Paleoclimatological Patterning In Southern Mesoamerica

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Abstract:
Paleoclimatological and archaeological data indicate a strong correlation between atmospheric and ground moisture and the political and socioeconomic prehistory and history of the Lowland Maya.

Article:
Introduction
In agreement with the eminent botanist-archaeologist, Cyrus Longworth Lundell, that both botanic and climatic factors are of utmost importance to our understanding of the ancient Maya and their accomplishments,[1] and that "Much of the so-called 'mystery of the Maya' could be discarded by a pragmatic consideration of environmental factors which influenced the rise and fall of great Maya cultural centers for over 2000 years,"[2] we offer the following analyses of the Lowland Maya through time and space as an explanation for the beginnings and ultimate decline of these people inhabiting the lower regions of Mesoamerica. For if the concept of a relationship between man and his environment is even partially correct, one can expect that cultures would tend to continue throughout at least one period of stable environment, but be more likely either to terminate or change at climatic discontinuities rather than during stable intervals.[3] R. H. Claxton and A. D. Hecht provide illuminating examples from the Guatemalan Highlands in which climatic change is clearly instrumental in forcing social and cultural change during the last 400 years.[4] Our intention here is to develop a similar framework for the Lowland Maya, extending the perspective into prehistory and setting the course of climatic change in the context of global and North American climatic changes. Although we do not claim that we have all the answers to culture change in southern Mesoamerica through time, we do think that we have touched upon one of the principal causal factors of change throughout the Maya area.

Even though the identification of major Maya regional centers has been known for a considerable period of time, the reason or reasons behind their development, distribution, and redistribution have been obscure. Joyce MarCUS,[5] in an attempt to demonstrate the differential distribution and development of Maya regional centers in the Southern Maya Lowlands, has suggested a quadrapartite distribution of the Maya world based on hieroglyphic texts. These texts strongly suggest that major centers such as Calakmul (south), Copan (east), Palenque (north), and Tikal (west) represented the directional capitals of the Southern Maya Lowlands during one point

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[1] Cyrus Longworth Lundell, "Some Observations from Fifty Years of Exploration of the Yucatan Peninsula," *Wrightia* 6 (1978) 1-3.
[2] Ibid. 2.
[3] Wayne M. Wendland and Reid A. Bryson, "Dating Climatic Episodes of the Holocene," *Quaternary Research* 4 (1974) 9-24.
[4] R. H. Claxton and Alan D. Hecht, "Climatic and human history in Europe and Latin America: An opportunity for comparative study," *Climatic Change* 1 (1978) 195-203. See also James Robert Moriority, "The Sufficience of Recent Climatic Change in the Development of Maya Civilization," *Katunob* 6 (1967) 18-28.
[5] Joyce Marcus, "Territorial Organization of the Lowland Classic Maya," *Science* 180 (1973) 911-916.

in the Classic Period (FIG. 1).[6] But for an unknown reason or reasons Copan and Palenque lost their role as capitals by 849 A.C., with Seibal and Motul de San Jose assuming this position.

Rathje has modeled the distribution of Maya centers in the Southern Lowlands on their range of ecological variety and access to primary resources such as obsidian for forming blades, and other hard materials for grinding

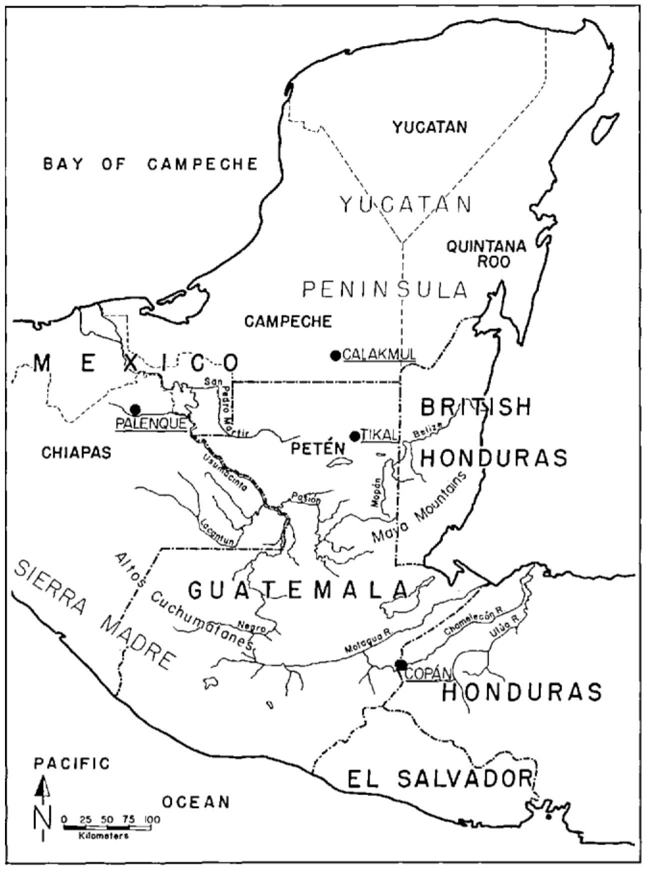

Figure 1. Map of the Maya area showing the location of the four regional centers of Calakmul, Copan, Palenque, and Tikal in the Southern Lowlands.

stones and querns.[7] Thus, the ecologically and primary resource-rich Buffer Zone of the Peten was thought to be inhabited before the comparatively resourceless Core Zone (FIG. 2).[8] In this way, Buffer Zone centers like Altar de Sacrificios would have been settled before the Core Zone by peoples in search of lands.

In yet another approach, W. J. Folan[9] suggested that the Core Zone of the Peten was settled by the Southern Lowland Maya because of the richness of its soils[10] and because it was central to transportation and communication with both the Northern Maya Lowlands and the Maya Highlands. It also had access to the transport facilities provided by the Gulf of Mexico and the Gulf of Honduras. Evidence indicates that even the 3D-day

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[6] Joyce Marcus, *Emblem and State in the Classic Maya Lowlands: an epigraphic approach to territorial organization* (Dumbarton Oaks Research Library and Collection: Washington, D.C. 1976) fig. 1.1.
[7] William L. Rathje, "Classic Maya Development and Denouement: A Research Design," in *The Classic Maya Collapse,* T. Patrick Culbert, ed. (University of New Mexico: Albuquerque 1973) 405-454.
[8] Ibid. fig. 50.
[9] William J.Folan, "The Political and Economic Organization of the Lowland Maya," *Mexicon* 2 (1980) 73-77.
[10] William T. Sanders, "The Cultural Ecology of the Maya Lowlands," in Culbert, ed., op. cit. (in note 7) 325-366; Richard E. W. Adams, *Mesoamerica* (Little, Brown and Company: Boston 1977) 316; Dennis E. Puleston, "Terracing, Raised Fields, and Tree Crop ping in the Maya Lowlands: A New Perspective in the Geography of Power," in *Prehispanic Maya Agriculture,* Peter D. Harrison and B. L. Turner II, eds. (University of New Mexico Press: Albuquerque 1978) 225-246.

round- trip on foot from Tikal to the Pacific Coast was not considered overly lengthy by the Maya of the Core Zone who sought to reach the rich trade routes of the Pacific shore. Maya in historical times, for example, commonly traveled this 3D-day distance.[11]

Folan[12] has suggested a rhythm to shifts in Maya settlements in the Northern Maya Lowlands over the millennia with notable movements in population concentration from the inland Interior Zone to the Coastal Zone and then back (FIG. 3).[13] The earliest demographic centers in the Northern Maya Lowlands are in the Interior Zone of the Yucatan Peninsula in such places as Mani and Toh.[14] This zone was the most fertile zone of the peninsula preceding the exploitation of coastal areas. At a later date the Yucatec Maya moved toward and into the Coastal Zone where they later built several important regional centers within 50 km. of the Gulf of Mexico and the Caribbean Sea. Then, reversing this trend, the Late Classic Period peoples built centers further inland. This tendency seems to continue in both the NW and the northern area of Yucatan, where major Postclassic Period centers are situated still further inland. An exception to this pattern during the Late Postclassic Period is apparent on the east coast of the peninsula where a considerable amount of development is notable at centers such as Tulum.

A possible clue to the reason or reasons behind shifting centers is found in Coba, Quintana Roo, a Classic Period regional center noted for several small lakes located within and around the ceremonial-civic core of the

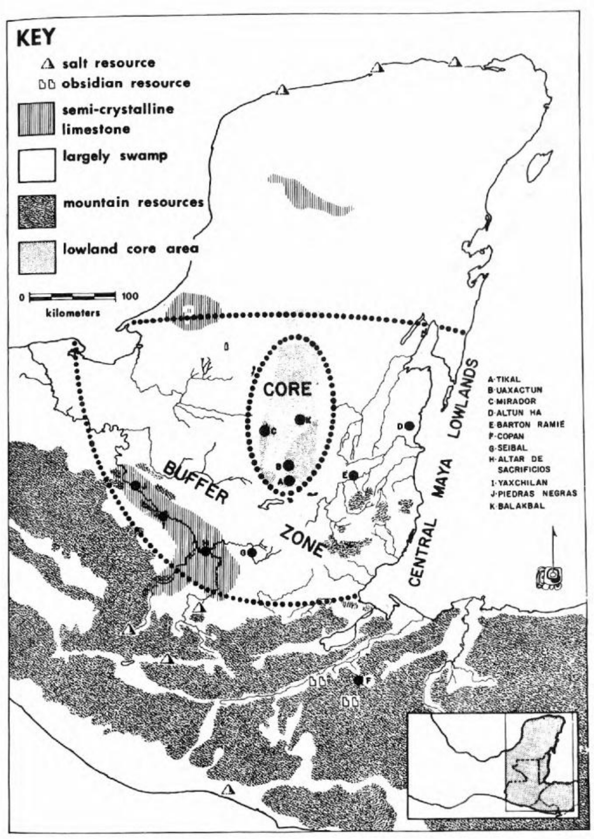

Figure 2. Map showing the location of the Southern Lowland Core and Buffer Zone, some of the principal Maya centers in and around the zone in addition to basic resource areas.

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[11] Roman Piiia Chan, "Commerce in the Yucatan Peninsula," in *Mesoamerican Communication Routes and Cultural Contacts,* Thomas A. Lee Jr. and Carlos Navarrete, eds., *Papers of the New World Archaeological Foundation* 40 (Brigham Young University: Provo 1978)37-48.
[12] William J. Folan, *The Puuc: Uxmal, Kabah, Sayil and Labna* (Ediciones Orto: Mexico, D. F. in production 1978); see also idem, loco cit. (in note 9).
[13] Folan, op. cit. (in note 9) fig. 1.
[14] William J. Folan, "Un botellon monopodio del Centro de Yucatan, Mexico," *EstCultMaya* 8 (1972) 67-75; idem, op. cit. (in note 9).

city and along numerous raised roads running out from this nu-

Figure 3. Map of the Yucatan Peninsula showing the location of the Yucatan Interior Lowlands Zone, the Central Yucatan Lowlands Zone, the unlabeled Coastal Zone and the name and location of various Classic Period regional centers, their ports and intermediary cities.

cleus to the fringes of the city.[15] Recent investigations indicate that these lakes are at least in part formed by ancient quarries that ostensibly had been excavated down to the phreatic water table sometime during the Classic Period. To facilitate communication between the core area of the city and its fringes, a road was built across a quarry (now known as Lake Macanxoc) when its bottom was dry or nearly dry. At a later date this quarry, in addition to others, became water-filled because of a rise in the phreatic water table, an event that could have been the direct result of increased rainfall or decreased evaporation after the construction of the road. Not only the bottom of the quarry was thus covered by water, but the road was covered as well.[16] An additional indication of fluctuating water levels in Coba is the presence of a road-associated ramp rising out of a relic quarry also under water in 1975.[17] Several walkways leading into Lake Coba are also currently under water, probably having been built when the water table was lower than it is now.[18] Further clues to this type of fluctuation of the water table are recordable around the rims of virtually all other major bodies of water in Coba. Here, during the rainy season, the water level rises above the tops of what can only be interpreted as the bases of ancient dikes[19] (FIG. 4) and spreads into the surrounding area.

Additional data for climatic fluctuation in Yucatan are available from John L. Stephens's description of a pond

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[15] J. Eric S. Thompson, Harry E. D. Pollock, and Jean Charlot, *A Preliminary Study of the Ruins of Coba, Quintana Roo, Mexico (CarnlnstPub:* Washington, D.C. 1932) fig. 14; William J. Folan, "EI Sacbe Coba-Ixil," *Nueva AntropoLogia* 6 (1977) 31-42; idem, "Informe interino numero 2, 6 de agosto de 1976 *(sic).* Coba, Proyecto Cartegrafico Arqueologico," *BoLetin de La EscueLa de Ciencias AntropoLogicas de La Universidad de Yucatan* 22,23 (1977a) 29-51; idem, "Informe interino numero 3. Coba Proyecto Cartografico Ar-queologico, Coba, Q. R. 14 de febrero, 1976," *BoLetin de La EscueLa de Ciencias Antropologicas de La Universidad de Yucatan* 22, 23 (l977b) 52-71; idem, 1978 loco cit. (in note 12).
[16] Thompson et al., op. cit. (in note 15) 22-27.
[17] Folan, 1977a op. cit. (in note 15) 37.
[18] Ibid. 39.
[19] Folan, 1977b op. cit. (in note 15) 66.

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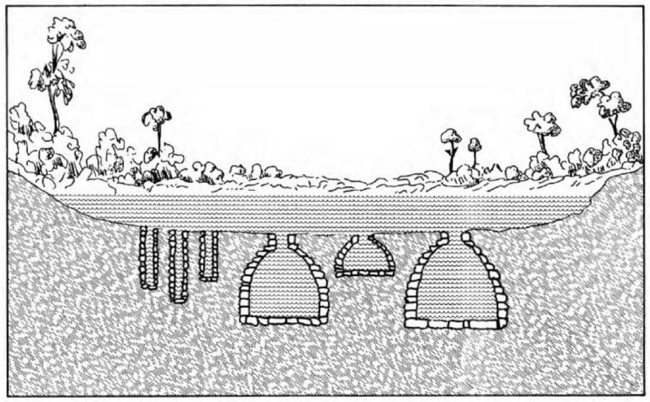

Figure 5. Cross section of a pond near Rancho Jalal, Yucatan, showing cisterns and wells redrawn from a Frederick Catherwood plate.

at Rancho Jalal in Yucatan associated with several cisterns and wells and a drawing by Frederick Catherwood (FIG. 5).[20] According to Stephens this pond was dry around 1830 and its bottom covered with several feet of mud.[21] While local people were digging into the bottom in search of water during a dry period, they located the opening to several cisterns and wells. If Stephen's description and Catherwood's section drawing of this pond at least in part reflect past reality, it may be suggested that the ancient Maya excavated cisterns in the bottom of this pond down to two, and wells down to three, different levels. The depths of these cisterns and wells could indicate that the phreatic water table of the peninsula was at three or more levels at different times, and that these

A Climatic Perspective for Culture Change in Yucatan

Much of the above would have remained more than somewhat of a mystery if it were not for recent work by Joel Gunn and Richard E. W. Adams on the paleoclimatology of Middle America and Texas.[22] In a recent article they have suggested that the record of Mesoamerican development may mark changes in global climate and that the environmental impetus to cultural change is most easily recognized in the archaeological record as, for example, in the case of the prehistoric Mill Creek culture in Iowa where predictions of prehistoric drought were proven archaeologically by David Baerris and Reid Bryson.[23]

In a similar fashion, the Mesoamerican archaeological record seems, in broad perspective, to match data compiled by George Denton and Wibjorn Karlén relating to the advance and the retreat of tree lines in the Alaskan and the Swedish mountains indicating periods of cold weather and glacial advance alternating with warmer weather and glacial retreat (FIG. 6).[24] The data of Denton and Karlén in conjunction with a study by

[20] John Lloyd Stephens, *Incidents of Travel in Yucatan* (Dover Publications, Inc. [reissue]: New York 1963) 150.

[21] Ibid. 149-150. water-collecting devices were excavated to varying depths to compensate for fluctuating water sources conceivably brought about by varying climatic conditions.

[22] Joel Gunn and Richard E. W. Adams, "Climatic Change, Culture and Civilization in North America," *WA* 13 (1981) 87-100.

[23] Reid A. Bryson and Thomas J. Murray, *Climates of Hunger: Mankind and the World's Changing Weatber* (University of Wisconsin Press: Madison 1977) 31-44.

[24] George Denton and Wibjorn Karlen, "Holocene Climatic Variations: Their Pattern and Possible Cause," *Quaternary Research 3* (1973) 155-205, fig. 1.

Sanchez and Kutzbach[25] may be used to determine the effects these climatic changes brought to southern Mexico.[26] The Sanchez and Kutzbach study shows that periods of global cooling are marked by cool, wet weather in Yucatan, while global warmth is associated with dry, hot weather in the peninsula. Extrapolating from the glacial chronology of Denton and Karlén, we may suggest that the climatic sequence outlined in their Table 1 indicates a wet period from 1400 B.C. to 500 B.C. This period was followed by a drier interval during the succeeding climatic optimum from 500 B.C. to 600 A.C. From 600 A.C. to 900 A.C. a cycle of cooler weather and heavier rainfall would have prevailed followed by a warmer and drier interval between 900 A.C. and 1250 A.C. A colder climate

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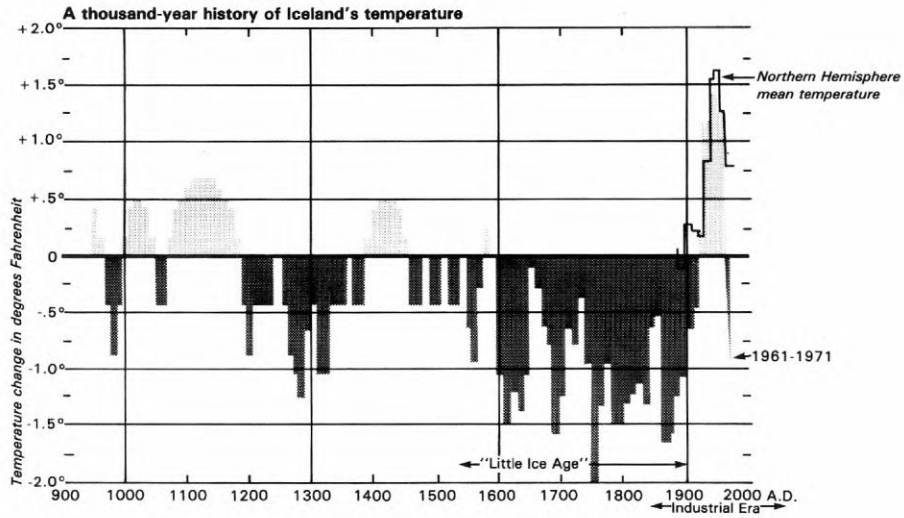
and heavier rainfall characterized the climatic picture between 1250 A.C. and ca. 1390 A.C. with a warmer and drier trend commencing at the end of that period and lasting until 1450 A.C. The latter date matches the age of a sample of dead coral removed from the frame of a coral reef off Costa Rica that corresponds closely with the onset of the Little Ice Age or Neoglaciation in the Northern Hemisphere that continued up to 1900 A.C.[27] Jean Grove has questioned the global contemporaneity of climatic changes posed by Denton and Karlén except at the most general levels of chronology.[28] Grove's critical evaluation represents a commendable effort to collect relevant data on glacial advances. His critique, however, ignores critical issues of latitude, lags, etc., all of which must be considered when evaluating glacial data. On the other hand, it has been known for some time that high-latitude situations such as those studied by Denton and Karlén are most sensitive to global climatic change. There is every theoretical reason to expect that the Denton and Karlén hypothesis will be born out by continued research in the field of globally synchronous climatic changes.

Fortunately, much more detail is available on the course of global climatic change since the 1Oth century A.C., thanks to the efforts of Pall Bergth6rsson.[29] By studying Icelandic historical records of climatic change, Bergth6rsson was able to determine the average annual temperatures around Iceland during this time. In that Icelandic average temperatures approximate temperatures of the northern hemisphere because of Iceland's location in the North Atlantic, Bergth6rsson's findings can be used to continue our exploration of the effects of climate on the high civilizations of Mesoamerica from 900 A.C. to the

[25] W. A. Sanchez and J. E. Kutzback, "Climate of the American Tropics and Subtropics in the 1960s and Possible Comparisons with Climatic Variations of the Last Millennium," *Quaternary Research* 4 (1974) 128-135.
[26] Gunn and Adams, loco cit. (in note 22).
[27] Peter W. Glynn, "Climatic Cycles May Affect Reef Growth," *Smithsonian Research Reports* Autumn (1979) 4.
[28] Jean M. Grove, "The Glacial History of the Holocene," *Progress in Physical Geography* 3 (1979) 1-54.
[29] . Pall Bergth6rsson, "An Estimate of Drift Ice and Temperature in Iceland in 1,000 years," *J6kull (Journal of the Icelandic Glaciological Society)* 19 (1969) 94-101.

Figure 7. "A thousand-year history of Iceland's temperature," based on Päll Bergthórsson's correlation between drift ice and temperatures from that area of the world.



present (FIG. 7).[30] Although Astrid Ogilvie's analysis of Bergth6rsson's historical sources for the period before 1100 A.C. and between 1450 and 1550 A.C. suggests a lack of reliability,[31]even when eliminating the decades thought unreliable by Ogilvie, it is apparent over the period of centuries that Bergth6rsson provides a valuable climatic data trend.

Cultural adjustments to the above climatic changes are recognizable in the archaeological record, as demonstrated by Gunn and Adams,[32] who state that all lowland florescences in southern Mesoamerica have taken place during periods of comparatively cold and wet climatic conditions. For example, the Olmec of SE Mexico established themselves at San Lorenzo as a major power at the beginning of a cool and wet period during the 2nd millennium B.C. The focus of Olmec occupation shifted from San Lorenzo to La Venta in 900 B.C. After a period of florescence, La Venta and the Olmec manifestation collapsed. The 400 B.C. date of this event corresponds with the end of the same cool and wet period, as judged by Denton and Karlén in their glacial chronology[33] and alluded to earlier by Heizer, who associated the end of Olmec culture with drought. [34] The data for termination of San Lorenzo also correlate nicely with Wayne M. Wendland and Reid A. Bryson's C-14 date of 2760 B.P. associated with world-wide pollen maxima and minima, sea-level maxima and minima, and top and bottom surfaces of peat beds simultaneously analyzed to identify times of global environmental discontinuities.[35] The termination date of 400 B.C. for Olmec culture at La Venta approximates the C-14 date of 2510 B.P. associated by Wendland and Bryson with environmental and cultural change as devised from a stratified ordering of all C-14 dates collected by these two scholars on a world-wide basis.

An important date in the development of Maya civilization is the beginning of the Early Classic Period, ca. 300 A.C., which correlates very well with the world-wide date of 1680 B.P. established by Wendland and Bryson for a major period of botanic change. The 600 A.C. beginning date for Tikal's maximum development matches the end of the 534-593 A.C. Maya hiatus associated with a decrease in the erection of stelae and other dated monuments during the Transition Period from Early to Late Classic,[36] which is marked by the beginning of a cold and wet weather cycle. It also seems worthwhile mentioning here that the Wendland and Bryson cultural

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[30] Tom Alexander, "Ominous Changes in the World's Weather," *Fortune* LXXXIX (1974) 91.
[31] M. J. Ingram, D. J. Underhill, and T. M. Wigley, "Historical Climatology," *Nature* 276 (1978) fig. 2; T. Wigley, "Climatic Changes since 1000 A.D.," *Evaluation des Atmospheres Planetaires et Climatologie de la Tierre* (Centre National des Etudes Spatiales: Toulouse 1979) 313, 324.
[32] Gunn and Adams, loco cit. (in note 22).
[33] Denton and Karlén, op. cit. (in note 24).
[34] Robert F. Heizer, "Agriculture and the Theocratic State in Lowland Southeastern Mexico," *AmAnt* 26 (1960) 220.
[35] Wendland and Bryson, loco cit. (in note 3).
[36] G. R. Willey and D. B. Shimkin, "The Maya Collapse: A Summary View," in Culbert, ed., op. cit. (in note 7) 457-501

discontinuity date of approximately 1260 B.P. equates reasonably well with the rapid drop off in the recording of dynastic texts in the Maya area after 790 A.C. following a burst of this activity 10 years earlier.

That climatic change coincided with important transitional stages in Maya civilization is suggested by recent research by Lawrence H. Feldman.[37] The latter believes that the inverse appearance of the fresh-water Pomacea and Neocyclotus shells in the Corozal District through time is the result of differing Maya farming techniques. It is, however, more reasonable to conclude from Feld- man's data[38] that stagnant-water-oriented Pomacea was more numerous during the opening years of the Early Preclassic, the Early Classic, and possibly the Early Postclassic because these were comparatively warm and dry periods in the Maya Lowlands. Conversely, the fresh water Neocyclotes commonly associated with burned-off farming areas were more numerous during the Middle Preclassic, Late Classic, and possibly the Late Postclassic Periods because these intervals were comparatively cooler and wetter, a fact that must have made essential the development of different farming techniques by the Maya. These farming techniques would probably have been more hydraulically oriented during dry periods, but better characterized by slash and bum in wet periods, with both dry and wet farming techniques evidently being used in the Late Classic Period, according to our observations.[39]

At a later date, Postclassic Period Chichen Itza was established by Toltec colonists during a warm period in the 9th century to control the exploitation of salt beds on the northern coast of Yucatan[40] and the major entrance to the Maya infraworld, the Cenote Sagrado.[41] Gunn and Adams suggest that the increased evaporation occurring during this warmer climate interval would have enhanced rather than detracted from Chichen Itza's economic orientation. Both increased salinity of seawater and accelerated rates of evaporation in the salt fields would have served to increase the production of salt and thus strengthened the city as a center of trade in this commodity.[42] It should also be mentioned here that the fall of Chichen Itza may well be related to a period of sudden cooling around 1250 A.C. and, therefore, more rain (FIG. 8)[43] that could have covered the salt beds, thus bringing about Toltec-Chichen Itza's economic demise during the mid-13th century and making way for a new Maya order in Mayapan.

That Chichen Itza functioned during a period of relative dryness is supported by the presence of several char-coal-filled incense burners of the Toltec-Maya Period discovered under ca. 1 m. of water in one of the inner passages of the Cave of Balancanche, Yucatan.[44] It can be inferred that these incense burners had been left by the ancient Maya on the floors of these passageways during a period of time drier than that of the 1959 rainy season in Yucatan and any season since.[45] In addition to Bergth6rsson's data,[46] the C-14 dates of discontinuity, determined by Wendland and Bryson both from the world geologic-botanic record and from the world cultural record, average out at 840 B.p.[47]and are thus in remarkable agreement with the dating of the transitional period occurring between Chichen Itza and Mayapan.

Historical records allow an even closer analysis of the sources of cultural change. Actual Mayan historical rec-ords are available for the period of Bergth6rsson's Icelandic temperature record. These indicate that in contrast

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[37] Lawrence H. Feldman, "Invertebrados Arqueologicos," *Bolettn de la Escuela de Ciencias Antropologicas de Yucatan* 33 (1978) 2- 23.
[38] Ibid. fig. 2.
[39] Ibid. 2-23.
[40] Jack D. Eaton and Joseph W. Ball, *Studies in the Archaeology of Coastal Yucatan and Campeche, Mexico. Middle American Research Institute Publication* 46 (Tulane University: New Orleans 1978) 12.
[41] William J. Folan, "Chichen Itza, El Cenote Sagrado y Xibalba: Una Vision Nueva," *Bolettn de la Escuela de CienciasAntropologicas de la Universidad de Yucatan* 44 (1980) 70-76.
[42] Gunn and Adams, Ope cit. (in note 22).
[43] M. R. Bloch, "The Social Influence of Salt," *SAm* 209:1 (1963) 88-99.
[44] E. Wyllys Andrews IV, *Balancanche, Throne of the Jaguar Priest. Middle American Research Publication* 32 (Tulane University: New Orleans 1970) 1; William J. Folan, personal observation.
[45] Folan, personal observation.
[46] Bergthorsson, loco cit. (in note 29).
[47] Wendland and Bryson, Ope cit. (in note 3) table 7.

to the cold and moist period benefiting the inhabitants of Mayapan between 1200 and 1400 A.C., the conquest of Mayapan around the latter date occurs during a period of higher temperatures and relative dryness. But following the fall of Mayapan, there were 20 years of abundance[48] that may actually have occurred during a relatively cool and wet period that began around the middle 1400s. This period of prosperity was brought to an end around the 1460s when a great hurricane was said to have leveled the land.[49] Following the hurricane, those who survived continued to flourish and replenish their numbers until many were eliminated by pestilential fevers,[50] probably associated with Ponce de Leon's arrival on the northern coast of Yucatan in 1513.[51] After this smallpox epidemic, 16 additional years were marked by good crops; all of this occurring during a period of comparative coolness and wetness (FIG. 7)[52] that reached its peak around 1550 A.C. following the conquest of the peninsula of Yucatan in 1546. Besides supplying us with a short descriptive history of Yucatan during the protohistoric period, the above also seems to indicate that in spite of natural disasters such as a hurricane and an epidemic such as that following Ponce de Leon's visit to Yucatan, the Maya still flourished if and when the weather affecting the peninsula was cool and wet as projected by our model.

In certain cases climate can cast some insight on historical controversies. It is of more than passing interest here that the chronological similarities between climatic and sociopolitical events in the Maya area favor the correlation between Maya and European calendars by Goodman, Martinez, and Thompson of 11:16:0:0:0 more than the Spinden correlation of 12:9:0:0:0, which is 260 years earlier. This agreement demonstrates that the former rather than the latter correlation matches the occurrence of major cultural events for the entire Maya area, thus also suggesting a single correlation for both the Northern and the Southern Maya Lowlands.

Historical Period

Other historical sources from the 15th century on tend to confirm our view that climatic changes in Yucatan, which paralleled those taking place in the rest of the world, had a notable impact on the historical development of the Maya.[53] As stated above, the Postclassic Period emergence of Mayapan as an important political center coincides with a colder and wetter climatic cycle than what existed before on the peninsula of Yucatan. The temporary reversal of this cycle in the early or mid- 15th century, that is, the beginning of a short cycle of warmer, drier climate, also coincides with the collapse of Mayapan and the political chaos endemic in precolonial Yucatan that was characterized by a division of the peninsula into several local jurisdictions. This warmer cycle seems to have culminated in the mid-16th century with a famine caused by drought.[54]

The trend towards a general cooling of the climate, which had begun in the late 13th century, was resumed in the second half of the 16th century after the preceding short-lived warm period had run its course. The return to a cooler and wetter climate, however, did not produce another cultural or economic florescence among the Maya as in the past. This lack of florescence resulted from the introduction by the Spaniards of epidemic and endemic diseases that thrived in the moister environment extant after ca. 1550 A.C. Consequently the Indian population continued to decline in numbers, even though no droughts, formerly an important factor in demographic decline, occurred during the 17th century.

In the 18th century another reversal of the climatic pattern took place, as the cooler and wetter climate characteristic of the previous century gradually gave way to a warmer and drier cycle that lasted into the early 19th century. This reduction in rainfall was a factor involved in the reversal of the earlier demographic decline, as diseases became less frequent because of drier conditions. The Indian population consequently increased rapidly

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[48] Diego de Landa, *Relacion de las Cosas de Yucatan*, English translation and notes by Alfred M. Tozzer, *Peabody Museum Publication* 18 (Harvard University: Cambridge 1941) 40.
[49] Ibid.
[50] Ibid. 41.
[51] Aurelio Tio, "Historia del descubrimiento de la Florida y Beimeni 6 Yucatan," *Academia Puertorriquena de la Historia. Boletin* 2 (1972) 81-82.
[52] Alexander, op. cit. (in note 30) 91.
[53] Much recent data on world climatic change are summarized by H. H. Lamb, *Climate. Present, Past and Future,* Vol. 2 (Methuen and Co. Ltd.: London 1977) 423-549.
[54] Fray Bernardo de Lizana, *Historia de Yucatan. Devocionario de nuestra Sra. de Izamal y conquista espiritual* (Mexico 1893) 8v; Fray Diego de Lopez de Cogolludo, *Historia de Yucatan* (Mexico 1957) Cpas. v. xv.

in the course of the 18th century.[55] On the other hand, the warmer, drier climate also was characterized by the return of drought, of which the first notice dates from 1747. In the second half of the 18th century, and at least until the second decade of the next century, the frequent lack of rain became a serious problem in Yucatan and helped bring about important social and economic changes.[56] Most importantly, frequent maize shortages resulting from the scarcity of rain caused maize prices to rise dramatically, a pattern that was paralleled in the Valley of Mexico and in Western Europe.[57] In Yucatan this rise in prices made grain production, for the first time in history, profitable for the descendants of early Spanish conquerors and colonists. The latter, therefore, began to convert their cattle ranches into estates devoted to grain production as well as livestock. They also began to acquire the requisite labor force to carry out this new branch of production.[58]

Socioeconomics of Coastal Yucatan As Related to Climatic and Eustatic Sea-level Changes

The sea around the peninsula of Yucatan has undoubtedly been a valuable asset to the Maya since ancient times. Coastal trade and the exploitation of marine resources, notably fishing and salt gathering, have been closely tied to the political and socioeconomic developments of the Maya Lowlands.

In this paper, we have argued that climatic change affected the dry-land food production, settlement, and economics of Yucatan. On the coast, eustatic sea-level changes in addition to climatic changes (and they are interrelated) affected the exploitation of marine resources. These shifts had adverse effects not only on coastal settlement, economics, and subsistence, but also throughout the Maya Lowlands because of shortages of certain natural resources such as salt.

World-wide climatic and sea-level changes have affected civilizations since ancient times.[59] One of the essential natural resources exploited in many parts of the world affected by changing climate and sea levels is sea salt produced by solar evaporation. Solar salt has been produced on the coast of Yucatan since at least the Late Preclassic Period, and probably earlier.[60] It was an important commodity through all subsequent periods.

At the height of ancient Greek and Phoenician civilizations, sea level was lower than today and solar salt production and trade flourished in the Mediterranean.[61] It was also during that time that conditions for solar salt production on the northern coast of Yucatan were evidently favorable for the Middle Preclassic Period Maya making exploitation and trade of this item a significant enterprise for them.

Although the sea level was gradually rising in Europe from 200 B.C. on, the Mediterranean salt works flourished for nearly 800 years before the sea began to flood the salt pans to the extent that they brought about the reduction of salt production. By 500 A.C. the sea had risen to well above the present level. This peak level was sufficient to inundate most salt pans all over the world, thus drastically affecting the production and traffic of salt. In Europe the commercially vital salt pans and salt peat beds were flooded, thereby producing an economic dark age. Population shifts occurred and former salt- producing areas were abandoned.[62] Some salt was produced from salt mines, desert salt lakes, and the Dead Sea, but not in quantities large enough to supplement the vast resources from the sea. Salt was essential, and in the 6th century A.C. ports and towns in places such as Palestine grew and became wealthy through providing mined inland salt and salt-cured food to the West.

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[55] Robert W. Patch, "A colonial regime: Maya and Spaniard in Yucatan," unpublished Ph.D. dissertation, Princeton University (Princeton 1979) 206-209
[56] Ibid. table 4.4.
[57] Enrique Florescano, *Precios del maiz y crisis agricolas en Mexico* (1708-1810) (EI Colegio de Mexico: Mexico 1969); Ernest Labrousse, *Esquisse du mouvement des prix et des revenus en France au XVIIle siecle* (Dalloz: Paris 1933); W. H. Beveridge, "Wheat Prices and Rainfall in Western Europe," *Journal of the Royal Statistical Society*, n.s. 85 (1922).
[58] Patch, loco cit. (in note 55); idem, "Una cofradia y su estancia en el siglo XVIII, Notas de investigacion," *Boletín de la Escuela de Ciencias Antropologicas de la Universidad de Yucatan* 46-47 (1981) 56-66.
[59] Bloch, op. cit. (in note 43).
[60] Jack D. Eaton, "Shell Celts from Coastal Yucatan, Mexico," *Texas Archaeological Society Bulletin* 45 (1974) 197-208; Eaton and Ball, op. cit. (in note 40) 207.
[61] Bloch, op. cit. (in note 43) 95.
[62] Ibid. 96.

In Yucatan, sea-salt production still flourished on the north coast during the Late Preclassic and Early Classic Periods.[63] Sometime around the end of the Early Classic Period (ca. 500 A.C.), however, occupation of the salt lagoons seems to have terminated and there was a population shift to the interior of the peninsula. Perhaps at this time the salt pans had been drastically flooded by the peak rise in global sea level. The region may also have been affected by the heavy rains that produced the relatively wet climatic conditions postulated for that period in Yucatan. The existence of this adverse climatic condition on the coast, as suggested by the apparent abandonment of the salt fields and a population shift, closely correlates with the Classic Period hiatus which evidently took place at the end of the Early Classic.[64] It was during this hiatus that global sea level attained its highest point. Then, after remaining in flood condition for nearly half a century, it began to recede. This situation seems to have been experienced in many parts of the world coincidental with peak sea level, and it is here thought that climatic change and the drastic reduction in the production and supply of salt were key factors in this socioeconomic decline.

As has been suggested, there have been alternating periods during the past 10 centuries when mean sea level rose above and fell below the present level,[65] and the changes were accompanied by climatic changes of alternating wet and dry periods (FIG. 8).[66] It is not surprising, therefore, that some of the most crucial events in Yucatan, and all of Mesoamerica, occurred during phases of major climatic and sea-level changes. The times of sea-level rise were evidently coincidental with periods

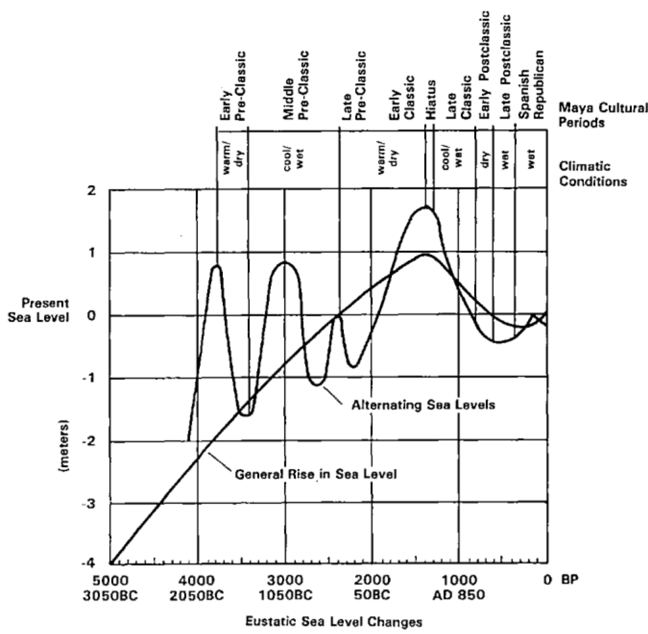

Figure 8. Interrelationships between climatic change, eustatic sea-level change, and cultural change in Yucatan.

of longer and heavier rainfall related to global climatic conditions when the downpour of rain water would dilute the surface salinity of the inshore sea waters used in solar salt production. During drier periods and lower sea level, however, surface salinity would be higher and the dry trade winds would bring about rapid evaporation and greatly increase salt production.

During the 7th and 9th centuries global sea level receded to where coastal salt pans were again producing. In Europe during the 10th century the making of salt from evaporation pans and peat bogs had fully resumed and salt traffic was again meeting demands. During the Maya Late Classic Period (600-900 A.C.) sea-salt pro-

[63] Eaton and Ball, op. cit. (in note 40) 12.
[64] Willey and Shirnkin, op. cit. (in note 36).
[65] J. M. Coleman and W. G. Smith, "Late Recent Rise in Sea Level," *GSA* 75 (1964) 833-840.
[66] Bloch, op. cit. (in note 43) 98.

duction evidently returned, although archaeological evidence is relatively scarce. Perhaps at this time seasonal salt harvest was performed by work forces from inland towns, as happened later during the colonial period. During the Maya Terminal Classic and Early Postclassic Periods of the 10th and 11th centuries, sea level had returned to where it is today and global climate was entering a drier period. During the Maya Postclassic Period, sea level actually dropped a little lower than current levels and drier climatic conditions on the coast were once again favorable to salt production. During this time there exists archaeological evidence for increased occupation of coastal salt lagoons. Moreover, there appears to be notable evidence of a foreign Toltec and Itza presence.

During the 16th century, sea level again rose and flooded European salt-making centers. Global sea rise was not as devastating as before and did not greatly affect Yucatan salt production. The colonial salt report of 1605 notes considerable salt production at this time.[67]

Lowland Maya Settlement Patterns and Climatic Change

In addition to explaining the ebb and tide of Mesoamerican cultures, the model by Gunn and Adams of climatic variation[68] also seems useful in explaining the location of major Maya regional centers throughout the Lowlands. For example, the early part of the Middle Preclassic Period of Maya prehistory would have been a wet period probably making the habitation of such places as the low, poorly drained Peten Core area relatively uninhabitable until a later date, because of flooding, while the outer Buffer Zone was more habitable because of its location on higher and better-drained ground than the Core (FIGS. 9, 10).[69] In the case of the Northern Maya Lowlands, heavy rainfall would have enrichened the Interior Zone of the peninsula of Yucatan making it more fertile for horticultural purposes than the Coastal Zone, which would have been characterized by large bodies of water that would have covered the coastal salt flats that were to become of greater importance from 500 B.C. to 600 A.C., when southern Mexico would have been warmer and drier. The latter part of this period was characterized by the development of such Coastal Zone centers as Edzna, Oxkintok, Dzibiichaltun, Izamal, and Coba in the Yucatan Peninsula and the Core Zone cities of the Peten such as Tikal and Uaxactun. The 600-900 A.C. period would have brought about cooler and wetter climes in southern Mexico, thus reducing the value of coastal area salt production and encouraging the development of at least a few regional centers such as Uxmal and T'ho, which are closer to the Interior Zone of the peninsula of Yucatan.

Explaining the movement of these two regional centers toward the Interior Zone of Yucatan during a wet period and the exact effect of changes in the annual atmospheric energy budget on local Yucatan climate is difficult without the detail of meteorological information available in areas further north of Yucatan where data collecting is much more intensive. The study by Sanchez and Kutzbach of climatic changes in the Americas between the

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[67] Ralph L. Roys, *Political Geography of the Yucatan Maya, CarnlnstPub* 613 (1957) 79-82.
[68] Gunn and Adams, op. cit. (in note 22).
[69] T. Patrick Culbert, "Introduction: A Prologue to Classic Maya Culture and the Problem of its Collapse," in Culbert, ed., op. cit. (in note 7) 3-19, fig. 3.

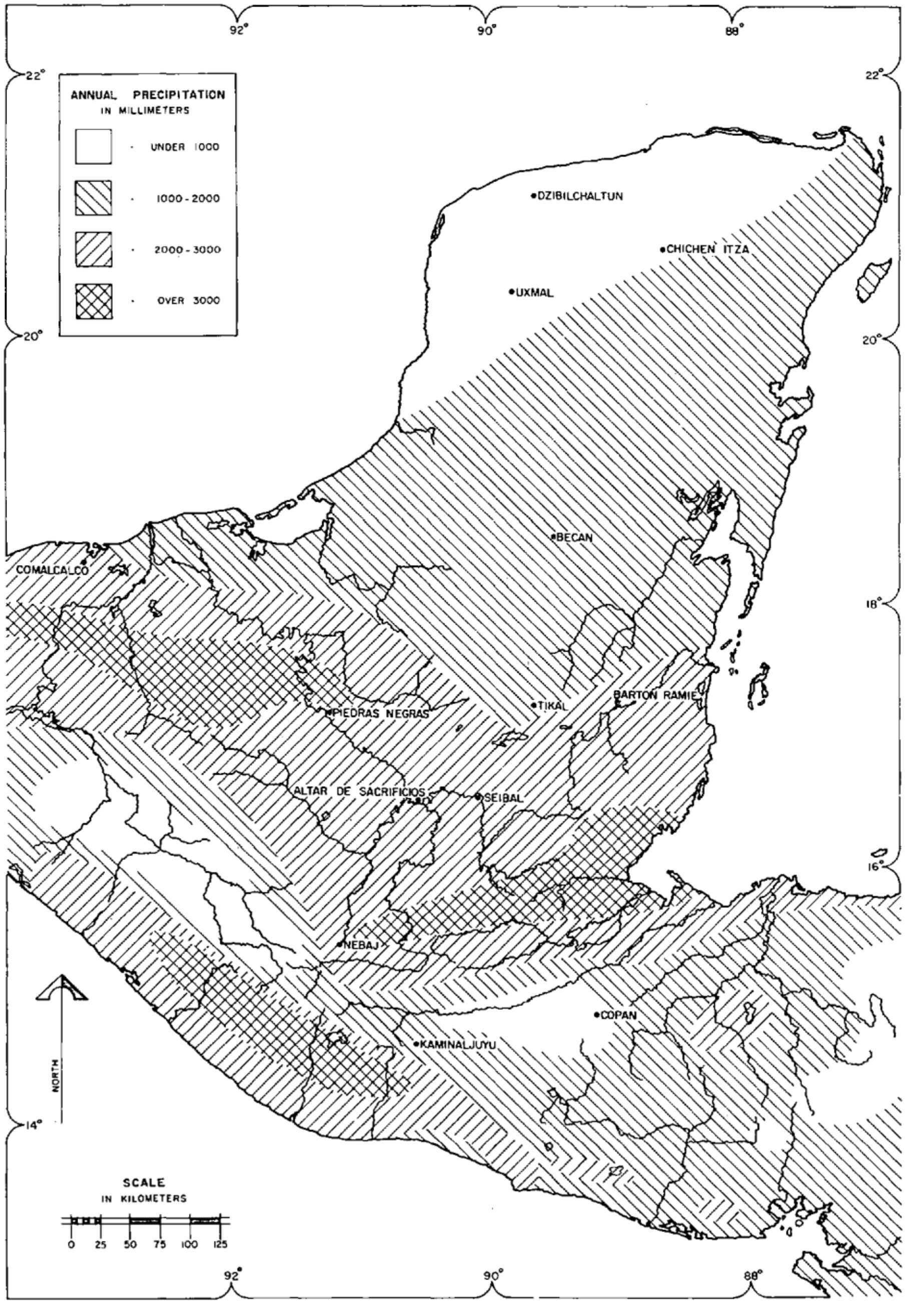

Figure 9. Map showing the rainfall pattern in the Maya Lowlands.

decades 1930-1960 and 1961-1970 demonstrates, however, that as the energy budget drops, winter moisture significantly increases (FIG. 11).[70] The fact that overall annual moisture remains stable (AG. 12),[71] suggests a shift from a summer rainfall, wet season to year-long wetness or perhaps a reversal of the present wet-dry season pattern. For now let us assume that colder global temperatures simply shorten the dry season while warmer global temperatures generate a longer dry season.

This surmise is supported by the barometric pressure maps provided by O. G. Ricketson (FIG. 13),[72] The 30.0 inches of mercury line, representing the ridge of high pressure known as the "subtropical high" or the Ber-

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[70] Sanchez and Kutzbach, op. cit. (in note 25), esp. fig. 3.
[71] Ibid. fig. 1.
[72] Oliver G. Ricketson Jr., "An Outline of Basic Physical Factors Affecting Middle America," in *The Maya and Their Neighbors* (Cooper Square Publications, Inc.: New York 1973) fig. 5.

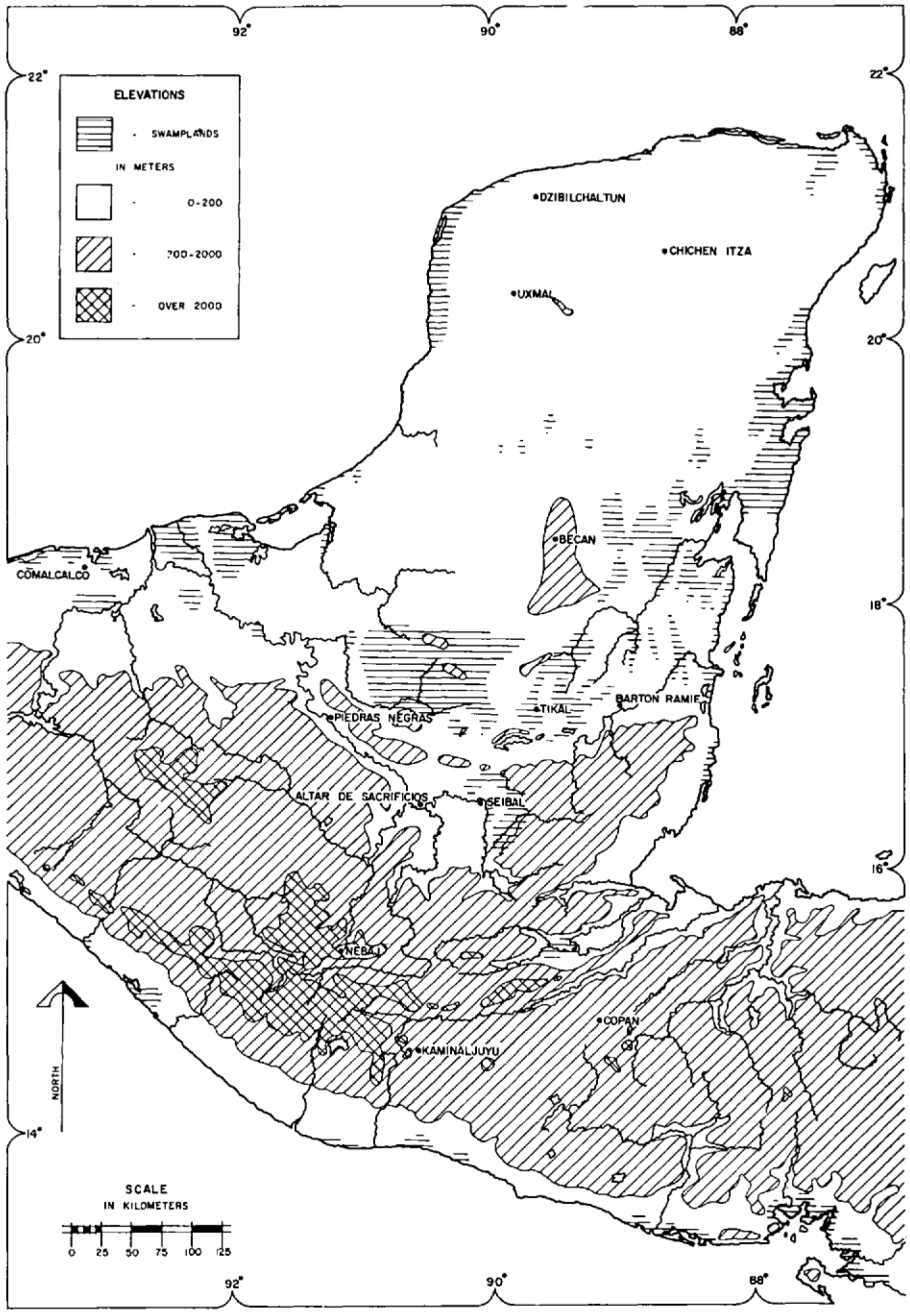


Figure 10. Map showing the elevations of the Maya Lowlands.

muda-Azores cell of the subtropical high, is the critical determining factor. In February, the height of the dry season, the high-pressure ridge crosses Yucatan directly, precluding rain since the dry, subsiding air of the high is devolving directly onto the peninsula.

During the summer, however, the ridge moves northward. Since the air circulates clockwise around the high as it subsides, characteristic winds carrying moist sea air develop on the periphery of the cell. The easterly trade winds represent such an air flow and account for part of the summer precipitation in the peninsula. This supposition is further supported by the distribution of contemporary rainfall in Yucatan as represented in Figure 9[73] and by a study of satellite photos by A. Williams (FIG.

[73] Culbert, Ope cit. (in note 69) fig. 4.

14).[74]

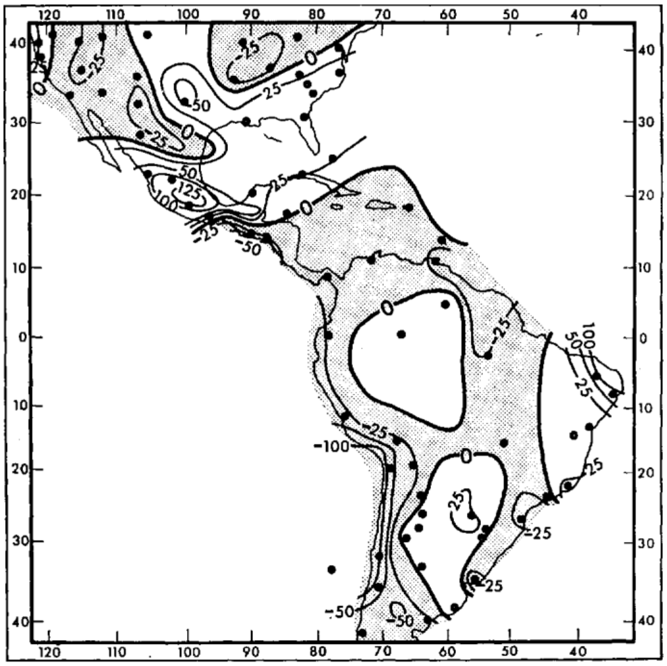


Figure 11. Departure of 1961–1970 mean January precipitation from the 1931–1960 average, expressed as a percentage of the 1930–1960 average. (•) Reporting station.

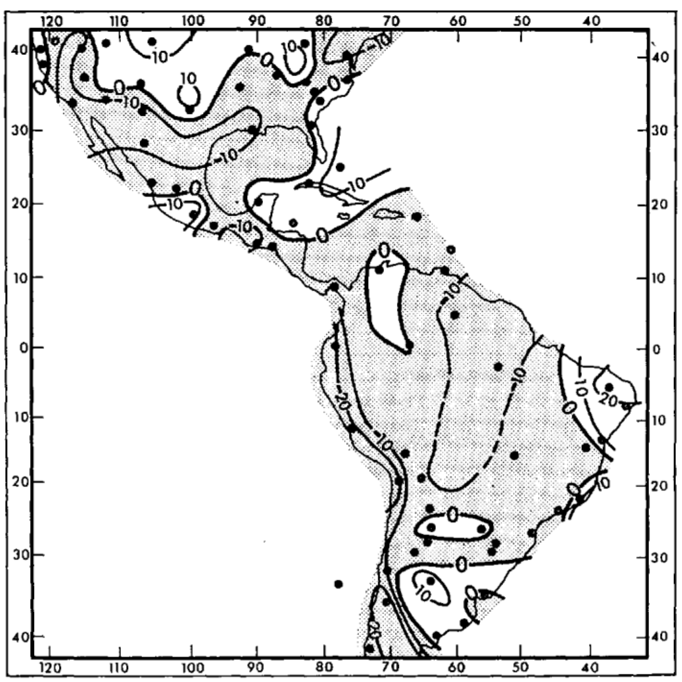


Figure 12. Departure of 1961–1970 mean annual precipitation from the 1930–1960 average. (•) Reporting station.

[74] Aaron Williams, Jr., "The Interpretation of Rainfall Patterns in Northern Yucatan Utilizing Meteorological Satellite Imagery," *Proceedings of the Association of American Geographers* 8 (1976) 15- 19, fig. 2.

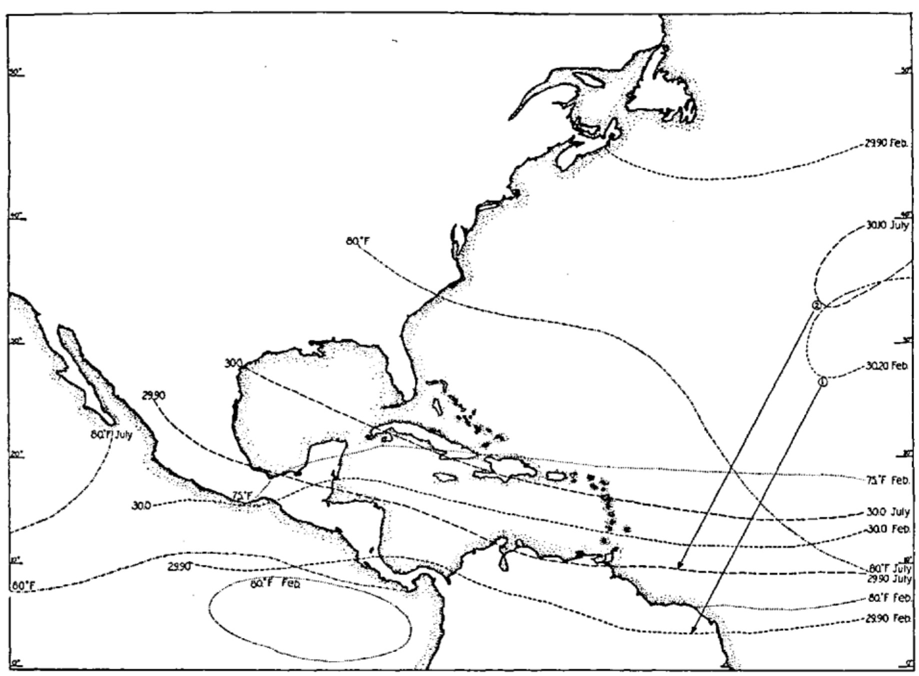
The final climatological question to be dealt with is how variation in the global energy budget moves the ecotone between wet eastern Yucatan and the dry western sector. We would suggest at least tentatively that the ecotone responds gradually and directly. That is to say that the colder the global energy budget, the further west the ecotone moves in response to increasing rainfall in the present dry season and in response to higher effective moisture as evapotranspiration is reduced by lowering temperature. Conversely, the ecotone moves east, or SE, as an increased energy budget lengthens the dry season.

We should note at this point that weather systems in the higher latitudes respond in a step-wise fashion tolerating ranges of change in the energy budget and changing suddenly when a threshold is crossed.[75] Whether or not the step-wise effect reaches the lower latitudes is a matter that awaits analysis of tropical climatic time series data, none of which has been performed to our knowledge. Numerous lines of evidence suggest, however, that the effects of global cooling are rapidly diminished as latitude decreases. We, therefore, pose for the moment a gradual response fully realizing that a more stepped reality may appear with intensive data analysis.

To this point we have dealt with Yucatan climate in the rather broad perspective of the global energy budget. There are, however, some interesting details known about the weather processes of climatic change. Williams[76] was attracted by the very curious occurrence of an arid climate on the otherwise tropical Karst Plain of northern Yucatan. He reasoned that if the entire area shares a dry winter because of the subtropical high phenomenon discussed above, then the aridity of the NW must lie in the summer rainfall-producing mechanisms. Given the virtual nonexistence of climatic data from the north of the peninsula he turned to satellite photos of the area to determine the cause involved.

Yucatan has two rainfall maxima during the year. One is during the fall, September and October, the other during early summer, June and July. Williams chose to study satellite photos of the peninsula every two hours during the day for the months of June and July, 1975, to determine the source of this summer rainfall. The hours selected for study were 10 a.m., 12 p.m., 2 p.m., and 4 p.m. After days disturbed by cold fronts and easterly waves were removed, a pattern of thunderstorm activity appeared over the eastern sector of the Karst Plain, as is

Figure 13. Barometric pressure maps of the Caribbean region.



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[75] Bryson and Murray, op. cit. (in note 23) 37.
[76] Williams, op. cit. (in note 74) fig. 2.

clearly shown in Figure 14.[77] A few thunderstorms appear in the photos as early as 10 in the morning. There exists, however, a persistent increase in thunderstorm activity along the east coast which reaches a crescendo in early afternoon.

Closer examination of the patterns along with the surface data available revealed the working of a phenomenon known among meteorologists as the "double sea breeze effect"[78] also known to occur in South Florida. The' 'double sea breeze effect" develops over the course of a day as follows. Early in the morning the land and the air over it begin to warm creating a low-pressure zone into which the cooler sea air moves. The air over the Caribbean, supported by persistent easterly trade winds responds first, usually about 10 a.m. It begins to move westward onto the land. As the day progresses thunderstorms begin to develop along this sea-breeze front. At a slightly later time a similar sea breeze develops off the Gulf of Mexico and moves south. Along the line at which the two sea breezes converge terrific thunderstorms generate the pattern of heavy rainfall which marks the summer along the east coast.

By contrast, the same northerly sea breeze off the Gulf of Mexico has a negative effect on moisture further west. There are no moist easterlies supporting the flow of air from the Gulf. Therefore, air rushing off the Gulf causes subsidence of dry, upper air along the NW coast. After the initial rush of moist, maritime air, it is followed by dry upper air which precludes thunderstorms in the western sector during the early afternoon, the period of the day most conducive to such activities.

The question we must ask ourselves at this point is, ,'Is there in this summer rainfall mechanism a likely cause of local climate given a change in the energy budget?" Under any circumstances could this pattern spread summer thunderstorms to western and northern Yucatan? One can suggest that since global cooling generally speeds up circulation in the atmosphere, cooler conditions might lead to stronger easterly support for the Caribbean sea breeze and thereby a more westward progress of the thunderstorm systems. This weather model is an hypothesis that needs to be tested in the modem weather and in the archaeological record.

Culturally both the global and local analyses of the weather system imply that occupations such as those represented by Dzibilchaltun and Oxkintok should move southward and eastward to places such as T'ho and Uxmal during globally warm periods in cultural situations where societies are only horticulturally or otherwise dependent on precipitation moisture. This tendency, however, is evidently not the case for Yucatan where the ancient Maya apparently moved from north to south and NW to SE in response to a cool, wet period during the Late Classic, Florescent Period, 600-800 A.C. Although we do not completely understand the reasons behind this move, it may be suggested that the Northern Maya gravitated toward the coast in warm, dry periods to take advantage of the benefits to be derived from sea and shore and moved toward the interior during cooler, wetter periods to exploit the rich, rain-soaked soils of the Interior Core Area. It would be at this time that rainfall would be available to fill the numerous cisterns and larger open reservoirs found in such places as Uxmal, Kabah, Labna, and Sayil, thus providing the citizens of the Puuc Region with water sufficient for urban use, a need underscored by the numerous representations of the rain- associated deity Chac in NW Yucatan.

Chichen Itza's later development during a warm drier period in the peninsula has already been explained by Eaton in reference to the northern salt beds and by Folan in reference to the entrance to the Maya infraworld, Xibalba. And the later location of such regional capitals as Mayapan toward the interior during a cold, wet period would match the location of such places as T'ho and Uxmal further inland than earlier capitals because of the flooding of the salt beds and the enrichment of interior lands for horticultural purposes. The location of still later regional centers such as Mani was also toward the Core where there was heavier rainfall. The only coastal area of much habitational importance at this time was along the east coast of the peninsula of Yucatan, which is the only coastal area of the Yucatan Peninsula benefited by a reasonable amount of rainfall (FIG. 9).[79] The east

[77] Ibid.
[78] Ibid. 17.
[79] Culbert, op. cit. (in note 69) fig. 4.

coast was also the only coastal area where there were no salt beds, according to historical sources. But although salt. was of much economic importance at the time of the conquest, fish were in first place, according to ethnohistorical research by Roman Pifia Chan,[80] quantified by Folan,[81] indicating that this may well have been the item most available and pursued by coastal peoples in Yucatan during cool, rainy periods such as those prevalent during Late Classic and Late Postclassic times.

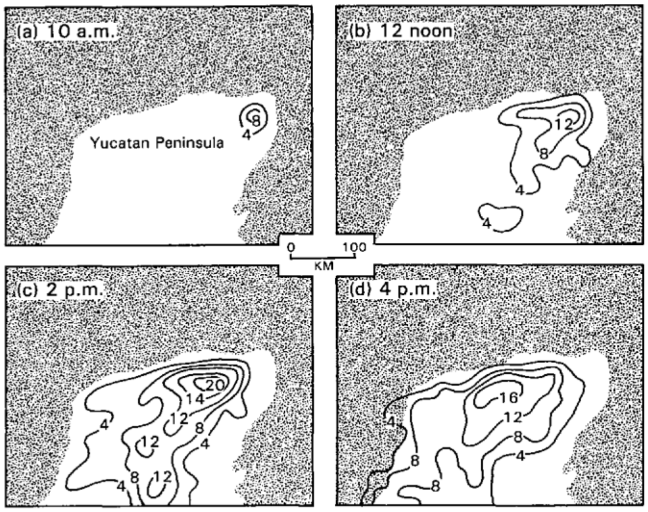

Figure 14. Distribution of contemporary rainfall in Yucatan determined from meteorological satellite imagery, June and July, 1975.

Conclusions

Based on the above data it can now be stated that Classic Period Maya culture did not fall only to the onslaught of outside invasion forces, epidemics, social decay, governmental disorganization, or economic collapse because of the failure of the Maya agricultural system to meet the needs of an increasing population or trade and market losses,[82] but like Mycenae two millennia earlier,[83] its collapse may have been brought about by a 9th-century climatic change that failed to provide sufficient moisture for needed horticultural production, thus bringing about a situation that would make any or all of the above reasons for the fall of the Maya Great Tradition possible, if not imperative.

Moreover, it is now clear that the shift by Europeans from ranching to farming in Yucatan, as demonstrated by the transition from cattle ranches to plantations, was to a certain extent influenced by a decrease in precipitation. The famous Caste War of the 19th century, therefore, could have resulted mostly from the land-grabbing activities of plantation owners, who were influenced unconsciously by the factor of climatic change that reduced corn production and drove its market value up to the point that cattle raising became less profitable than farming.

Acknowledgments

We wish to thank Eugene Wilson, Dena Dincauze, James R. Wiseman, and others for reading and commenting on our manuscript. As usual, however, all errors or omissions are those of the authors exclusively.

[80] Piña Chan, op. cit. (in note 11).
[81] Folan, op. cit. (in note 9).
[82] Sylvanus Griswold Morley and George W. Brainerd, *The Ancient Maya*, rev. by George E. Brainerd (Stanford University Press: Stanford 1956); Willey and Shimkin, op. cit. (in note 36); E. S. Deevey, Don S. Rice, Prudence M. Rice, H. H. Vaughan, Mark Brenner, and M. S. Flannery, "Maya Urbanism: Impact on a Tropical Karst Environment," *Science* 206 (1979) 298-306.
[83] Bryson and Murray, op. cit. (in note 23) 4.