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LASER TECHNOLOGY CHANGE KNOWLEDGE ABOUT THE MAYAN EMPIRE: THE MAJOR DECLINE OF THE MAYAN CULTURE AROUND THE YEARS 800-1,000

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The Maya Empire which includes areas that we now know as southern Mexico, western Belize and Guatemala peaked on its development with population of up to 16 million. That's far more than previously thought. It was formerly believed that the Maya culture peaked with a population of around 7 to 11 million people spread across the territory 95,000 square km. The latest research builds on the 2018 analysis and has resulted in a 45% jump in the new population estimates of Maya civilization. The new estimates now range from 9,5 million to 16 million people in the late period from the year 600 to 900. In this article the author analyse the reasons why the Mayan culture experienced a breakdown more than 1,000 years ago. These reasons are established in the context with the influence of climate on the course of history and the vulnerability of mankind in the in the terms of transformations caused by climate change.

Keywords: Maya Empire, climate changes, droughts, Yucatán peninsula, Uxmal, Stalagmites, Lake Chichancanab, Chitzen Itza, Tecoh Caves, Maya collapse, Mesoamerica, Guatemala, Belize.

ЛАЗЕРНЫЕ ТЕХНОЛОГИИ ИЗМЕНИЛИ ПРЕДСТАВЛЕНИЯ ОБ ИМПЕРИИ МАЙЯ: ОСНОВНОЙ УПАДОК КУЛЬТУРЫ МАЙЯ ПРОИЗОШЕЛ ПРИМЕРНО В 800-1000 ГГ.

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Империя майя, включавшая в себя районы, которые мы теперь знаем как южную Мексику, западный Белиз и Гватемалу достигла пика своего развития с населением до 16 миллионов человек. Это гораздо больше, чем считалось ранее. Прежде считалось, что культура майя достигла своего пика с населением от 7 до 11 миллионов человек, проживавших на территории площадью 95 000

квадратных километров. Последнее исследование основано на анализе 2018 г. и привело к 45% скачку в новых оценках численности населения цивилизации майя. В настоящее время эти оценки варьируются от 9,5 до 16 млн. человек в поздний период с 600 по 900 гг. В данной статье автор анализирует причины, по которым культура майя пережила упадок более 1000 лет назад. Эти причины устанавливаются в контексте влияния климата на ход истории и уязвимости человечества в условиях трансформаций, вызванных климатическими изменениями.

Ключевые слова: империя Майя, климатические изменения, засухи, полуостров Юкатан, Ушмаль, сталагмиты, озеро Чичанканаб, Читцен-Ица, пещеры Теко, падение Майя, Мезоамерика, Гватемала, Белиз.

Prologue – Mesoamerican pre-Columbian cultures

Mesoamerica is the region extending from central Mexico south to the north-western border of Costa Rica that gave rise to a group of stratified, culturally related agrarian civilizations spanning an approximately 3,000-year period before the visits to the Caribbean by Christopher Columbus. Mesoamerican is an adjective generally used to refer to that group of pre-Columbian cultures. This refers to an environmental area occupied by an assortment of ancient cultures that shared religious beliefs, art, architecture, and technology in the Americas for more than three thousand years. Between 2000 and 300 BC complex cultures began to form in Mesoamerica [2, p. 279].

Pre-Columbian societies refer to the Indigenous civilizations that flourished in the Americas before the arrival of Christopher Columbus in the late 15th century. Key examples include the Maya, Aztec and Inca empires in Mesoamerica and South America, which developed complex social structures, advanced mathematics, astronomy and sophisticated urban centres. These civilizations developed diverse agricultural practices, sophisticated art and unique belief systems that influenced cultures for centuries after their decline. Volcanic eruptions can be very powerful natural events that can have very wide-ranging effects on the Earth’s climate,

ecosystems, and human societies. An overview of how volcanoes influence climate change**,** temperature, hunger, and destruction:

Agriculture: Societies relied on staple crops like corn, beans, and squash in Mesoamerica, and the potato in the Andes. Agriculture was absolutely the most advanced field in the Maya Civilization.

Social structures: Developed intricate social hierarchies with political and religious leaders, artisans, and farmers.

Knowledge and technology: Exhibited advanced knowledge in mathematics, astronomy, architecture, and the creation of complex irrigation and road systems.

Culture: Developed diverse artistic expressions, spiritual systems, and various forms of governance, influencing subsequent cultures in the region [10, p. 200-202].

The period between 250 and 650 was a time of intense flourishing of Maya civilized accomplishments. While the many Maya city-states never achieved political unity on the order of the central Mexican civilizations, they exerted tremendous intellectual influence upon Mexico and Central America. The Maya built some of the most elaborate cities on the continent and made innovations in mathematics, astronomy and calendar [2, p. 122].

Maya also developed the only true writing system native to the Americas using pictographs and syllabic elements in the form of texts and codes inscribed on stone, pottery, wood or perishable books made from bark paper.

Early inhabitants of the Americas developed agriculture, developing and breeding wild teosinte into modern corn. Potatoes, cassava, tomatoes, pineapples, tomatillos (a husked green relative of the tomato), pumpkins, chili peppers, squash, beans, onions, avocados and vanilla were among other plants grown by natives. Over two-thirds of all types of food crops grown worldwide are native to Americas [10, p. 27-28].

Early indigenous peoples began using fire in a widespread manner. Intentional burning of vegetation was taken up to mimic the effects of natural fires that tended to clear forest understories, thereby making travel easier and facilitating the growth of herbs and berry-producing plants that were important for both food and medicines.

While not as widespread as it was in Afro-Eurasia, indigenous Americans did have livestock. Domesticated turkeys were common in Mesoamerica and some regions of North America; they were valued for their meat, feathers and, possibly, eggs. There is documentation of Mesoamericans utilizing hairless dogs, especially the Xoloitzcuintle breed, for their meat [10, p. 30].

In 1519 the Spaniard Hernán Cortés arrived in Mexico among the Aztecs and destroyed their capital Tenochtitlán, where Mexico City now stands, in two years. However, he spared the older city of Teotihuacán (from 100 BC to 700), which has now been restored and excavated. The land of the Mayan Indians was also conquered by the Spaniards in the 16th century. They had lived there for over 2,700 years but had their heyday in the 4th-11th centuries. The Inca Empire had its heyday between 1200 and 1533, when their land was also conquered. Mesoamerican pre-Columbian cultures were forever extincted.

Maya Empire and the terminal Classic period

In historical scholarship the Maya civilization is divided into three periods: the Preclassic (2,000 BC-250), the Classic (250-950) and the Postclassic (950-1539). It followed the Archaic period (8,000 BC-2,000 BC) of Mesoamerica, which was characterized by hunter-gatherer culture. The key civilizational achievements – sedentary settlements, pottery and agriculture, whose combination marked the transition from the Archaic period to the Preclassic, emerged independently of the Maya and were subsequently adopted by them [3, p. 170].

It is not entirely clear how the Maya spread; their probable origin lies in the Sierra de los Cuchumatanes, where they formed a small linguistic community. From around 1500 BC they migrated from there in several waves, including to the north of the Yucatán Peninsula and the Olmec lowland region along the Gulf Coast. By the end of the 2nd millennium BC, Maya farmers using pottery were already settled along the Belizean coast and increasingly moved inland towards the Upper Belize River Valley; settlements such as Cahal Pech and Cuello emerged there around 1200 BC. From the western part of their settlement area, numerous migrants moved down

into the lowlands along the Río Chixoy, while others gradually migrated north along the east coast of Yucatán [3, p. 179].

Scholars divide the Classic era of Maya Civilization into three periods. In the early Classic period (ca. 250-600) a series of cities (for instance Copan) in the southern lowlands expanded and flourished, making that area centre of Maya power. During the late Classic period (ca. 600-800) populations in the cities of the southern lowlands reached their peak. New city-states also rose to prominence. The terminal Classic period (ca. 800-1,000) is, however, marked by the decline of the city-states in the southern lowlands, while in the Yucatán and the highlands new cities rose.

This decline of the Mayan Empire has always been a riddle to the scientist. In many years archaeologists believed in the theories that there were many factors that led to this decline of the cities that had flourished in the late Classic period. It could be a combination of overpopulation, over exploitation of an already exhausted environment, destructive warfare, and loss of faith in a political system that could not solve these problems, which forced people to seek a better life in other regions nearby [3, p. 184].

Already from the beginning of the terminal Classic period most city-states were suffering from one or several of the abovementioned problems. By the end of the period there was no construction, no new monuments, no strong kings in the former powerhouses of the region – Tikal, Calakmul, Palenque and Copan. Another key reason people abandoned the southern lowlands was that they no longer believed the gods would assist their ruler in solving their earthly problems. People in the Maya regions wondered, why contribute to expensive, massive building projects when the only outcome was a better life for the elite. The labour force dwindled and the elite were no longer satisfied either – they were still distant seconds to the kings. Especially in Copan the elite around the king had tasted the taste of power and the elite would not return to old hierarchies. The balance of power shifted [14, p. 45-47].

This could also be seen in the paintings of the pyramids. Most Classic period portraits show individual kings bearing all the trappings of supernatural and secular power, alone and aloof, except for downtrodden captives. But it changed drastically –

in the late Classical period the Maya Kings began to share centre stage subordinate nobles, who appear on monuments, hold prestigious titles, and live in larger and more elaborate residences. However, during the terminal Classic period the individualized portrait of the ruler is replaced by images of the new leader in society – the nobility which shared power within each polity [2, p. 145].

In this way, power sharing or lack thereof may have been a factor in the downfall of the cities, like in Copan. Another factor was, however, that Mayas had made a serious impact on the environment. A certain overuse of the agrarian land combined with cutting down forests and flooding all played their part in the decline of the Mayan civilization in the southern lowlands. In the Puuc region some kings were in power, but in many cities, the most common form of rule was by councils of noblemen. Increasing trade, thereby, also shifted the balance of power. A kind of trader middle class appeared, because traders gained more wealth. Furthermore, the economy was no longer almost controlled by the elite [1, p. 185].

The results were a real catastrophe – buildings fell into disrepair, fields were left untended and the great powerhouses of the Classic Period were swallowed by the jungle. Warfare was a certain factor in the decline too. When the new Maya centres grew and began to infringe on one another, the various polities of the Maya found themselves in a battle of dominance [15, p. 100].

Maya Empire and climate

From the 9th century onwards individual Maya centres in the southern lowlands were abandoned, followed by a rapid population decline throughout the central region of Yucatán. Numerous cities were deserted and the irrigation systems fell into disrepair. After the mid-10th century, no more monumental stone stelae were erected throughout the lowlands. The collapse of Maya society is the subject of extensive and on-going scholarly debate. Two main approaches can be distinguished: ecological and non-ecological explanatory models.

The “non-ecological models” encompass explanatory various explanations, such as invasions, natural disasters and epidemics. Archaeological evidence of the Toltec invasion into northern Yucatán (Seibal) seems to support the invasion

hypothesis. However, most Maya scholars doubt that conquest can be considered the main reason for the widespread societal collapse in the lowlands. Another proposed reason for the collapse of the Classic Maya civilization in the central lowlands is the decline of the metropolis of Teotihuacan in central Mexico, which allegedly left an enormous power vacuum that extended to Yucatán and could not be filled by the rival Maya city-states. However, this is problematic, as the fall of Teotihuacan is now dated to the 6th/7th century, i.e., before the cultural and political heyday of the Classic Maya in the 8th century [6, p. 283].

The decline of the central Mexican metropolis is more likely to explain the period of weakness in the history of Tikal, rather than the Maya collapse of the 9th century. The "ecological explanatory models" focus on the relationship between humans and their environment. During the late Classic period this relationship appears to have deteriorated significantly. A rapidly growing population faced with limited arable land with, in some areas, only poor soil quality, which despite irrigation was apparently cultivated primarily using the traditional, land-intensive milpa system. Based on these observations, Orator Fuller Cook formulated his soil depletion hypothesis in 1921 [9, p. 327].

The theory that climatic fluctuations and particularly droughts were responsible for the decline of the civilization gained further support in 2003 with the discovery of reduced rainfall in Venezuela during the 9th and 10th centuries, as reported by geologist Gerald Haug [q.v.: 7]. Computer simulations by NASA researcher Benjamin Cook have shown that the droughts were exacerbated by extensive deforestation, suggesting that this was likely a case of human-influenced local climate change. Scientists Martín Medina Elizalde of the Yucatán Centre for scientific research in Mexico and Eelco Rohling of the University of Southampton in England confirmed this theory in February 2012. As they wrote in the scientific journal "Science", their comparison of rainfall levels between 800 and 1000 revealed a decrease of up to 40%, which, in their view triggered devastating droughts [6, p. 284-285].

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Centuries before the first European explorers reached Central America Maya, known as one of history most spectacular civilizations, has reached the peak of its development. The culture existed until about 1,000 when cities with up to 100,000 inhabitants were abandoned and swallowed by the jungle. Ever since the discovery of the Maya's magnificent buildings, it has been a mystery what caused the civilization downfall – was it catastrophic drought, civil war or disease? [9, p. 328].

In recent years, scientists have increasingly blamed a series of droughts, but for the first time, two researchers have now been able to put a figure on the amount of rainfall and show that drought was probably the decisive factor. The results show that there was a moderate decrease in precipitation during the period from the rise of the Classic Maya civilization to its decline between 800 and 950. It was only a 25-40% drop in annual precipitation. But it was big enough that evaporation exceeded precipitation, and the available open water was quickly reduced. The figures indicate that the main reason was a decrease in summer hurricane activity [1].

The Maya lived on the Yucatán Peninsula in southern Mexico and Guatemala. Especially in the lowlands, where there are no rivers, precipitation from rain has been crucial for their survival. The Maya were skilled engineers and mathematicians, who were able to calculate the positions of celestial bodies several hundred years in advance and developed intensive agriculture with water reservoirs and irrigation. They mainly grew corn and, towards the end of the period, fed millions of Mayas with very large cities of 100,000 inhabitants.

Drought and the decline of the Mayan civilization

Constructing thousands of architectural structures and developing sophisticated concepts in astronomy and mathematics, the Maya civilization rose to a cultural florescence between 600 and 800. Then, between 800 and 950 many southern cities were abandoned and most cultural activities ceased. This period is known by archaeologists as the collapse of the Classic Maya civilization. The Maya, never able to regain their cultural or geographical prominence, were assimilated into other Mesoamerican civilizations until the time of the Spanish conquest in 1530. The cause of the collapse of the Classic Maya civilization is one of the great archaeological mysteries of our time, and scholars have debated it for nearly a century. Some scientists suggest that a period of intense drought occurred in conjunction with the Classic Maya collapse and could have contributed to the Mayans' misfortune [9, p. 322].

Scientists have reconstructed climate at the time of the Mayan civilization by studying lake sediment cores from the Yucatan Peninsula. It is possible to reconstruct changes in the balance between precipitation and evaporation (P-E), a common indicator of drought, by measuring oxygen isotope data from the shells of gastropods and ostracods. Lake H_2O molecules containing isotope 18O evaporate less easily than H_2O molecules with 16O. Thus, during periods of strong evaporation, the lake water becomes enriched in 18O (values of δ18O are high). These isotopic values are incorporated into the growing shells of gastropods and ostracods that live in the lake. Another proxy for P-E is the percent of sulphur in the lake sediments. Evaporation concentrates sulphur in the lake water. If the sulphur concentration becomes high

enough, salts such as gypsum ($CaSO_4$) will start to precipitate from the lake water and add sulphur to the lake sediments. The variations of sulphur percentage match the variations in oxygen isotopes closely. Corroborating one paleoclimate proxy with another is an important check on proxy records and gives us more confidence in them. Distinct peaks in these two proxies reflect times of aridity on the Yucatan Peninsula [7, s. 1734-1735].

The most arid time of the last 2,000 years occurred between 800 and 1000 AD, coincident with the collapse of the Classic Maya civilization. A newer high-resolution analysis of rainfall proxies from cave deposits in the Yucatán and in Belize indicates that multiple, decadal-scale severe droughts occurred during this interval. Similar, though not necessarily synchronous, droughts appear to have happened in central Mexico as well. These findings support a strong correlation between times of drought and a major cultural discontinuity in Classic Maya civilization. It is also important to remember that other factors such as overpopulation, deforestation, soil erosion, and disease could have contributed to the demise of the Mayans. Distinct peaks in these two proxies reflect times of aridity on the Yucatan Peninsula. The most arid time of the last 2,000 years occurred between 800 and 1000 AD, coincident with the collapse of the Classic Maya civilization. A newer high-resolution analysis of rainfall proxies from cave deposits in the Yucatán and in Belize indicates that multiple, decadal-scale severe droughts occurred during this interval. Similar, though not necessarily synchronous, droughts appear to have happened in central Mexico as well. These findings support a strong correlation between times of drought and a major cultural discontinuity in Classic Maya civilization [6, p. 285-286].

Some important datasets related to drought and the collapse of the Mayan civilization:

– David A. Hodell et al. (1995), sediment geochemistry data from Lake Chichancanab, Mexico;

– Jason H. Curtis et al. (1996), sediment data from Punta Laguna, Mexico;

– David A. Hodell et al. (2005), high-resolution sediment data from Lake Chichancanab, Mexico;

– Martin Medina-Elizalde et al. (2010), speleothem record from Tzabnah Cave, Mexico;

– D.W. Stahle et al. (2011), tree ring records of Mesoamerica;

– Douglas J. Kennett et al. (2012), speleothem record from Yok Balom Cave, Belize;

– Matthew S. Lachniet et al. (2012), speleothem record from Juxtlahuaca Cave, Mexico.

Failed harvests were critical for Maya people. The Maya probably exploited the land to the breaking point and were completely dependent on the harvest coming in, so if it failed for several years, or even decades, in a row, it would have been critical. Summer was the most important time for cultivation and filling the Maya water reservoirs. It is likely that unrest arose and that the cities were abandoned because there were many multi-year periods of drought in quick succession. But even if the drought played a role, he is not convinced that it is the only reason for the extinction of the Maya people [5, p. 111].

Many scientists today agree that it was not a monocausal thing, because if a society and a culture are really stressed, and then three years of significant drought come, then of course it helps to increase the crisis. However, droughts may have been decisive after all those other factors such as disease, overpopulation and social and political unrest probably led to the actual collapse [5, p. 230].

However, the researches point out that disease and uprising may have been triggered by the pressure from lack of water and food over 150-200 years of climate change for the worse.

Classic Maya collapse

The Classic Maya civilization, which flourished between 250 and 900, represents one of the most extraordinary cultural achievements of the ancient world. Renowned for its soaring temple-pyramids, intricate hieroglyphic writing, advanced calendar systems, and vibrant urban centres such as Tikal, Copán, and Palenque, the Classic Maya dominated much of present-day Guatemala, southern Mexico, Belize, Honduras, and El Salvador [13].

Yet around the 8th to 9th centuries, this flourishing society experienced a dramatic transformation, often referred to as the classic Maya collapse. Within a century or two, many great city-states were abandoned, monumental construction ceased, long-distance trade dwindled, and inscriptions recording royal power largely disappeared. Though Maya peoples and culture endured, the collapse marked the end of an era of political and cultural brilliance [4, p. 27].

Modern scholarship has moved beyond the notion of a single, sudden downfall. Instead, the collapse is now understood as a complex and regionally varied process shaped by multiple, interrelated factors. These include environmental stresses, overpopulation, warfare, shifting trade routes, political fragmentation, and prolonged drought [4, p. 28].

The classic Maya collapse is not a story of disappearance, but of resilience and adaptation. Maya descendants still live throughout Mesoamerica today, preserving elements of language, cosmology, and tradition. Their endurance highlights the difference between the collapse of a political order and the survival of a people.

The classic Maya collapse refers to the period between approximately 750 and 950 when many southern lowland Maya cities were abandoned or drastically depopulated. The phenomenon is marked archaeologically by the halt of monumental construction, the decline of carved inscriptions, evidence of warfare and fortification, and a reduction in elite goods. In contrast, some northern and western Maya centres, such as Chichén Itzá, continued to flourish, showing that the collapse was not uniform across the Maya world. (3, pp. 23-24)

The Classic Maya collapse remains one of archaeology’s most debated subjects, with scholars emphasizing different causal factors:

Environmental stress and drought. Paleoclimate studies reveal evidence of severe droughts in the 9th century combined with deforestation and intensive agriculture, this likely strained food production and water management systems.

Demographic pressure. Some regions may have reached carrying capacity, leading to resource depletion and internal tensions.

Political instability and warfare. Epigraphic evidence points to an escalation of warfare among rival city-states, undermining political alliances and disrupting trade networks.

Economic shifts. The collapse coincided with changes in trade routes and the decline of certain economic systems, weakening the political power of southern centres.

Most scholars now view the collapse as a synergistic process: environmental stress exacerbated existing political rivalries, which in turn destabilized economic systems, creating a cascading effect. Importantly, the collapse was neither total nor universal Maya culture continued, adapted, and flourished in new forms, especially in northern centres and later in the Post-classic period.

Caves in Tecoh area

1. What the stalagmites show

A stalagmite sampled from Grutas Tzabnah (near Tecoh, Yucatán) records seasonal to annual variability in rainfall between 871 and 1021 (the terminal Classic). The geochemical record shows a series of multi-year wet-season droughts – eight drought events of ≥3 years each in that window, with the longest lasting ~13 consecutive wet seasons. Analysed with laser beams [11; 12].

2. The evidence and methods (why researchers trust this record)

High-resolution sampling across growth layers: the stalagmite was cut and sampled at sub-annual (seasonal) resolution so changes from one wet season to the next can be resolved. Layers correspond to seasonal growth cycles.

– Oxygen isotopes (delta-O-18): the primary paleohydrology proxy used. Lower (more negative) delta-O-18 values in this Yucatán context are interpreted as wetter wet seasons (more rainfall/stronger isotopic depletion in precipitation); higher (less negative) delta-O-18 values correspond to reduced wet-season rainfall (drought). The record therefore allows reconstruction of wet-season intensity and its interruptions.

– Absolute chronology: U-Th (uranium-thorium) dating provides precise ages for the stalagmite growth bands, making it possible to date drought events to specific years/intervals within the Terminal Classic [12].

– Modern cave monitoring/calibration: researchers used drip-monitoring and cave climate observations to better link stalagmite delta-O-18/growth to rainfall seasonality and to verify that the cave's speleothem chemistry is sensitive to external wet-season changes (not dominated by only local cave processes) [12].

3. Main scientific conclusions

There were multiple prolonged interruptions of the wet season between AD ~8710-1021, including one exceptionally long ~13-year dry period. These droughts coincide in time with the terminal Classic political and demographic disruptions (abandonment and decline of many southern lowland cities). The new stalagmite therefore provides direct, seasonally resolved evidence that severe, repeated wet-season failures occurred at the same time as major social change.

4. Strengths of the record

– Seasonal resolution: unlike many lake or marine records that average many years, this stalagmite reaches seasonal/wet-season resolution so the duration of dry spells can be estimated precisely.

– Robust dating: multiple high-precision U-Th dates anchor the chronology, reducing age uncertainty across the terminal Classic window.

– Local relevance: the cave lies within the adaptive region of many southern lowland Maya polities (Uxmal, Puuc sites), so the record is directly relevant to water availability where some of the political changes occurred.

5. Limitations and caveats (what to be careful about)

– Local vs. regional signal: stalagmites record the local isotopic composition of drip water, which is strongly influenced by precipitation that recharges that cave's karst system. While the Tecoh stalagmite lines up with other regional proxies, one must be cautious extrapolating a single-cave record to the entire Maya area spatial variability in rainfall means impacts could vary between sites.

– Multiple influences on delta-O-18: stalagmite delta-O-18is primarily a precipitation signal here, but it can also be affected by changes in moisture source, seasonality, temperature, kinetic fractionation in the cave, or prior calcite precipitation. The authors addressed many of these by cave monitoring and multi-proxy checks, but residual ambiguity remains.

Dating uncertainties still exist at fine scale: U-Th gives very good ages, but small offsets can remain; when comparing to archaeological events (monument dates, abandonment windows) one should use ranges, not single years.

Agricultural resilience and adaptation: archaeological resilience (reservoirs, trade, differing water strategies) means a drought recorded in the cave is a necessary but not always sufficient cause of collapse social, political, and economic factors mediate outcomes. Correlation is strong; causation is plausible but multi-factorial.

6. How this record compares with other proxies from the region

– Earlier stalagmite and lake records (e.g., the Chaac stalagmite and Lake Chichancanab records) also show pronounced dry intervals across the late Classic / terminal Classic, though with lower resolution. The Tecoh stalagmite corroborates those drought timings and crucially gives the durations and seasonality at much finer temporal scale. That strengthens the case that multi-year wet-season failures were real and sustained.

7. Implications for Maya history and archaeology

– The new, high-resolution stalagmite evidence makes it much harder to dismiss drought as a major stressor during the Terminal Classic. Multi-year wet-season failures especially a 13-year event would have severely tested rain-fed agriculture and cistern/reservoir systems, amplifying social stress and contributing to political fragmentation in the south. That said different polities responded differently: some moved, some reorganized, and some (e.g., Chichén Itzá) show signs of adaptation, implying that social choices and connectivity also mattered.

Bottom line. The stalagmite(s) from Grutas Tzabnah (Tecoh) provide seasonally resolved, uranium-dated evidence for multiple multi-year wet-season droughts during AD ~871–1021 – including a ~13-year drought. Those data

significantly strengthen the argument that severe, prolonged droughts were an important environmental stressor during the Terminal Classic and likely contributed to the political and demographic changes that characterize the Classic Maya collapse in parts of the region — while also underscoring that drought alone did not determine outcomes (local adaptation and social factors mattered).

Post-Classic period

The post-Classic period is characterized by a pervasive influence from northern Mesoamerica, affecting all aspects of life. However, key elements of the Classic period culture remained. Although the divine kingship that defined the Classic period ended, the nobility continued to rule and shape the destiny of the Maya. Writing and the calendar remained in continuous use, even though the Long Count system was no longer used. Most of the revered gods were also already known from the Classic period. Two independent centres of Maya culture emerged in Yucatán and the highlands, with limited cultural exchange between them, yet they followed a very similar development. Accordingly, the end of the post-Classic period is also difficult to pinpoint precisely. While the highlands were conquered in the 1520s, the Spanish only established their control over Yucatán in the 1540s. In Petén, the post-Classic Maya culture ended abruptly only in 1697 [8, p. 225].

After the collapse of the Classic Maya civilization in the lowlands the centres in northern Yucatán continued to flourish for some time. Uxmal, for example, reached its cultural peak in the 9th and 10th centuries, long after Copán and Palenque had been abandoned. Uxmal itself seems to have been abandoned in the 12th century. From the 13th century onwards, increasing Toltec influences can be observed in Yucatán in architecture, pottery, culture, and religion. According to the Chilam Balam, Chichén Itzá, which had previously been the dominant power in Yucatán, was abandoned again in 1221, and the Cocom dynasty rose to power, establishing their capital at Ichpaa and dominating large parts of Yucatán. (See also the so-called League of Mayapán). This rule was finally broken in 1441 by a rebellion led by the Xiu, who were associated with Uxmal, which was indeed located within their territory. The conflict between the Xiu and Cocom families, the leading lineages of

Yucatán, persisted, and the Spanish exploited this situation. During the same period, classical centres such as Cobá, Ek Balam and Izamal were re-populated. In Xuch, in the Puuc region, about 15 km southwest of Uxmal, monumental architecture was continuously built from the Classic period until the 16th century.

Dzibilchaltún and Lamanai were also continuously inhabited from the Classic period to the early colonial period. After the fall of Chichén Itzá, or at the latest after Mayapán, approximately 16 independent principalities emerged in Yucatán, which remained in existence until the conquest. The urban and cultural centres of the post-Classic period, with populations of several thousand, were primarily the residences or capitals of these principalities. In Yucatán, these included Kaan Peec, Champoton (Chanputun), Maní, Motul, Sotuta, Tihosuco, Tecoh, and Ch'aak Temal. Within the Ecab principality on the west coast, numerous sites such as El Rey, El Meco, Polé, Xel Há, Zama, and Muyil possessed stone architecture, some of monumental scale. San Gervasio on Cozumel and Tiho were also regional religious centres for the deities Ix Chel and Itzamná. Uxmal, and even more so Chichén Itzá, continued to be visited for religious ceremonies. During the upheavals of the Postclassic period, the Ko'woj Maya and the Itzá left Yucatán and migrated to Petén, founding new centres at Topoxté and Tayasal, the latter of which would endure longer than any other centre in the entire Maya world [8, p. 277].

The development of post-Classic Maya culture in Chiapas, the highlands of what is now Guatemala and El Salvador followed a similar pattern. For example, the sites of Casa Blanca, Tazumal and San Andrés were only abandoned around 1200, although Casa Blanca continued to be used as a religious site. Cultural influences from northern Mesoamerica were also evident here. For instance, double temples were built, modelled after the Templo Mayor. Around 1250, the Mam people chose Zaculeu as their capital. In the highlands, the K'iche' began their rise to power with their capital at Q'umarkaj, steadily expanding their territory through military conquest until they were halted by their neighbours and former allies, the Cakchiquel at the end of the 15th century. The Cakchiquel abducted the idol of Tohil to their capital, Iximché, whereupon the K'iche' ceased their military campaigns against the

Cakchiquel but continued to attempt to dominate the highlands. After the Mexica conquered Xoconochco in 1486, the K'iche' were also required to pay tribute in 1510. The animosity between the K'iche' and the Cakchiquel persisted until the Spanish conquest of Yucatán, and this conflict contributed to the decline of Mayan culture in the 1520s.

Conclusion

The integration of paleoclimatology, archaeology and epigraphy has transformed our understanding of the Maya collapse. Oxygen isotope analysis, sediment chemistry and other climate proxies provide the environmental framework, while archaeological surveys reveal evidence of abandoned cities, disrupted trade routes and declining construction. Together these findings underscore the profound impact that environmental instability can have on even the most sophisticated. The decline of the Classic Maya civilization remains one of the most enduring mysteries of world history. For centuries scholars debated why the once-flourishing cities of the Maya Lowlands renowned for their monumental architecture, advanced astronomy, and complex writing system fell into decline between the 8th and 10th centuries AD. Increasingly, scientific evidence suggests that climate change, particularly a series of severe droughts, played a central role in the collapse.

One of the strongest themes emerging from recent scholarship is the correlation between prolonged drought and the societal disintegration of the Maya during the so-called Classic Maya collapse (c. 750-950). While warfare, political upheaval, and overpopulation were important contributing factors, paleoclimatological studies point to extreme and recurring dry periods as the environmental stressors that undermined Maya resilience.

Sediment cores extracted from lakes and marine basins have been critical in reconstructing past climate conditions. Researchers studying Lake Chichancanab in the Yucatan Peninsula have found significant shifts in oxygen isotopes and sulphur content indicators of reduced rainfall and heightened evaporation. These findings reveal that the region endured extended drought episodes during the 9th century, the

very period when major Maya cities such as Tikal and Copán experienced political fragmentation and population decline.

Complementary evidence comes from marine sediment cores in the Cariaco Basin off the coast of Venezuela. These provide finely dated records showing four major drought episodes between roughly 760 and 910. The synchronicity of these dry periods with the unravelling of Maya political and social structures suggests more than coincidence it points to climate as a decisive factor.

The extinction of the Classic Maya civilization was not the result of a single cause but rather the convergence of multiple stresses – political, social and environmental. Among these, climate change, manifested in a sequence of severe droughts appears to have been a tipping point. Modern research continues to deepen our understanding of how ancient climate events shaped human history. The Maya case offers a sobering reminder of the vulnerabilities that complex societies face when environmental systems falter.

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