing rainfall that facilitated the Puuc florescence.

²It is possible that Dzibilchaltun’s economy was based not on maize agriculture but on control of salt-producing areas of the nearby coast, which would be enhanced by drier climatic conditions (Andrews 1981). Furthermore, the water table in this region is closer to the surface than in the case in the Puuc zone, and thus it is accessible through cenotes.

³Discussion and Conclusions

The ninth and tenth centuries are a critical period for understanding the history of Maya civilization, but the complexities of this period are masked when it is framed as a unitary, event-like “collapse” (see Cowgill 1988). A growing body of archaeological data demonstrates that the Maya collapse can only be understood as a set of interrelated historical processes, not as a single event. Furthermore, contrary to popular conception, these processes did not bring about the end of Maya civilization. They did, however, correspond with a shift in the center of gravity of Maya civilization away from the central and southern lowlands, as new centers of political power and cultural innovation rose in the northern lowlands and, later, the highlands. New political structures and ideologies and changes in the economic foundations of these new centers mark the Post-Classic Period of Maya civilization, distinct from but in no ways inferior to the Classic Period (Sabloff 1990).

What role did climatic change play in these remarkable transformations? Several observations are pertinent. First, the accumulating evidence demonstrates that there was a multigenerational period of significantly elevated evaporation-to-precipitation ratios (i.e., drier conditions) across much of the Yucatan Peninsula during the Terminal Classic Period (AD 800–1000). Oxygen isotope ratios in cores from four of the five lakes studied show an increase in δ18O values in the Terminal Classic Period beginning around AD 800 (figs. 4 and 16). These results are supported by the data from the Cariaco Basin that indicate an extended dry period from ca. AD 750 to 950. Moreover, the sediments from cores from Lake Chichancnab and the Cariaco Basin strongly suggest that this period of generally reduced precipitation was punctuated by distinct multiyear drought events with a 40- to 50-year periodicity (ca. AD 760, 810, 860, and 910; Haug et al. 2003; Hodell et al. 2005a).

Equally important, though, is the geographic variability in the paleoclimatic signal (fig. 16). The strongest evidence for reduced rainfall levels comes from the north-central and northeastern region of the Yucatan Peninsula, where cores suggest two phases of drier conditions during the Terminal Classic Period (ca. AD 770–870 and AD 920–1020) with an intervening period (ca. AD 870–920) of relatively moister conditions. In contrast, sediment cores from Aguada X’caamal in the northwestern part of the Yucatan Peninsula record no change during the same period. The δ18O values in cores from both Lakes Peten Itza and Salpeten increased during the Terminal Classic Period, indicating either increased E/P (i.e., reduced rainfall) and/or reduced runoff as a consequence of reforestation of the lakes’ drainage basins.

The general chronological correspondence between climatic shifts evident in the various proxy records and the diverse sociopolitical transformations experienced by different Maya polities in the ninth and tenth centuries that we have described above is striking, and it demands explanation. But it can also lead to simplistic models of cause-and-effect without modeling the complex relationships between climatic change, environmental transformation, and sociocultural processes. For example, Peter deMenocal (2001: 672, emphasis added) states that “available paleoclimate and archaeological
data show that societal collapse and prolonged drought were coincident within respective dating uncertainties. Coincidence alone cannot demonstrate causality. However, joint interpretation of the paleoclimatic and archaeological evidence now underscores the important role of persistent long-term drought in the collapse of Maya civilization. The simple fact that climatic changes and cultural changes are effectively contemporaneous in our observational record serves as a very weak empirical foundation for scientifically evaluating the causal relationship between the two, given the limitations described above in precisely dating either record, which are then amplified when trying to correlate the two records.

If we are to confidently move from temporal correlation to causality, we must model how climatic changes would have affected human populations and the environment in which they lived. Indeed, until that occurs, conclusions about the relative importance—or unimportance—of climatic change will be almost entirely determined by a scholar’s a priori knowledge about the role of climate (see Erickson 1999; Webster 2002: 247). Two facts complicate this kind of modeling. First, obtaining a quantitative estimate of past rainfall reduction from the measurable changes in proxy records is problematic, requiring complex modeling and many assumptions about the relationships between proxy measures and past climatic conditions. Second, available proxy records lack the temporal resolution needed to assess intra-annual rainfall differences. This is critical, because there is no simple linear correlation between crop yields and annual precipitation. Annual rainfall levels can drop significantly before passing a threshold at which they adversely affect yields. The seasonal distribution of rainfall is the key factor, because the yields of many crops, including maize, are most affected by shortages in moisture availability during certain critical phases of crop development, such as germination and pollination. The same was likely true of water needed for domestic purposes like cooking; reduced rainfall during the rainy season would probably not prevent most households from storing enough water to last through the dry season, whereas reduced dry season rainfall could lead to critical shortages. Although the discovery of proxy records with seasonal resolution seems unlikely at present, we will likely be able to more securely retrodict seasonal patterns of past rainfall as models of regional climatic patterning improve.

Despite these limitations, we believe that the data currently available do permit some broad conclusions about the role of climate in the Terminal Classic Period. First, neither the paleoclimatic nor the archaeological data presently available support assertions that climatic change or drought was a primary cause for the Classic Maya collapse (cf. Gill 2000). The paleoclimatic data from the Maya lowlands show markedly distinct regional signals (fig. 16) that belie models of a monolithic, long-lasting, peninsula-wide drought. Although the proxy data suggest an overall reduced precipitation profile punctuated by some drought periods, it is not at all clear that the normal precipitation in the drier ninth century would have resulted in reduced agricultural yields during the rainy season or dry-season water shortages in the central and southern lowlands.

Although some scholars like Richardson Gill (2000) and Peter deMenocal (2001) argue that the scope of the Terminal Classic transformations were such that only significant environmental stress like that caused by climatic change could have triggered them, the variability observable in the archaeological record suggests otherwise. In the southern and central lowlands, the ninth century is generally characterized by the abandonment of many large cities, a shift away from the ideology of divine kingship, and significant demographic decline, but the details and timing of these transformations vary considerably between regions. The Puuc region, in contrast, experienced a demographic explosion in the ninth century before undergoing a broadly parallel decline in the later tenth century. Chichen Itza, in further contrast, apparently grew to dominate the northern lowlands in the tenth century and only later experienced a decline. To force these three cycles of political florescence and subsequent decline and decentralization, each separated by a century or more, into a unitary drought-driven model obscures more than it explains about the transformation of Maya civilization in the Terminal Classic Period.

At the regional level, significant differences from site to site also argue against any moncausal model. In many parts of the central and southern lowlands, for example, the processes that were integral to the collapse—intense interpolity competition, population growth, and increased warfare, for example—were well underway by the mid-eighth century. Similarly, at Xunantunich, on the other side of the central lowlands, significant demographic decline occurred prior to AD 780, although the site remained a political center until at least AD 850. In contrast, in other polities—Tikal and Calakmul, for example—political decentralization is most pronounced in the first half of the ninth century, although others like Caracol and Seibal experienced a political renaissance during that same period. One could attempt to correlate the various severe droughts suggested by the Cariaco data with the different sequences within the central and southern lowlands, but any correspondence would still beg the question of why the people in different sites responded in such distinct ways.

Many riverside and lakeside sites were completely abandoned during the ninth and tenth centuries, despite their prime locations in the putatively drier environment. This is true not only of sites that were the capitals of polities founded on the ideology of divine kingship, like Quirigua and Piedras Negras, but also of many small villages and rural populations like those of the Mopan River valley in Belize (Ashmore et al. 2004; cf. Lucero 2002). Furthermore, the population density in most of the central and southern lowlands remained low for centuries, even after a return to moister climatic conditions (Cuéllar 1988). These patterns force us to again recognize the strong roles that sociopolitical factors played in the collapse, and they highlight the utility of thinking of the collapse in terms of local responses to sociopolitical, climatic, and environmental conditions (see Palka 1997).

To conclude, there is no evidence that climatic change was any more of a "trigger" for the Terminal Classic transformation of Maya civilization than
were population growth, interpolity conflict, soil erosion, and the other observable processes that began prior to or coeval with climatic changes in various regions. One could argue that climatic change is qualitatively different from these processes in that people cannot in most cases regulate its causes, but they certainly respond to adverse climatic changes to mitigate their effects. Indeed all climatic changes, even those we might consider negative, encourage some kinds of behaviors and practices and discourage others. At Chichen Itza, for example, drier conditions apparently favored economic strategies that emphasized long-distance trade and production of salt and other nonagricultural products, as well as a shift to a more decentralized political structure.

The rich and rapidly growing body of available archaeological, environmental, and climatological data leads us to offer three criteria that any model of the Maya collapse should meet. First, it must conceptualize the collapse not as a catastrophe or an event, but as a complex set of processes that were inherently social and cultural, and that transformed the demography, economy, and political organization of lowland Maya civilization over the course of several centuries. Second, it must include explicit discussion of the ways in which climatic change affects the natural and cultural contexts that shape people’s decisions, past and present. Interdisciplinary research programs following the “conjunctive approach” (Marcus 1995; Fash and Sharer 1997) provide the diverse kinds of data we need to evaluate the interrelationships between climatic change, the environment, and Maya civilization. Finally, these models must pay close attention to local climatic, environmental, and cultural conditions. The results of decades of archaeological, paleoenvironmental, and paleoclimatic research leave no room to doubt that the factors that led to the collapse of Maya polities and the abandonment of Maya sites during the Terminal Classic Period, as well as the processes of collapse themselves, varied significantly in time and space across the Maya lowlands.

ACKNOWLEDGMENTS

We would like to thank Jeffrey Quilter and Daniel Sandweiss for inviting us to participate in the 2002 Pre-Columbian Studies symposium at Dumbarton Oaks. This chapter benefited from feedback from Minette Church, David Lentz, Joyce Marcus, Robert Sharer, and the volume’s anonymous reviewers, although the authors retain responsibility for any errors of fact and the interpretations presented herein.

REFERENCES CITED


THE COLLAPSE OF MAYA CIVILIZATION

deMenocal, Peter

Diamond, Jared M.

Drennan, Richard D.

Dunning, Nicholas P.

Dunning, Nicholas P., and Timothy Beach

Dunning, Nicholas P., Timothy Beach, and David Rue

Drennan, Richard D.

Ericsom, Charles J.

Ely, Lisa L., Yahouda Enzel, Victor D.dMenocal, Peter

Diamond, Jared M.

Drennan, Richard D.

Dunning, Nicholas P.

Dunning, Nicholas P., and Timothy Beach

Dunning, Nicholas P., Timothy Beach, and David Rue

Enfield, David B., and Eric J. Alfaro

Erasmus, Charles J.

Erickson, Clark L.

Fagan, Brian M.

Fash, William L., E. Wyllys Andrews V, and T. Kam Manahan

Fash, William L., and Robert J. Sharer

Folan, William J.

Folan, William J., and B. H. Hyde

Flan, William J., Ellen R. Kintz, and Laraine A. Fletcher (eds.)

Folan, William J., Joyce Marcus, Sophia Pincemin, María del Rosario Doménguez Carrasco, Laraine A. Fletcher, and Abel Morales López

Ford, Anabel

Freidel, David A.

Freidel, David, and Justine Shaw

García Campillo, José Miguel

Giannini, Alessandra G., Yochanan Kushnir, and Mark A. Cane


Gill, Richardson B.

Yarger and Hodell
THE COLLAPSE OF MAYA CIVILIZATION

Gray, Calvin R.
Meteorological Service, Jamaica.

1993 Regional Meteorology and
Hurricanes. In Climatic Change in
the Intra-Americas Sea (George A.
Environmental Program, Edward
Arnold, London.

Gunz, Joel D., and Richard
E. W. Adams
1986 Climatic Change, Culture,
and Civilization in North America. World
Archaeology 17: 87–100.

Gunz, Joel D., William J. Folan,
and Hubert R. Rubichaux
1993 A Landscape Analysis of the
Candelaria Watershed in Mexico: Insights into Paleoclimates Affecting
Upland Horticulture in the Southern
Yucatan Peninsula Semi-Karst.
Geoarchaeology 10: 1–42.

Gunz, Joel D., Ray T. Matheny,
and William J. Folan
2003 Climate–Change Studies in the
Maya Area: A Diachronic Analysis. Ancient
Mesoamerica 13: 79–84.

Harvison, Peter D.
1999 Lords of Tikal: Rulers of
an Ancient Maya City. Thames
and Hudson, London.

Hastenrath, Stefan
1986 On General Circulation and Energy
Budget in the Area of the Central
American Seas. Journal of Atmospheric
Sciences 43: 704–711.

1987 Rainfall Distribution and Regime in
Central America. Archiv für Meteorologie,
Geophysik und Bioklimatologie, Ser. B 35:
201–241.

1998 Variations in Low-Latitude
Circulation and Extreme Climatic Events
in the Tropical Americas. Journal of
Atmospheric Sciences 26: 202–265.

1999 Interannual Variability and
the Annual Cycle: Mechanisms of
Circulation and Climate in the Tropical
Atlantic Sector. Monthly Weather Review
117: 2097–2107.

2003 Climate Dynamics of the Tropics.
Kluwer Academic Publishers, Dordrecht,
The Netherlands.

Haug, Gerald H., Konrad A.
Hughes, Daniel M. Sigman, Larry
C. Peterson, and Ursula Rohli
2000 Southward Migration of the
Intertropical Convergence Zone through

Haug, Gerald H., Dietel Günther,
Larry C. Peterson, Daniel M.
Sigman, Konrad A. Hughen,
and Beat Aeschlimann
2003 Climate and the Collapse of Maya:

Hodell, David A., Jason H. Curtis,
Glenn A. Jones, Antonia Higuera-
Gundy, Mark Brenner, Michael W.
Binford, and Kathleen T. Dorsey
1991 Reconstruction of Caribbean
Climate Change over the Past 10,500

Hodell, David A., Jason H.
Curtis, and Mark Brenner
1995 Possible Role of Climate in the
Collapse of Classic Maya Civilization.

Hodell, David A., Mark Brenner,
Jason H. Curtis, and Thomas P. Guilderson
2002 Solar Forcing of Drought Frequency
in the Maya Lowlands. Science 292:
1567–1580.

Hodell, David A., Mark Brenner,
George Kamenov, and Rhonda Quinn
2003 Spatial Variation of Strontium
Isotopes (87Sr/86Sr) in the Maya Region:
A Tool for Tracking Ancient Human
Migration. Journal of Archaeological

Hodell, David A., Mark Brenner,
and Jason H. Curtis
2005a Terminal Classic Drought in the
Northern Maya Lowlands Inferred from
Multiple Sediment Cores in Lake
Chichancanab (Mexico). Quaternary
Science Reviews 24: 1413–1427.

2005b Climate Change on the Yucatan
Peninsula during the Little Ice Age.

Houston, Stephen D.
1989 Archaeology and Maya Writing.
Journal of World Prehistory 3: 1–32.

1993 Hierarchy and History at Das Pilas:
Dynastic Politics of the Classic Maya.
University of Texas Press, Austin.

Islebe, Gerald A., Henry
Houghhismatra, Mark Brenner, Jason
H. Curtis, and David A. Hodell
1998 A Holocene Vegetation History
from Lowland Guatemala. The Holocene
8: 269–271.

Jones, Christopher
1991 Cycles of Growth at Tikal. In Classic
Maya Political History: Hieroglyphic and
Archaeological Evidence (T. Patrick
Culbert, ed.): 102–127. Cambridge

Kepcs, Susan
1998 Diachronic Ceramic Evidence and
Its Social Implications in the Chichnchel
Region, Northeast Yucatan, Mexico.

Kepcs, Susan, Gary Feinman,
and Sylviane Boucher
1994 Chicken Itza and its Hinterland:
A World-Systems Perspective. Ancient

Kowalski, Jeff Karl
1986 Lords of the Northern Maya:
Dynastic History in the Inscriptions of
Uxmal and Chichen Itza. Expedition 27
(3): 50–60.

1987 The House of the Governor: A Maya
Palace at Uxmal, Yucatan, Mexico. The
Civilization of the American Indian 176.
University of Oklahoma Press, Norman.

1989 Who Am I among the Itza? Links
between Northern Yucatan and the
Western Maya Lowlands and Highlands.
In Mesoamerica after the Decline of
Teotihuacan, A.D. 700–900 (Richard A.
Dumbarton Oaks Research Library and
Collection, Washington, D.C.

1994 The Puuc as Seen from Uxmal.
In Hidden among the Hills: Maya
Archaeology of the Northwest Yucatan
Peninsula (Hanna J. Prem, ed.): 90–110.
Acta Mesoamerican 5. Verlag von
Flammon, Mönchsmihl, Germany.

Kowalski, Jeff Karl,
and Nicholas P. Manning
1999 The Architecture of Uxmal: The
Symbols of Statemaking at a Puuc
Maya Regional Capital. In Mesoamerican
Architecture as a Cultural Symbol (Jeff
University Press, New York.

Kurjack, Edward B.,
and E. Wyllys Andrews V
1976 Early Boundary Maintenance in
Northeast Yucatan. Mesoamerican

Kurjack, Edward B.,
and Merle G. Robertthson
1994 Polities and Art at Chichen Itza.
In Seventh Palenque Round Table, 1989
(Merle G. Robertson and Virginia M.
Fields, eds.): 19–23. Pre-Columbian Art
Research Institute, San Francisco.

Leyden, Barbara W.,
Mark Brenner, and Bruce H. Dahlín
1998 Cultural and Climatic History of
Cozumel and Island Maya in Quintana
Roo, Mexico. Quaternary Research 49:
111–122.

Lowe, John W. G.
1984 The Dynamics of Apocalyse: A
Systems Simulation of the Classic Maya
Collapse. University of New Mexico
Press, Albuquerque.

Lucero, Lisa J.
2003 The Collapse of the Classic Maya:
A Case for the Role of Water Control.


Puleston, Dennis E. 1979 An Epistemological Pathology and the Collapse or, Why the Maya Kept the Short Count. In Maya Archaeology and Ethnobiology (Norman Hammond and Gordon R. Willey, eds.): 83–74. University of Texas Press, Austin.


Robles Castellanos, Fernando 1990 La secuencia cerámica de la región de Cobá, Quinatana Roo. Instituto Nacional de Antropología e Historia, México, D. F.


Smith, Robert E. 1994 Ceramic Sequence at Uxactun. Guatemala. Publication 40, Middle American Research Institute, Tulane University, New Orleans.


THE COLLAPSE OF MAYA CIVILIZATION


