Climate and the Collapse of Maya Civilization

A series of multi-year droughts helped to doom an ancient culture

Larry C. Peterson and Gerald H. Haug

With their magnificent architecture and sophisticated knowledge of astronomy and mathematics, the Maya boasted one of the great cultures of the ancient world. Although they had not discovered the wheel and were without metal tools, the Maya constructed massive pyramids, temples and monuments of hewn stone both in large cities and in smaller ceremonial centers throughout the lowlands of the Yucatán Peninsula, which covers parts of what are now southern Mexico and Guatemala and essentially all of Belize. From celestial observatories, such as the one at Chichén Itzá, they tracked the progress of Venus and developed a calendar based on a solar year of 365 days. They created their own system of mathematics, using a base number of 20 with a concept of zero. And they developed a hieroglyphic scheme for writing, one that used hundreds of elaborate signs.

During its Classic period (250–950 A.D.), Maya civilization reached a zenith. At its peak, around 750 A.D., the population may have topped 13 million. Then, between about 750 and 950 A.D., their society imploded. The Maya abandoned what had been densely populated urban centers, leaving their impressive stone edifices to fall into ruin. The demise of Maya civilization (which archaeologists call "the terminal Classic collapse") has been one of the great anthropological mysteries of modern times. What could have happened?

Scholars have advanced a variety of theories over the years, pinning the fault on everything from internal warfare to foreign intrusion, from widespread outbreaks of disease to a dangerous dependence on monocropping, from environmental degradation to climate change. Some combination of these and other factors may well be where the truth lies. However, in recent years, evidence has mounted that unusual shifts in atmospheric patterns took place near the end of the Classic Maya period, lending credence to the notion that climate, and specifically drought, indeed played a hand in the decline of this ancient civilization.

Rainforest Crunch

Given the common image of lost Maya cities buried beneath tangles of jungle vegetation, it may come as a surprise to discover that the Yucatán is, in fact, a seasonal desert. The lush landscape depends heavily on summer rains for nourishment, rains that vary considerably across the peninsula. Annual precipitation ranges from as little as 500 millimeters along the northern coast to as high as 4,000 millimeters in parts of the south. As much as 90 percent of this moisture falls between June and September, and a pronounced winter dry season runs from January to May.

This wet-dry contrast results from the seasonal migration of moisture associated with the intertropical convergence zone, an atmospheric feature that is sometimes known as the "meteorological equator." In this zone, the easterly trade winds of the northern and southern tropics converge, forcing air to rise and bringing on cloudiness and abundant rainfall. During the winter months, the intertropical convergence zone shifts far to the south, and dry conditions prevail over both the Yucatán Peninsula and northern South America. Then, with the coming of summer, this zone migrates north again, bringing life-giving rain to the Yucatán and southern Caribbean region.

The Maya had to deal with this seasonal contrast and, in particular, had to cope with a long dry season each year. This feature of their environment had special significance, because surface waters tend to dissolve the limestone bedrock of the Yucatán, forming caves and underground rivers but leaving little opportunity for water to flow over land. So the Maya could not simply locate their settlements along major watercourses. Even important regional centers—such as Tikal, Caracol and Calakmul—developed in places that were without permanent rivers or lakes. The lack of surface water for four or five months of the year in such areas spurred the construction of large-scale water-collection systems.

Many cities were designed to catch rainfall and channel it into quarries, ex-

Figure 1. As this 19th-century engraving depicts, Victorian-era explorations of the Yucatán revealed many ancient Maya ruins enveloped by jungle—an observation that might lead one to believe that the onset of steamy tropical conditions contributed to the collapse of Maya civilization. In fact, drought appears to have been the culprit. The authors describe how they were able to gauge the climate for Classic Maya times during the first millennium A.D. Their record shows a series of severe droughts that coincide remarkably well with the abandonment of Classic Maya sites. (Engraving by Frederick Catherwood.)

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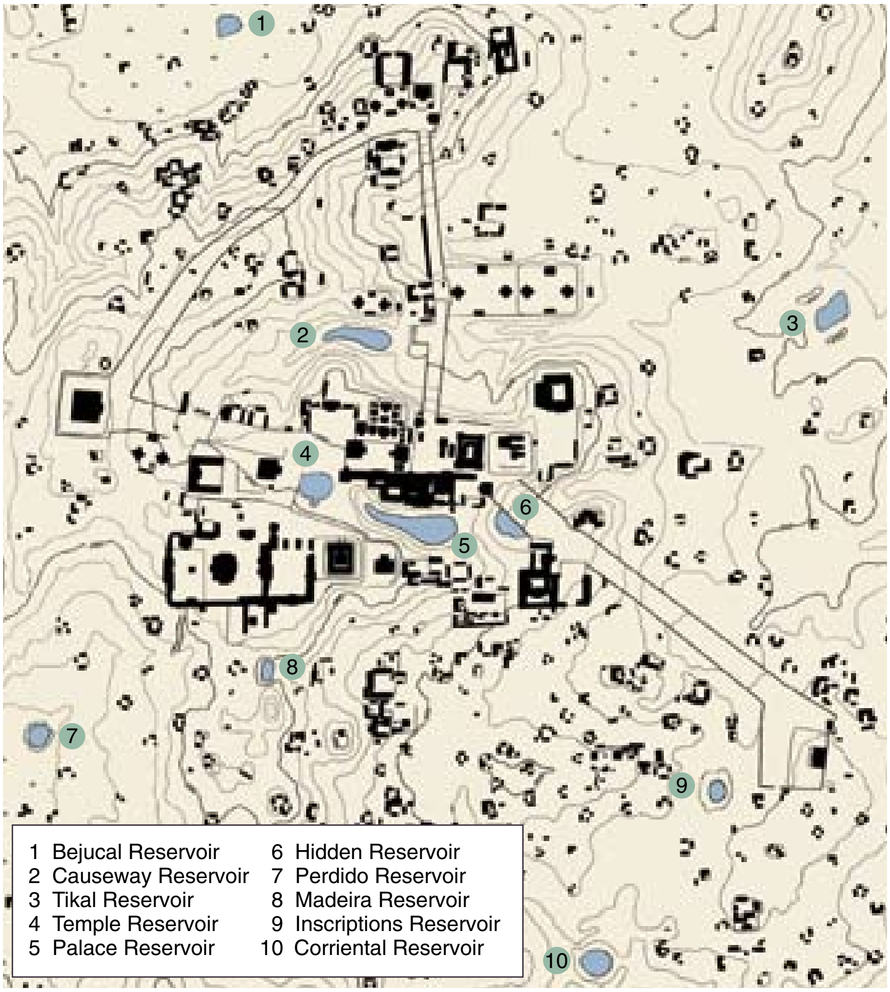

Figure 2. Maya cities commonly depended on artificial reservoirs to provide a year-round source of water. The residents of Tikal, for example, constructed several reservoirs *(blue)* near the city center, enough to provide 10,000 people with drinking water for 18 months. (Adapted from map of Carr and Hazard 1961, courtesy of the University of Pennsylvania Museum.)

cavations and natural depressions that had been specially prepared to retain the captured water without letting it seep into the ground. Tikal, for example, had numerous reservoirs, which together were capable of holding enough water to meet the drinking needs of roughly 10,000 people for about 18 months. The Maya also built reservoirs on the tops of hills, using gravity to distribute the water through canals into complex irrigation systems. Despite the sophistication of their hydrological engineering, the Maya ultimately depended on the seasonal rains to replenish their water supplies, natural groundwater being inaccessible over a considerable portion of their realm.

In his fascinating book, *The Great Maya Droughts*, independent archaeologist Richardson B. Gill persuasively argues that a lack of water was a major factor in the terminal Classic collapse. Gill pulls together an enormous amount of information on modern weather and climate, draws on the record of historical droughts and famines, and heaps on evidence from archaeology and from geological studies of ancient climates. To demonstrate the importance of the porous limestone bedrock, for example, he quotes Diego de Landa, Bishop of Yucatán, who in 1566 wrote: "Nature worked so differently in this country in the matter of rivers and springs, which in all the rest of the world run on top of the land, that here in this country all run and flow through secret passages under it."

Gill builds an impressive case. When his work was first published (five years ago), the most compelling evidence for drought came from sediment cores that David A. Hodell, Jason H. Curtis, Mark Brenner and other geologists at the University of Florida had collected from a number of Yucatán lakes. Their measurements of these ancient deposits indicate that the driest interval of the last 7,000 years fell between 800 and 1000 A.D.—coincident with the collapse of Classic Maya civilization. Later work by these same investigators found evidence for a recurrent pattern of drought, which seems also to explain other, less dramatic breaks in Maya cultural evolution.

The Venezuelan Connection

Our own contribution to the understanding of climatic conditions during the time of the terminal Classic collapse comes from a distant location, one not inhabited by the Maya at all. Offshore of the northern coast of Venezuela sits a remarkable depression in the continental shelf known as the Cariaco Basin. Reaching depths of about a kilometer but surrounded by the shallow shelf and banks, the Cariaco Basin acts as a natural sediment trap. What is more, the shallow lip of the basin prevents its deeper waters from mixing readily with the open ocean to the north. As a result, deep Cariaco waters are devoid of dissolved oxygen (and have been since near the end of the last glacial period, some 14,500 years ago). The lack of oxygen means that the muddy floor of the basin cannot support bottom-dwelling marine organisms, which in other places churn up the sediment in their search for food. This lack of a deep-sea fauna preserves the integrity of the sediments, which here are made up of paired light and dark layers, each less than a millimeter thick.

The origin of these layers is easy enough to understand: During Northern Hemisphere winter and spring, the intertropical convergence zone sits at its southernmost position near the equator, which means that little rain falls over the Cariaco Basin. At this time of year, strong trade winds blow along the northern coast of Venezuela, causing cool, nutrient-rich waters to rise, which in turn allows plankton living near the surface to proliferate. When these organisms die, their shelly remains fall to the bottom, where they form a light-colored layer. During the summer, as the northern hemisphere warms, the intertropical convergence zone moves steadily northward until it takes up a position near the northern coast of South America. The trade winds diminish, and the rainy season begins, increasing the flow of local rivers, which then deliver a considerable load of suspended sediment to the sea. These land-derived

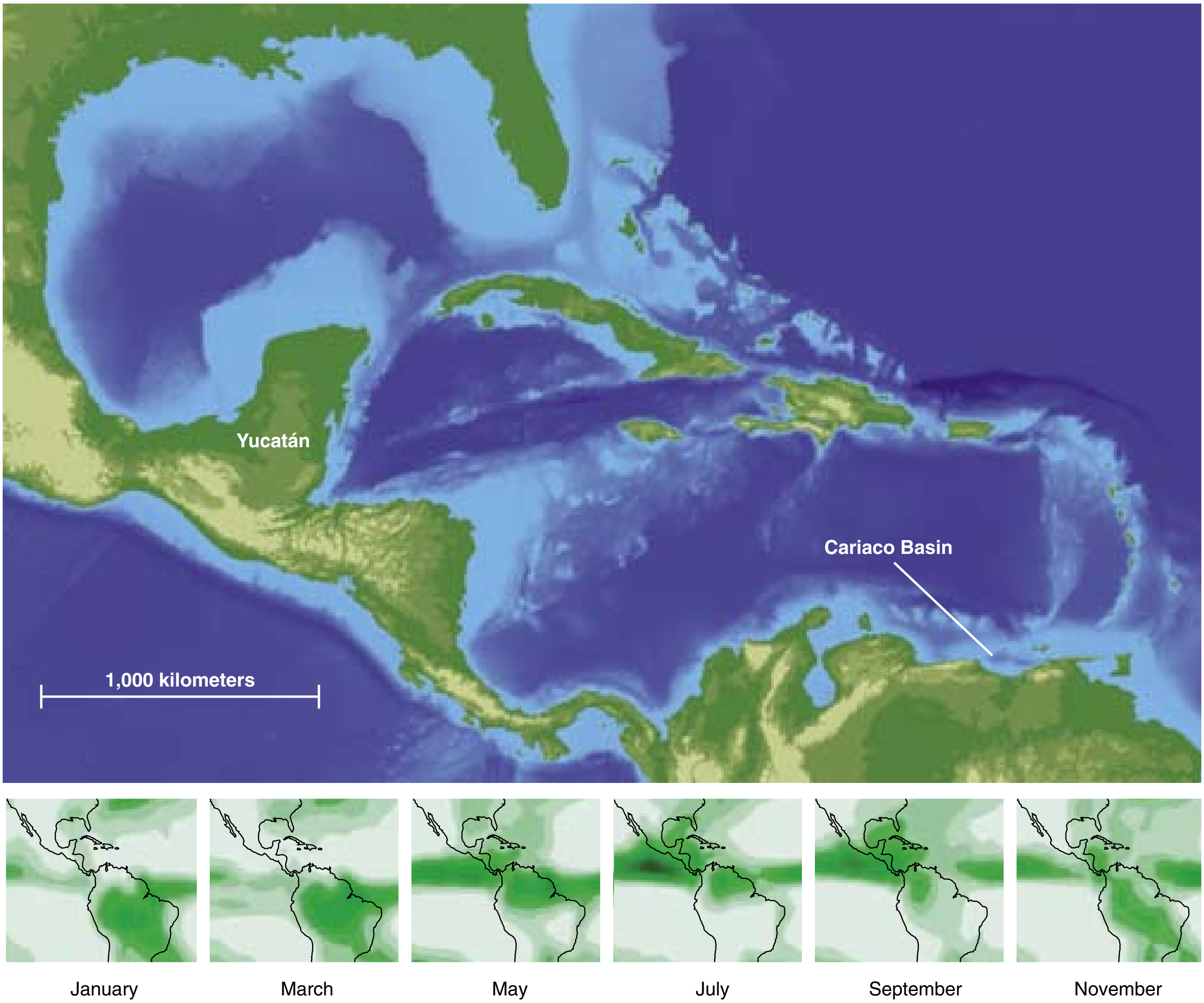

Figure 3. The authors turned to sediments from the Cariaco Basin off Venezuela to investigate climate conditions affecting the Classic Maya, who lived in the Yucatán Peninsula, more than 2,000 kilometers away *(top)*. Both places experience the same general climate, with distinct rainy and dry seasons. This yearly pattern arises because the equatorial band of high precipitation falls to the south of both the Yucatán and Cariaco Basin during Northern Hemisphere winter but by summer moves north to encompass both areas *(dark green in lower panels)*. Why did the authors choose to examine the sediments of the Cariaco Basin in particular? Unlike other deep-sea sites, this basin is surrounded by shallow continental shelf on all sides, a configuration that prevents deep Cariaco waters from mixing with the open ocean. As a result, these waters lack oxygen and do not support burrowing deep-sea organisms, which would otherwise churn up the fine layers of sediment laid down during each wet and dry season. The undisturbed sediments of the Cariaco Basin thus preserve a detailed record of ancient climate.

materials eventually settle out of the water, leaving on the ocean floor a dark-colored layer of mineral grains on top of the earlier accumulation of light-colored microfossil shells.

Although burrowing organisms mix up such seasonal deposits elsewhere, the anoxic Cariaco Basin preserves these distinct light-and-dark couplets. This dramatic alternation in composition provides a built-in clock that geologists can use to determine with yearly resolution just when the sediments were laid down. And fortunately, at least for people interested in the history of Maya civilization, both the Yucatán and northern Venezuela experience the same general pattern of seasonal rainfall, with both areas today near the northern limit of the intertropical convergence zone. Hence marine sediments from the Cariaco Basin hold considerable information about the shifts in climate that the Maya experienced.

Our efforts to read that archive began in 1996, when the scientific drillship *JOIDES Resolution*, operated by an international research collaboration called the Ocean Drilling Program, sailed to the center of the Cariaco Basin. Once there, technicians obtained a 170-meter-long sequence of sediment cores expressly for the purpose of probing tropical climate change. The study of those sediments, which had accumulated at an enormous rate and had remained completely undisturbed since the time of deposition, offered us and other geologists a rare, high-resolution glimpse into the distant past. An important aspect of our work on these sediments has been to use the concentration of mineral grains eroded from land to gauge the amount of rain that fell on adjacent parts of the South American continent.

One could, of course, gain such an understanding by examining these

Figure 4. Sediments from the Cariaco Basin contain finely laminated sediments. The lighter layers are composed mostly of microscopic shells formed in the surface waters during the dry season, whereas the darker layers contain an abundance of mineral fragments swept into the basin from nearby portions of the South American continent during the rainy season. This section of core measures about 10 centimeters across. (Photograph courtesy of the authors.)

sediments directly under a microscope, but characterizing vast numbers of sediment couplets in this way would have been extraordinarily tedious. So we sought out a more efficient approach. Of the several methods we explored, the most useful proved to be the measurement of titanium and iron, elements that are abundant in most continental rocks but not in the shelly remains of marine organisms. High levels of titanium and iron thus indicate that large amounts of silt and clay were washed off the adjacent land and swept into the basin. That is, finding lots of titanium and iron at a particular level in these sediments means that rainfall in this region—and by inference over the Yucatán—must have been high at the time of deposition. Low titanium and iron, by contrast, means that rain was sparse.

A First-millennium Rain Gauge

The measurement of elemental concentrations in sediments by traditional methods is time consuming and has the further drawback that it destroys the material under study. But recently geologists have overcome these problems with a technique called x-ray fluorescence, which involves illuminating a sample with x rays and measuring the amount of light given off as a function of wavelength. Suitable analysis of this light spectrum (which can be fully automated) reveals the concentration of various elements in the sample. This approach allows for the rapid assessment of elemental abundances in sediment cores that have been split down the middle, producing records that are far more detailed than what could be expected from extracting and measuring individual samples.

We initially made measurements of x-ray fluorescence using a core scanner housed at Bremen University in Germany, where the Ocean Drilling Program maintains a repository of cores. We determined the titanium and iron concentration at 2-millimeter spacings over a sediment section of interest, one that had already been dated using radiocarbon, but after finding nearly identical variations in these two elements, we chose to track only titanium.

Within this interval, and at this measurement resolution, the most obvious feature is the generally low titanium level in layers deposited between about 500 and 200 years ago, a period that corresponds to what some climatologists call the Little Ice Age. These results presumably reflect dry conditions and indicate that the intertropical convergence zone and its associated rainfall must not have reached as far north as they do now. We also found several other broad intervals of low titanium, including one in sediments deposited between about 800 and 1000 A.D., which corresponds to the period of severe drought that Hodell and his colleagues had inferred from their Yucatán lake cores.

Hodell's work had led to the impression that an extended "megadrought" plagued the Maya homeland for a century or two, with devastating consequences for the indigenous population. But this interpretation troubled some Mayanists. They pointed out archaeological evidence for considerable variability in the timing and regional pattern of collapse. A "one drought fits all" model seems too simplistic, given that the collapse apparently happened at different places at different times, while affecting some population centers hardly at all.

Although the Cariaco Basin is quite distant from the Yucatán, its unique sediments offered the possibility of obtaining an immensely detailed chronology of ancient climate swings, and we wanted to push the record as far as it would go so as to provide further insight into the climate during the Maya collapse. Unfortunately, we had reached the maximum analytical resolution of the Bremen core scanner. But with the help of Detlef Günther and Beat Aeschlimann at the Swiss Federal Institute of Technology in Zurich, we did much better using a special "micro" x-ray fluorescence system they had set up in their lab. This instrument was designed for small samples, not long stretches of deep-sea sediment, but it could accommodate short slabs of material cut from our cores. This device allowed us to make elemental analyses with a 50-micrometer measurement spacing, which in the Cariaco cores corresponds to about two months of time—an incredibly fine resolution for marine sediments, which more typically encompass hundreds to thousands of years of geologic history in a single sample.

Using Günther and Aeschlimann's wonderful instrument, we measured two slabs of sediment that together cover the time interval from about 200 to 1000 A.D., focusing on those layers deposited during the terminal Classic collapse. This interval revealed a series of four distinct titanium minima—likely multi-year droughts, which took place during a period that was already drier than normal. When exactly did these intense dry spells settle over the Maya heartland? Although the counting of sediment couplets gives precise information on the duration of these droughts (which range from three to nine years) and the spacing between them (around 40 to 50 years), the absolute dating of these events remains a little vague. Radiocarbon measurements for the core we used in combination with counting couplets would

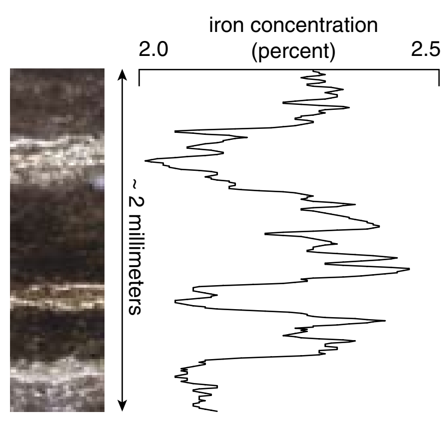

Figure 5. To register changes in sediment composition quantitatively and at high resolution, the authors measured the concentration of iron and titanium, elements that reflect the amount of material eroded from continental rocks. A 2-millimeter-long section of sediment *(left)* shows three light-dark sediment couplets (three years of deposition) and three corresponding cycles in elemental concentration *(right)*.

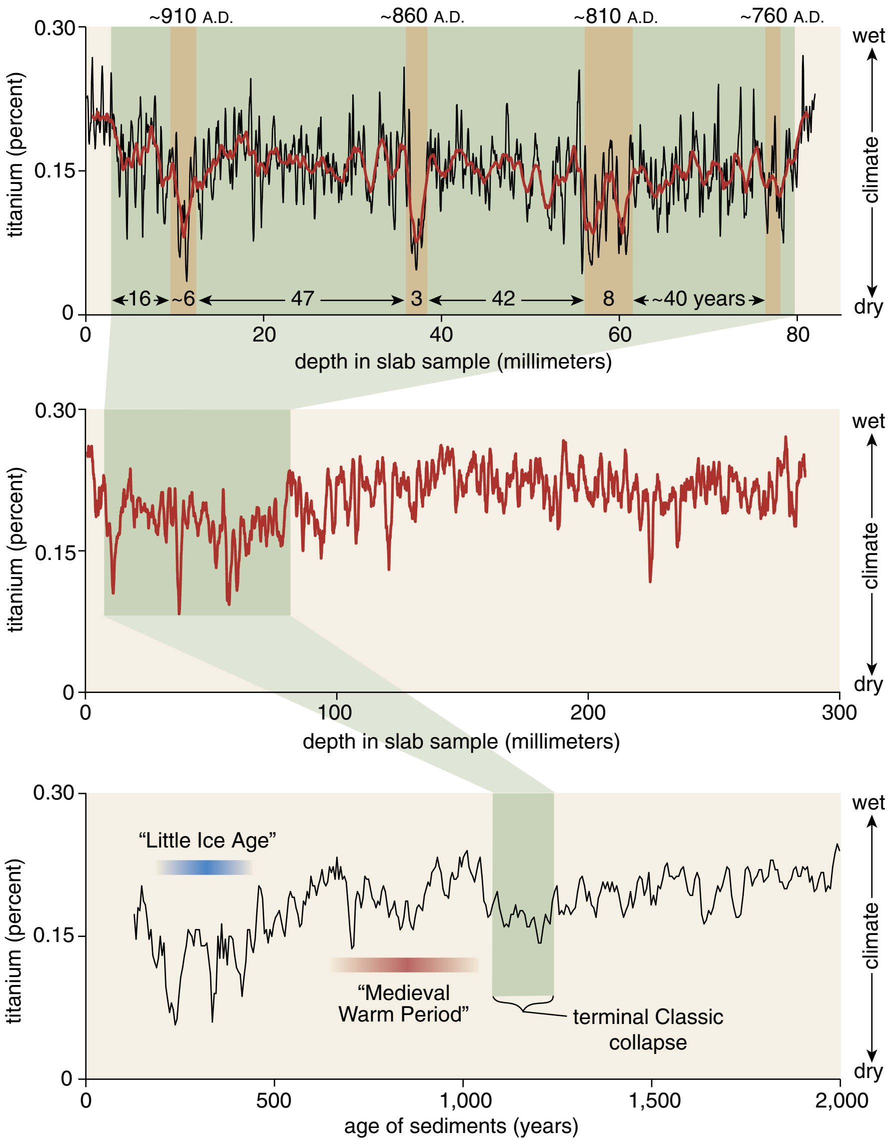

Figure 6. Measurements carried out on Cariaco Basin cores obtained by the Ocean Drilling Program reflect broad variations in Earth's climate through time, including manifestations of what have become known as "the Medieval Warm Period" and "the Little Ice Age" ***(lower panel).*** **Using slabs of sediment taken from one of the recovered cores, the authors were able to track swings between wet and dry conditions with a resolution in time of about two months, although the record shown here has been smoothed for clarity** ***(middle panel).*** **Focusing their efforts on the sediments laid down during the terminal Classic collapse of Maya civilization, the authors found evidence of four multi-year droughts, separated by some 40 to 50 years of more moderate conditions** ***(top panel).*** **The smoothed version of this highly detailed climate record** ***(red)*** **helps to delineate these major droughts.**

indicate that the four droughts struck around 760, 810, 860 and 910 A.D., but quoting such precise dates is somewhat misleading, given that the radiocarbon technique has an uncertainty of about ±30 years for samples of this age.

All in the Timing

Scholars generally agree that the terminal Classic collapse occurred first in the southern and central Yucatán lowlands and that many areas of the northern lowlands underwent their own decline a century or more later. This pattern of abandonment is opposite to what one might expect based on the modern pattern of rainfall, which diminishes markedly from south to north. Some Mayanists have pointed to this incongruity as evidence against drought having played a significant role. However, an additional factor that must be considered is the availability and access to natural water sources, which could have sustained the population during extended periods of drought.

During the peak of Maya civilization, as now, an important source of fresh water for human activities was from the natural underground aquifer. This aquifer is generally more accessible in the northern end of the peninsula, where the Maya were able to reach the water table at various sinkholes (places where the roof of an underground cavern had collapsed) or by digging wells. However, as one moves to the south, the landscape rises in elevation, and the depth to the water table increases, making direct access to groundwater unfeasible, at least for the Classic Maya with the technology of their time. Thus the more southern settlements, which were totally dependent on rainfall and reservoirs for their water needs, were more likely to be susceptible to the effects of prolonged drought than were cities with direct access to subsurface sources. This critical difference helps explain why drought could have caused greater problems in the normally wetter south.

Although there is general agreement that the abandonment of major population centers began first in the south and then spread to the north, Gill proposed a more controversial tripartite pattern of collapse. Based on an analysis of the last recorded dates carved into stone monuments known as stelae at major Maya sites. Gill argued that there were, in fact, three phases of drought-related collapse between about 760 and 910 A.D., with a distinct regional progression.

The first phase, according to Gill, occurred between 760 and 810. The second phase was largely over by about 860. The third and final phase terminated around 910. Noting a similarity between the end dates of these three phases and the timing of especially severe cold spells in Europe (as evidenced in Swedish tree-ring records), Gill speculated that the abandonments occurred rather abruptly at the end of each phase, that they were primarily the result of droughts and that these droughts were linked to the cold conditions at higher latitudes.

Gill's model of three phases of collapse, and especially the archaeological basis for their proposed timing, has been the subject of much debate. There is considerable disagreement, for example, over the interpretation of the last dated inscriptions on stelae as accurate records of city abandonment. Furthermore, Gill considered only the

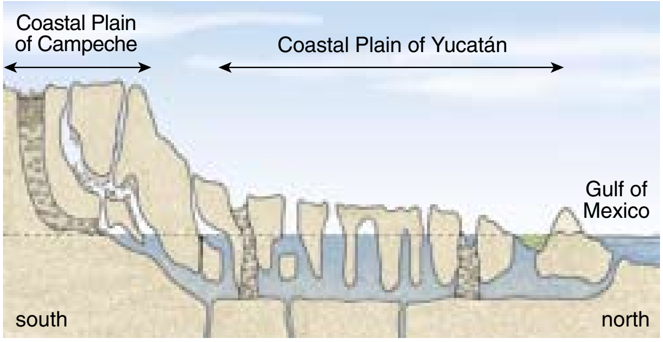

Figure 7. Droughts did not affect all Classic Maya settlements equally. In particular, people living in the northern Yucatán were only somewhat dependent on seasonal rains because sinkholes, caves and other natural openings provided them with access to groundwater. That access was not, however, always easy. At right, an 1844 engraving by Frederick Catherwood *(The Well at Bolonchen)* shows the lengths to which residents of this area of the northern Yucatán sometimes went to gain access to groundwater, just as their Classic Maya forebears had done centuries earlier. This "well" required one to negotiate a complicated system of ladders, which descended more than 100 meters below the surface. To the south, however, the elevation of the land increases, and groundwater becomes even harder to reach *(top)*. Having only stone tools, Maya of the Classic era could not tap the deep groundwater of the south and had to depend exclusively on the seasonal rains and whatever water they could collect in surface reservoirs. (Diagram adapted from Gill 2000.)

largest Maya sites in his original analysis. So there is certainly some room for doubt. Nevertheless, the drought events we inferred from the Cariaco Basin record match Gill's three phases of abandonment remarkably well.

The onset of Gill's first phase at about 760 A.D. is clearly marked in the Cariaco record by an abrupt decrease in inferred rainfall. Over the subsequent 40 years or so, there appears to have been a slight long-term drying trend. This period then culminated in roughly a decade or more of severe drought, which, within the limits of our chronology, agrees well with the end of Gill's first phase. Societal collapse at this time was limited to the western lowlands, a region with little accessible groundwater and where the inhabitants depended almost entirely on rainfall to satisfy their needs.

The end of Gill's second phase of collapse is also marked in the Cariaco Basin record by a distinct interval of low titanium concentrations, suggesting an unusually severe drought that lasted for three or four years. City abandonment during this phase of collapse was largely restricted to the southeastern portion of the lowlands, a region where freshwater lagoons may have provided a source of water up to that point.

According to Gill, the third and final phase of collapse occurred at about 910 A.D., affecting population centers in the central and northern lowlands. And low titanium values in the Cariaco Basin sediments indicate yet another coincident period of drought, one that lasted for five or six years.

Although the match between Gill's drought model and our findings is quite good, we accept that no single cause is likely to explain a phenomenon as complex as the Maya decline. In his recent book *Collapse: How Societies Choose to Fail or Succeed*, Jared Diamond argues that a confluence of factors may have combined to doom the Maya. These include an expanding population that was operating at or near the limits of available resources, environmental degradation in the form of deforestation and hillside erosion, increased internal warfare and a leadership focused on short-term concerns. (Sound familiar?) Nevertheless, Diamond posits that climate change, in the form of droughts, may have helped bring things to a head, triggering a series of events that destabilized Maya society.

Some archaeologists have pointed out that the control of water reserves provided a centralized source of political authority for the ruling Maya elites. Periods of drought might then have undermined the institution of Maya rulership when existing technologies and rituals failed to provide sufficient water. Large population centers dependent on this control were abandoned and people moved sequentially eastward and then northward during the successive droughts to find more stable sources of water. However, unlike what transpired during previous intervals of too little rainfall, which the Maya must certainly have weathered before, the landscape during the final stages of collapse was at carrying capacity (because of the growth of Maya population during wetter times), and migration to areas less affected by drought was no longer possible. In short, they ran out of options.

Climate in Human History

The ability to combine geological archives with traditional archaeological and historical information provides a powerful means to examine the societal response to climate shifts of the distant past. Although the socioeconomic impacts of recent El Niño events or of the infamous Dust Bowl drought of the 1930s are easy enough to study, climatologists still know relatively little about the consequences of older and longer-period changes in climate. In recent years, however, high-resolution records from ice cores, tree rings,

Figure 8. Independent archaeologist Richardson B. Gill found that Classic Maya cities underwent three phases of abandonment. One set *(green at left)* appears to have been abandoned by 810 A.D.; a second set *(pink)* by 860 A.D.; and a third set *(purple)* by 910 A.D. *(left)*. These phases of abandonment correspond remarkably well with the timing of severe droughts revealed by the authors' examination of deep-sea sediments. Although Classic Maya civilization underwent this staged collapse, many of these people survived—and their descendants continue to populate the region today, as does this Maya woman from the Chiapas region of Mexico *(above)*. (Map adapted from Gill 2000. Note that because of space constraints, Gill's published map, which indicated many smaller cities not reproduced here, did not show two sites, Yaxhá and Ucanal, included in his table of abandonment dates.)

corals and certain deep-sea and lake sediments have begun to provide an increasingly precise record of climate change for the past few millennia.

The coincidence of drought and collapse within the Maya civilization is just one example. In the American Southwest, tree-ring evidence for a prolonged drying of climate between about 1275 and 1300 has long been thought to play a role in the disappearance of the cliff-dwelling Anasazi people. And there are indications that similar changes in climate may have been responsible for other major events in human history as well. The collapse of the Akkadian Empire in Mesopotamia about 4,200 years ago, the decline of the Mochica culture in coastal Peru about 1,500 years ago and the end of the Tiwanaku culture on the Bolivian-Peruvian altiplano some 1,000 years ago have all now been linked to persistent long-term drought in those regions. Before the geological evidence for these ancient droughts became available, each of these cultural collapses, like that of the Maya, had been interpreted solely in terms of human factors—warfare, overpopulation, resource depletion.

The rise and fall of the Classic Maya provides a textbook example of human social evolution. It is therefore significant to discover that the history of the Maya was so closely tied to environmental constraints. If Maya civilization could collapse under the weight of natural climate events, it is of more than academic interest to ponder how modern society will fare in the face of an uncertain climate in the years ahead. An understanding of how ancient cultures responded to climatic changes in the past may thus provide important lessons for humanity in the future.

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