Chapter 3

In the Beginning: Early Events in the Development of Mesoamerica and the Lowland Maya Area

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INTRODUCTION

The purpose of this chapter is to describe early background events and processes that ultimately contributed to the definition of the Maya lowlands. Some of these occurred at the time of origin of the Yucatán Peninsula, while others were in operation when the earliest humans arrived. Those most relevant to the human occupation can be organized around the geologic, climatic, and vegetational history of the region.

GEOLOGIC HISTORY

The Lowland Maya area is noteworthy as the site of two ancient geologic events that are of great importance to the subsequent history of Mesoamerica. One was catastrophic and altered the course of biological evolution, while the other was gradual and determined the ultimate nature of the physical environment.

The catastrophic event occurred at the end of the Cretaceous (65 Ma), when an asteroid 10±4 km in diameter impacted the Yucatán Peninsula and left a crater roughly 180 km in diameter buried beneath Chicxulub in north-coastal Mexico (lat. 89–90^{o} N, long. 21.5–20.5^{o} W; Hildebrand et al. 1995). The asteroid impact was a spectacular occurrence that profoundly affected climates, atmospheric chemistry, and evolutionary patterns. In particular, it removed the dinosaurs as the main predator of the mammals, thereby accelerating mammal diversification and radiation into modern forms. The less dramatic event involved the position and sedimentary history of two crustal blocks that would shape the landscape morphology and edaphic environment of the peninsula.

The geologic origin of a region significantly influences the environment under which successive communities of organisms exist, and is the basis, in part, for their adaptations to the prevailing physical conditions. In the case of Mesoamerica, its origin involved two blocks or terranes (Figure 3.1).

The Maya (Yucatán) Block is a fragment resulting from the separation of South America from North America and was originally situated near its present position in the Gulf of Mexico (Ross & Scotese 1988). The Maya Block was sutured onto central Mexico during the Cretaceous, and the contact is represented by the Saline Cruz Fault Zone that runs across the Isthmus of Tehuantepec.

The Chortis Block was originally located along the western coast of Mexico in the Mesozoic; it moved southeastward along the Motagua-

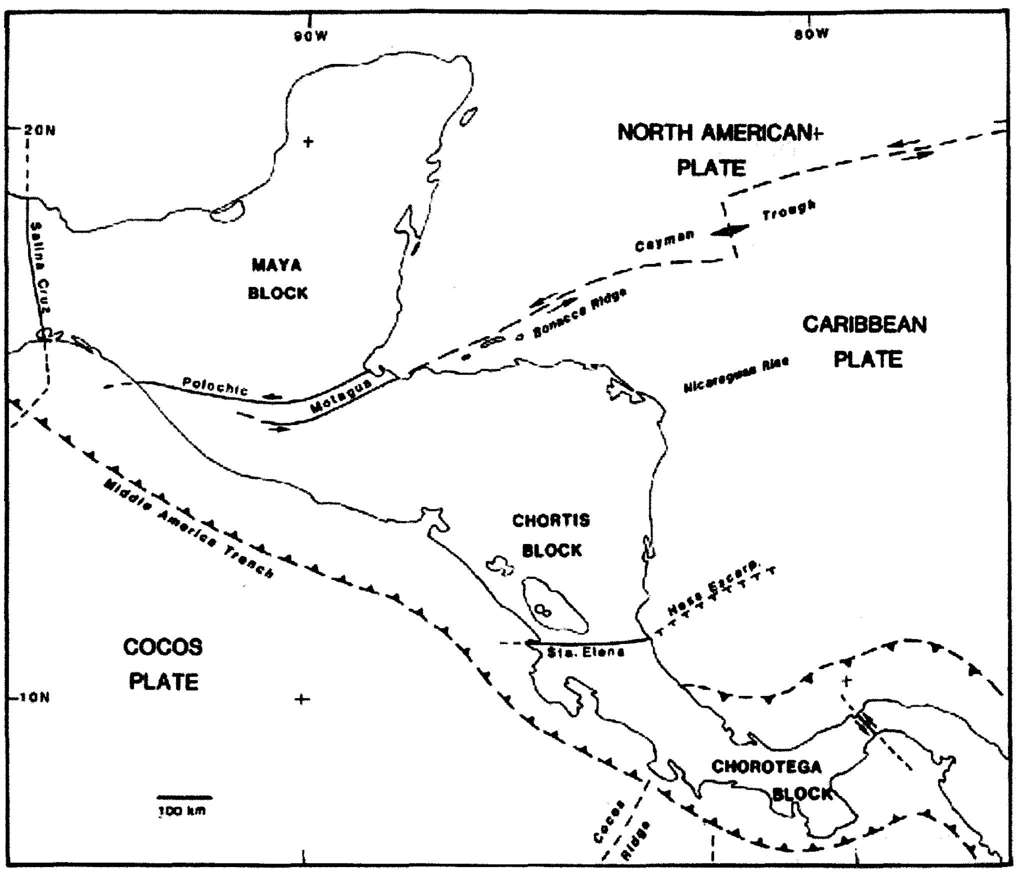

FIGURE 3.1. The Maya and Chortis blocks and their boundaries. (*Source*: From Donnelly et al. (1990). Used with permission of the authors.)

Polochic Fault Zone of northern Guatemala. The Chortis Block also was in place by the end of the Cretaceous, and its northern boundary with the Maya Block represents the contact between the North American and South American plates. Movement along the fault still generates earthquakes that periodically devastate the region (e.g., Guatemala on 4 February 1976) (see Espinosa 1976; Plafker 1976). The southern boundary of the Chortis Block is the Santa Elena fault just south of Lake Nicaragua.

An important geological feature of the Maya Block is that throughout most of its history it was a shallow marine platform (Logan 1969; Driscoll and Diebold 1999, Figures 12, 13; see Figures 3.2, 3.3 in this chapter). A sequence of mangrove-bearing lignites—extending from Malpaso, Chiapas, near the Veracruz border southeast to San Cristobal—identify the shoreline in the Oligo-Miocene as being approximately 90 km inland from its present position (Frost & Langenheim, Jr. 1974). The carbonate sediments and coral reef material that accumulated in this depositional setting formed limestone;

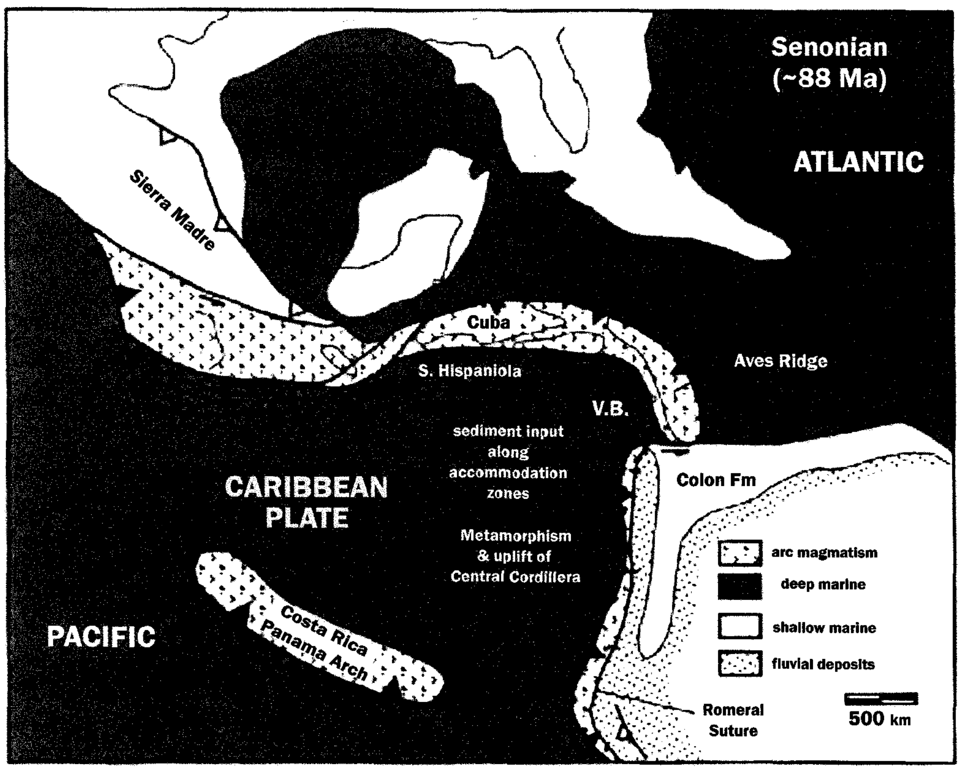

FIGURE 3.2. Location of the Yucatán sedimentary platform in the Senonian (~88 Ma). Note deposition in shallow marine waters. (*Source:* Reprinted from N.W. Driscoll and J.B. Diebold, 1999, Tectonic and stratigraphic development of the eastern Caribbean: New constraints from multichannel seismic data, in *Caribbean Basins*, p. 616, with permission from Elsevier Science.)

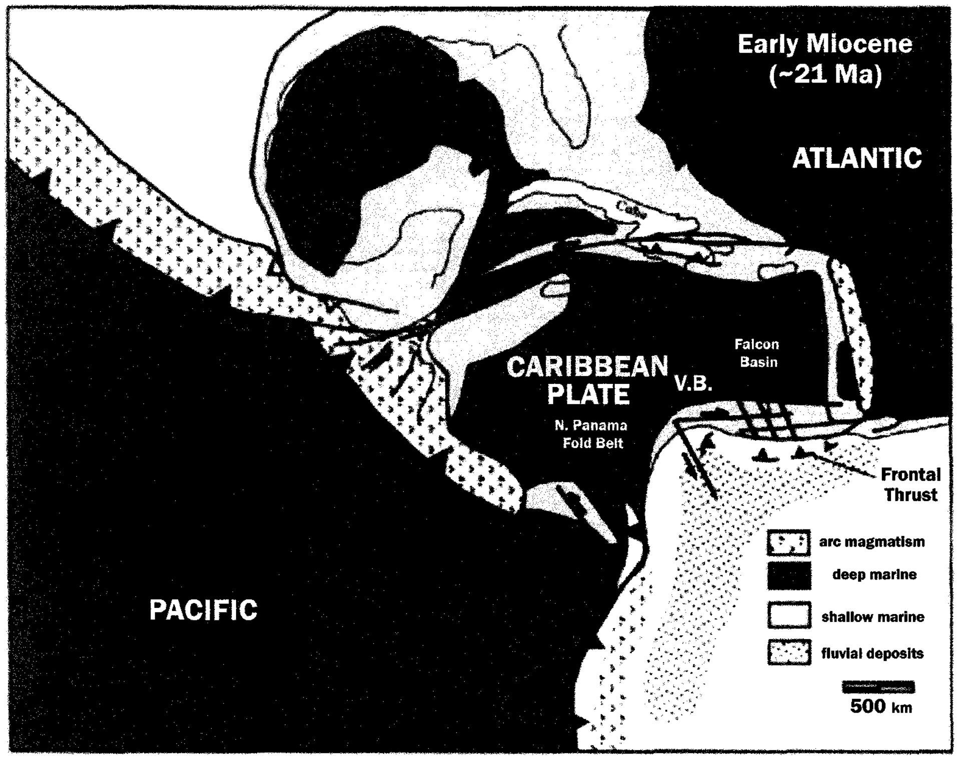

Figure 3.3. Location of the Yucatán sedimentary platform in the early Miocene (~21 Ma). Note continued deposition in shallow marine waters. (Source: Reprinted from N.W. Driscoll and J.B. Diebold, 1999, Tectonic and stratigraphic development of the eastern Caribbean: New constraints from multichannel seismic data, in *Caribbean Basins*, p. 619, with permission from Elsevier Science.)

with subsequent tectonic movement, combined with sea-level fluctuations, these depositions became emergent and weathered into the karst topography that now characterizes the region. (A karst topography is one that results from the subaerial erosion of limestone to produce a rough porous surface, numerous aquifers, and little surface drainage.)

The legacy of this geologic origin is apparent in the present biota. The mean annual precipitation (MAP) is plentiful; at Cozumel, for example, the MAP is 61 inches. Yet the vegetation is a dry deciduous forest resulting from the rapid percolation of water through the porous substrate. The impact on the human population that settled in this environment is reflected in the numerous studies focused on methods of water conservation, as well as the necessity of coping with water shortages in the midst of plentiful rainfall. Examples of these studies include Maya lowland hydraulic systems (Matheny 1976), Maya impact on a tropical karst environment (Deevey et al. 1979), water storage among the ancient Maya (Adams 1991), and water storage adaptation in the Maya lowlands (Scarborough & Gallopin 1991).

CLIMATIC HISTORY

Our concepts of the climatic history of the tropics have undergone three significant changes within the past few decades. Earlier it was believed that while Quaternary climates fluctuated widely in the high latitudes, those in the low latitudes were comparatively stable. For example, mean annual temperature (MAT) in the polar regions was estimated at 12 to14^{o}C colder than at present at the latest glacial maximum 18 Kyr, while in the tropics it was placed at only 0 to 2^{o}C colder. This view was based on results of the Climate Long-Range Investigation and Mapping Program (CLIMAP 1976), which was concerned with the climates of the last glacial and interglacial interval, and the Cooperative Holocene Mapping Project (COHMAP 1988), which attempted to reconstruct northern hemisphere climates at selected time intervals of the Holocene (i.e., the past 11 Kyr).

Information was slowly accumulating, however, that suggested climates were not as uniform in the tropics during the late Cenozoic as the CLIMAP and COHMAP data suggested. The early work of van der Hammen (e.g., van der Hammen, Absy, & Gonzalez 1960) indicated that the MAT was about 8^{o}C colder at glacial maximum at 2,560-meter (m) elevation in the Sabana de Bogotá, Colombia; subsequent work established that significant temperature variations had occurred at high elevations throughout the tropics (e.g., Hooghiemstra 1984).

It was uncertain, however, whether these variations extended into the tropical lowlands. The Haffer model of biological diversification assumed that they did (Haffer 1969), and there was supporting evidence for this assumption (Prance 1982). Some version of the model still appears valid (see review in Burnham and Graham 1999); its mechanism depends on cool and dry climates during glacial intervals, which alternate with warmer and wetter periods during Amazonia interglacials. During the former intervals, the dry caatingas-cerrado vegetation from the surrounding uplands would move onto the lowlands, and geographically and reproductively isolate the rainforest into refugia where moist conditions would be maintained during drying cycles, such as at the confluency of major rivers or at the base of mountain slopes. During the latter intervals, the rainforest would expand from these refugia, coalesce into the nearly continuous cover as at present (thereby facilitating hybridization), and the caatingas-cerrado vegetation would move back onto the drier slopes.

Direct evidence from the Amazon lowlands is emerging now based on noble gases (5.4^{o} ± 0.6^{o}C cooler; Stute et al. 1995), pollen diagrams (van der Hammen and Absy 1994), and speciation patterns among arboreal echimyid rodents derived from mitochondrial DNA (mtDNA) analyses (de Silva & Patton 1993). In addition, strontium-calcium ratios in corals from Barbados (lat. 13^{o} N) suggest temperatures were 5^{o}C cooler at 19 Kyr (Guilderson, Fairbanks, & Rubenstone 1994). Thus, an important revision in our concept of tropical climates is the increasing acceptance that temperature fluctuations in the range of 4–6^{o}C likely affected terrestrial lowland populations throughout the late Cenozoic.

A second development is realizing how the rapid pace of these changes compared with the older four-stage model, which depicted a more leisurely rate of climatic and glacial fluctuations. According to the four-stage model there were four glacial advances separated by three interglacials, each of ~175,000 years duration, in addition to the present interglacial (Holocene) that began at approximately 11 Kyr. Data from the Ocean Drilling Program, the Deep Sea Drilling Project, the Greenland Ice Core Project, and the Greenland Ice Sheet Program II now show that, for the past ~800,000 years, northern hemisphere glaciations have followed the 100,000-year Milankovitch eccentricity cycle. [This cycle is based on the fact that Earth's orbit around the Sun is not a perfect circle, but an ellipse. Furthermore, there is a patterned variation in the shape of the ellipse (eccentricity), so that at times Earth is closer to the Sun (the perihelion) or farther away (the aphelion), and this variation observes a 100,000-year cycle.] Oxygen isotope studies from deep-sea cores and other evidence reveal nine glacial cycles within the past ~800,000 years, with glacial intervals lasting ~90,000 years and interglacial intervals lasting only ~10–11,000 years (Johnson 1982; see review in Graham 1999a, 40, 274–280).

Superimposed on these longer cycles are shorter ones of a few thousand years (known as Heinrich events) and of a few hundred years or less in duration [called Dansgaard-Oeschger (D-O) events]. The pace of these fluctuations is quite rapid: "in the period from 40 to 8 Kyr there were sudden changes of 5–10^{o}C that sometimes lasted less than 5 years, and in the past 8 ky [thousand years] changes of up to 10–12^{o}C were recorded in a few decades and lasted as little as 70 years" (Graham 1999a, 40). These data were derived from the high latitudes; the question was whether they were expressed further south and affected the terrestrial biota. Some evidence is emerging that they did.

Lake Tulane in Avon Park, south-central Florida, occupies a limestone sinkhole; an 18.5-m core provided pollen and spores that reflected vegetational changes for the past 50,000 years (Grimm et al. 1993; Watts and Hansen 1994). Of special interest are peaks in the amount of *Pinus* (pine) pollen for periods 14-16, 21-23, 26-28, 30-33, 36-37, and 48-51 Kyr. All but the 30-33 Kyr interval correspond with Heinrich events (Figure 3.4). This suggests that the rapid climatic changes, documented in North Atlantic

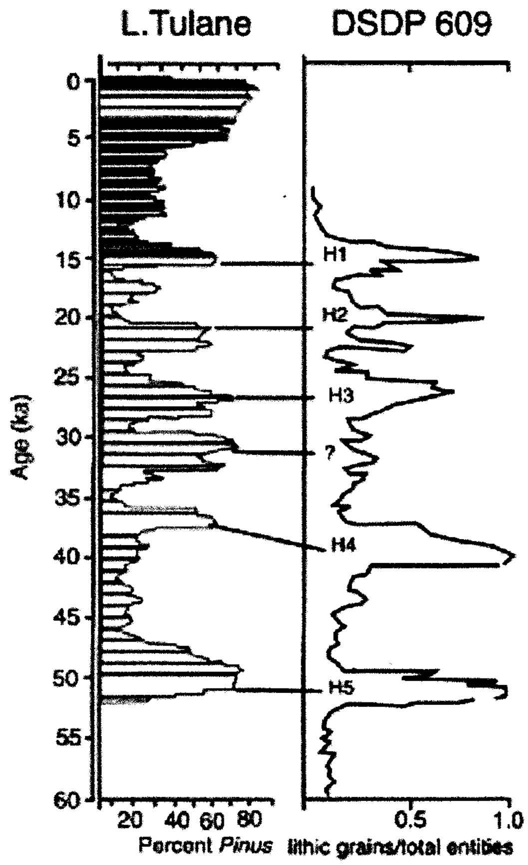

FIGURE 3.4. Pollen profile from Lake Tulane, Avon Park, Florida, showing pine pollen peaks, and DSDP (Deep Sea Drilling Project) site 609 (north Atlantic) Heinrich events 1-5. (Source: Reprinted from Palaeography, Palaeoclimatology, Vol. 109, Watts and Hansen, "Pre-Holocene and Holocne pollen records of vegetation history from the Florida Peninsula and their climatic implication, "pp. 163-176. Copyright 1994 with permission from Elsevier Science.)

marine sediments, affected lowland terrestrial communities at least as far south as lat. 27.5°N. It is further known that the most tumultuous times are at the glacial-interglacial interface.

A third aspect of climate to emerge recently is the correlation between El Niño–Southern Oscillation (ENSO) events and a myriad of global temperature and precipitation patterns. An El Niño is a warming of equatorial Pacific Ocean waters with consequent atmospheric disturbance and redistribution of rainfall. During El Niño years there is a weakening of the northeast trade winds, and few hurricanes form in the Gulf of Mexico and the Caribbean Sea. In non–El Niño years, hurricanes increase by tenfold and bring immense amounts of water suddenly and unpredictably into the region. Notable examples are "the Great Hurricane" of 1831 that killed over

1,500 people on Barbados; Hurricane Floyd of 1999, which was one of the fiercest atmospheric disturbances ever recorded in the Atlantic Ocean; and, particularly noteworthy, Hurricane Gilbert, with recorded windspeeds up to 280 km/hr. (175 mi/hr.) that devastated the Yucatán Peninsula in 1988. During these disturbances, unrelenting torrents of rain can strike areas marginal to the path of the hurricane, such as those that fell for weeks across central Mexico in October 1999.

There is an imprecise cycle to ENSO events, but they generally occur every three and seven years and persist for three or more seasons, with the strongest effects often lasting one to two years. The sequence of some strong ENSO events for the nineteenth and twentieth centuries is given in Box 3.1. There is evidence from lake sediments in New England (17,000 years old; Rittenour, Brigham-Grette, & Mann 2000) and from corals (100,000 years old; Hughen, Schrag, & Jacobson 1999) that El Niños are a long-established feature of global climates. One of the many significant contributions of modern climatological research has been to provide a chronology for ENSO events and to demonstrate the extent of their effect on regional precipitation patterns, including those of the Maya lowlands.

VEGETATIONAL HISTORY

The nature of the mid- to late-Cenozoic vegetation leading up to the modern communities of Mesoamerica is recorded in a sequence of Oligo-Miocene palynofloras from mangrove-bearing lignites along the Front Ranges and High Plateaus physiographic province of Chiapas (Langenheim, Hackner, and Bartlett 1967; Tomassini-Ortiz and Martínez-Hernández 1984; Martínez-Hernández 1992; Palacios and Rzedowski 1993; Graham 1999b), in Mio-Pliocene upland swamp deposits of northern Guatemala

BOX 3.1. Strong (S) to very strong (VS) ENSO events in the nineteenth and twentieth centuries.

1803–1804 (S+)	1877–1878 (VS)	1925–1926 (VS)
1814 (S)	1884 (S+)	1932 (S)
1828 (VS)	1891 (VS)	1940–42 (S)
1844–1845 (S+)	1899–1900 (S)	1957–1958 (S)
1864 (S)	1911–1912 (S)	1972–1973 (S)
1871 (S+)	1917 (S)	1982–1983 (VS)

Source: Graham 1999a, 32, and references cited.

(Graham 1998), and in mangrove-bearing lignites of the middle Pliocene Paraje Solo palynoflora near Coatzacoalcos in Veracruz, Mexico (Graham 1976). An interesting pattern evident in these floras is that the older Oligo-Miocene assemblages contain little or no pollen of northern temperate elements [e.g., *Abies* (fir), *Picea* (spruce), *Juglans* (hickory), *Liquidambar* (sweetgum), *Quercus* (oak), *Ulmus* (elm), and others], while pollen is present in Miocene and younger floras. The event that correlates with their gradual introduction into the northern Latin American biota is the global temperature decline that began near the end of the early Miocene (Graham 1999a, 86–92; 1999c). By the middle Pliocene (as shown by the Paraje Solo flora), the principal components of the modern vegetation were in place—with one exception—and final modernization was accomplished during the climatically turbulent events of the Quaternary.

The exception was the absence (or poor development) of the lowland neotropical rain forest near its present northern limits in Veracruz. The dominants of the modern community include *Bernoullia*, *Brosimum*, *Calophyllum*, *Dialium*, *Ficus*, *Pseudolmedia*, and *Terminalia*. None of these were recovered from the middle Pliocene Paraje Solo Formation of coastal southeastern Veracruz. Rather, the prominent paleocommunities represented by pollen were coastal mangrove, upland deciduous and pine-oak forest, and even the high-altitude bosque de oyamel [*Abies* (fir) and *Picea* (spruce); the latter no longer grow this far south in Mexico].

Although the middle Pliocene was globally a warm interval (Cronin and Dowsett 1991; Wrenn, Suc, and Leroy 1999), upwelling of cold bottom waters, intensified by the closure of the Isthmus of Panama 3.5 Ma, was likely a factor in cooling coastal temperatures. The effects were disruption of the rain forest; lowering of ecotones, thereby bringing the deciduous forest, pine-oak forest, and high-altitude conifer forest into closer proximity to the lowland depositional basin; the appearance of *Picea* far south of its present range; and possibly the introduction of *Quercus oleoides* and *Podocarpus guatemalensis*, primarily upland temperate genera, into the present Veracruz lowlands. If this is the vegetational history in the early stages of the late Cenozoic climatic fluctuations, it is likely that the biota of lowland Mesoamerica was an especially dynamic assemblage in terms of its range and composition during the tumultuous Quaternary.

Another aspect of late Tertiary vegetation relevant to its subsequent modernization is that even though there were no extensive dry communities evident in the Pliocene flora, there were dry elements growing in the region. These included *Acacia*, *Bursera*, *Casearia*, *Celtis*, *Cupania*, *Eugenia*(?), and *Mimosa*. They probably grew in drier habitats afforded by slope, exposure, and edaphic conditions, or in local communities such as the current *Nolina-Hechtia-Agave* desert in the limestone hills west of Perote on the Veracruz-Puebla border (Gómez-Pompa 1973). These restricted communities and preadapted forms of the Pliocene were representative of taxa that were available to coalesce and expand into dry deciduous forest and related vegetation types as dry conditions developed during intervals of the Quaternary.

There is a general relationship between cool climates and reduced precipitation because, with lower temperatures, less water evaporates from the ocean surface into the atmosphere. This system operated in the Maya lowlands during the Quaternary as demonstrated by pollen profiles from lakes in Guatemala (Leyden 1984, 1987; Leyden et al. 1993, 1994). Marine isotopic data indicate that temperatures were cooler by 4.7 to 6.5^{o}C approximately 36 to 24 Kyr, and pollen profiles from Late Quexil provide proxy data from the vegetation that precipitation was somewhat less than at present.

Approximately 24 to 12 Kyr, temperatures were lower by 6.5 to 8.0^{o}C, and conditions were arid as indicated by the vegetation, lower lake levels, and an increase in charred particles. When this pattern is combined with recent evidence for the rapidity of climatic change, and the increasing documentation that these changes affected the terrestrial biota in the lower latitudes (e.g., Figure 3.3), the dynamic nature of the environment is evident. The response of the vegetation to these changes is reflected in several additional spore and pollen profiles and other evidence from the region (Cowgill et al. 1966; Tsukada & Deevey 1967; Wiseman 1978, 1983; Covich 1978; Miksicek et al. 1981; Folan & Hyde 1985; Hansen 1990; Hodell, Curtis, & Brenner 1995; Jauregui 1997).

CONCLUSION

Events that shape the conditions under which civilizations must live include those of ancient geologic origin that determine the structure, topography, and substrate of the physical environment. These features of the lowland Maya region were set in the Cretaceous with the formation of a submerged carbonate platform that gave rise to a karst topography, creating the need for innovative water conservation practices and devices, and with the asteroid impact that led to the development of cenotes. Subsequent climatic trends favored the development of a seasonally dry vegetation and subjected the region to fluctuating periods of cool/dry and warm/moist conditions. These cycles are a long-term feature of Mesoamerica, and the most rapid changes occur at glacial-interglacial boundaries as climates adjust to new thresholds. With these geologic, climatic, and biotic components of the lowland Mesoamerica ecosystem in operation, the region was now to experience a novel interaction with human occupants that would begin a new phase in its environmental history.

LITERATURE CITED

Adams, R. E. W. 1991. Nucleation of population and water storage among the ancient Maya. *Science* 252: 632.

Burnham, R. J., and A. Graham. 1999. The history of neotropical vegetation: new developments
and status. *Ann. Missouri Bot. Gard.* 86:546–589.

CLIMAP Project Members. 1976. The surface of the ice-age Earth. *Science* 191:1131–1137.

COHMAP Members. 1988. Climatic changes of the last 18,000 years: observations and model simulations. *Science* 241:1043–1052.

Covich, A. P. 1978. A reassessment of ecological stability in the Maya area: evidence from lake studies of early agricultural impacts on biotic communities. Pages 145–155 in P. D. Harrison and B. L. Turner II, editors. Pre-Hispanic Maya agriculture. University of New Mexico Press, Albuquerque.

Cowgill, U. M., G. E. Hutchinson, A. A. Ra�ek, C. E. Goulden, R. Patrick, and M. Tsukada. 1966. The history of Laguna de Petenxil, a small lake in northern Guatemala. *Mem. Connecticut Acad. Arts Sciences* 17:1–126.

Cronin, T. M., and H. J. Dowsett, editors. 1991. Pliocene climates. *Quat. Sci. Rev.* 10:115–96.

Deevey, E. S., D. S. Rice, P. M. Rice, H. H. Vaughan, M. Brenner, and M. S. Flannery. 1979. Mayan urbanism: impact on a tropical karst environment. *Science* 206:298–306.

de Silva, M. N. F., and J. L. Patton. 1993. Amazonian phylogeography: mtDNA sequence variation in arboreal echimyid rodents (Caviomorpha). *Molecular Phylogenetics Evol.* 2:243–255.

Donnelly, T. W., G. S. Horne, R. C. Finch, and E. López-Ramos. 1990. Northern Central America: the Maya and Chortis blocks. Pages 37–76 in G. Dengo and J. E. Case, editors. The Geology of North America, vol. H, The Caribbean region. Geological Society of America, Boulder, Colo.

Driscoll, N. W., and J. B. Diebold. 1999. Tectonic and stratigraphic development of the eastern Caribbean: new constraints from multichannel seismic data. Pages 591–626 in P. Mann, editor. Caribbean basins. Elsevier Science, Amsterdam.

Espinosa, A. F., editor. 1976. The Guatemalan earthquake of February 4, 1976, a preliminary report. *U. S. Geol. Surv. Prof. Paper* 1002:1–90.

Folan, W. J., and B. H. Hyde. 1985. Climatic forecasting and recording among the ancient and historic Maya, an ethnohistoric approach to epistemological and paleoclimatological patterning. Pages 15–46 in W. J. Folan, editor. Contributions to the archaeology and ethnohistory of Greater Mesoamerica. Southern Illinois University Press, Carbondale.

Frost, S. H., and R. L. Langenheim, Jr. 1974. Cenozoic reef biofaces. Northern Illinois University Press, De Kalb.

Gómez-Pompa, A. 1973. Ecology of the vegetation of Veracruz. Pages 73–148 in A. Graham, editor. Vegetation and vegetational history of northern Latin America. Elsevier Science, Amsterdam.

Graham, A. 1976. Studies in neotropical paleobotany. II. The Miocene communities of Veracruz, Mexico. *Ann. Missouri Bot. Gard.* 63:787–842.

Graham, A. 1998. Studies in neotropical paleobotany. XI. Late Tertiary vegetation and environments of southeastern Guatemala: palynofloras from the Mio-Pliocene Padre Miguel Group and the Pliocene Herrería Formation. *Amer. J. Bot.* 85:1409–1425.

Graham, A. 1999a. Late Cretaceous and Cenozoic history of North American vegetation (north of Mexico). Oxford University Press, New York.

Graham, A. 1999b. Studies in neotropical paleobotany. XIII. An Oligo-Miocene palynoflora from Simojovel (Chiapas, Mexico). *Amer. J. Bot*. 86:17–31.

Graham, A. 1999c. The Tertiary history of the northern temperate element in the northern Latin American biota. *Amer. J. Bot.* 86:32–38.

Grimm, E. C., G. L. Jacobson, Jr., W. A. Watts, B. C. S. Hansen, and K. A. Maasch. 1993. A 50,000-year record of climate oscillations from Florida and its temporal correlation with the Heinrich events. *Science* 261:198–200.

Guilderson, T. P., R. G. Fairbanks, and J. L. Rubenstone. 1994. Tropical temperature variations since 20,000 years ago: modulating interhemispheric climate change. *Science* 263: 663–665.

Haffer, J. 1969. Speciation in Amazonian forest birds. *Science* 165:131–137.

Hansen, B. C. S. 1990. Pollen stratigraphy of Laguna de Cocos. Pages 155–186 in M. D. Pohl, editor. Ancient Maya wetland agriculture, excavations on Albion Island, northern Belize. Westview Press, Boulder, Colo.

Hildebrand, A. R., M. Pilkington, M. Connors, C. Ortis-Aleman, and R. E. Chavez. 1995. Size and structure of the Chicxulub crater revealed by horizontal gravity gradients and cenotes. *Nature* 376:415–417.

Hodell, D. A., J. H. Curtis, and M. Brenner. 1995. Possible role of climate in the collapse of Classic Maya civilization. *Nature* 375:391–394.

Hooghiemstra, H. 1984. Vegetational and climatic history of the High Plain of Bogotá, Colombia: a continuous record of the last 3.5 million years. Dissertationes Botanicae, ed. J. Cramer, Band 79. Vaduz, Germany.

Hughen, K. A., D. P. Schrag, and S. B. Jacobson. 1999. El Niño during the last interglacial period recorded by a fossil coral from Indonesia. *Geophysical Research Letters* 26:3129–3132.

Jauregui, E. 1997. Climate changes in Mexico during the historical and instrumented periods. *Quaternary International* 43/44:7–17.

Johnson, R. G. 1982. Brunhes-Matuyama magnetic reversal dated at 790,000 year B.P. by marine-astronomical correlations. *Quaternary Research* 17:135–147.

Langenheim, J. H., B. L. Hackner, and A. Bartlett. 1967. Mangrove pollen at the depositional site of Oligo-Miocene amber from Chiapas, Mexico. *Botanical Museum Leaflets Harvard University* 21:289–324.

Leyden, B. W. 1984. Guatemalan forest synthesis after Pleistocene aridity. *Proc. Natl. Acad. Sci. USA* 81:4856–4859.

Leyden, B. W. 1987. Man and climate in the Maya lowlands. *Quaternary Research* 28:407–414.

Leyden, B. W., M. Brenner, D. A. Hodell, and J. H. Curtis. 1993. Late Pleistocene climate in the Central American lowlands. *Geophysical Monograph* 78:165–178.

Leyden, B. W., M. Brenner, D. A. Hodell, and J. H. Curtis. 1994. Orbital and internal forcing of climate on the Yucatán Peninsula for the past ca. 36 ka. *Palaeogeography, Palaeoclimatology, Palaeoecology* 109:193–210.

Logan, B. W., editor. 1969. Carbonate sediments and reefs, Yucatán Shelf, Mexico. *Amer. Assoc. Petrol. Geol. Memoir* 11:1–198.

Martínez-Hernández, E. 1992. Caracterización ambiental del Terciario de la region de Ixtapa, estado de Chiapas—un enfoque palinoestratigráfico. *Revista* (Universidad Nacional Autónoma de Mexico, Instituto Geología) 10:54–64.

Matheny, R. T. 1976. Maya lowland hydraulic systems. *Science* 193:639–646.

Miksicek, C. H., R. McK. Bird, B. Pickersgill, S. Donaghey, J. Cartwright, and N. Hammond. 1981. Preclassic lowland maize from Cuello, Belize. *Nature* 289:56–59.

Palacios Chávez, R., and J. Rzedowski. 1993. Estudio palinologico de las floras fosiles del Miocene inferior y principios del Mioceno medio de la region de Pichucalco, Chiapas, Mexico. *Acta Botánica Mexicana* 24:1–96.

Plafker, G. 1976. Tectonic aspects of the Guatemala earthquake of 4 February 1976. *Science* 193:1201–1208.

Prance, G. T., editor. 1982. Biological diversification in the Tropics. Columbia University Press, New York.

Rittenour, T. M., J. Brigham-Grette, and M. E. Mann. 2000. El Niño–like climate teleconnections in New England during the late Pleistocene. *Science* 288:1039–1042.

Ross, M. I., and C. R. Scotese. 1988. A hierarchical tectonic model of the Gulf of Mexico and Caribbean region. *Tectonophysics* 155:139–168.

Scarborough, V. L., and G. G. Gallopin. 1991. A water storage adaptation in the Maya lowlands. *Science* 251:658–662.

Stute, M., M. Forster, H. Frischkorn, A. Serejo, J. F. Clark, P. Schlosser, W. S. Broecker, and G. Bonani. 1995. Cooling of tropical Brazil (5^{o}C) during the last glacial maximum. *Science* 269:379–383.

Tomasini-Ortiz, A., and E. Martínez-Hernández. 1984. Palinologia del Eoceno-Oligoceno de Simojovel, Chiapas. *Paleontologia Mexicana* 50:1–61.

Tsukada, M., and E. S. Deevey, Jr. 1967. Pollen analyses from four lakes in the southern Maya area of Guatemala and El Salvador. Pages 303–333 in E. J. Cushing and H. E. Wright, Jr., editors. Quaternary paleoecology. Yale University Press, New Haven, Conn.

van der Hammen, T., and M. L. Absy. 1994. Amazonia during the last glacial. *Palaeogeography, Palaeoclimatology, Palaeoecology* 109:247–261.

van der Hammen, T., M. L. Absy and E. Gonzalez. 1960. Upper Pleistocene and Holocene climate and vegetation of the "Sabana de Bogota" (Colombia, South America). *Leidse Geologische Mededelingen* 25:261–315.

Watts, W. A., and C. S. Hansen. 1994. Pre-Holocene and Holocene pollen records of vegetation history from the Florida Peninsula and their climatic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology* 109:163–176.

Wiseman, F. M. 1978. Agricultural and historical ecology of the Maya lowlands. Pages 63–115 in P. D. Harrison and B. L. Turner II, editors. Pre-Hispanic Maya agriculture. University of New Mexico Press, Albuquerque.

Wiseman, F.M. 1983. Analysis of pollen from the fields at Pulltrouser Swamp. Pages 105–119 in B. L. Turner II and P. D. Harrison, editors. Pulltrouser Swamp. University of Texas Press, Austin.

Wrenn, J. H., J.-P. Suc, and S. A. G. Leroy, editors. 1999. The Pliocene: time of change. American Association of Stratigraphic Palynologists Foundation, Dallas, Tex.