OPEN ACCESS
BY-NC-ND
ISSN: 2997-0350
TAR TransAmerica Review
an interdisciplinary journal of politics, society and economics
Received: 2024-09-11
Accepted: 2024-10-24
Published: 2024-10-30
VOLUME 2 | ISSUE 2 | Jul – Dec 2024 | DOI: https://doi.org/10.62910/transame24006

Tulum's underwater caves: insights into the oldest human fossils in the Americas

Octavio A. Del Río Lara [a]

[a] Nautical Archaeology Society, México. Correspondence: nas_mexico@aol.com

ABSTRACT

Evidence of late Pleistocene human and fauna remains has been documented within the extensive cave systems of the Tulum region in northeast Yucatán, Mexico. This unique area is vital for paleontological and paleoanthropological research, providing insights into early human adaptation in the Americas. To date, 10 human fossils have been thoroughly studied, with two additional recent discoveries under investigation. These remains, dating from 13,700 to 8,000 BP, emphasize the paleoanthropological significance of Tulum's submerged caves. A key discovery is the skeleton of Eva de Naharon, dated to 13,721 years cal BP, making her the oldest known human fossil in the Americas. Using 3D facial reconstructions and DNA analysis, researchers have identified craniofacial similarities with South Asian populations, suggesting shared ancestry and migration patterns. These findings enrich our understanding of human migration and adaptation. Ongoing research continues to highlight the role of Tulum's underwater caves in shaping early human history, survival strategies, and social structures over millennia.

Keywords: Eva de Naharon, 3D facial reconstruction, Paleoamericans, Yucatán Peninsula, Tulum cenotes, Migration patterns, Late Pleistocene.

Article originality and practical implications: The study offers evidence linking ancient human remains to migration patterns, highlighting Tulum's underwater caves as fundamental for understanding early human adaptation and ancestry, with implications for future paleoanthropological explorations in the Americas.

INTRODUCTION

Over the last thirty years, we have been consistently conducted archaeological research in the cenotes and caves of the Yucatán Peninsula, with a particular focus in the Tulum area of Quintana Roo due to the discovery of remains from some of America's earliest inhabitants, which constitute a significant collection of human fossils for North America (Bonnchsen, et al., 1999; Jiménez, et al., 2011). This region has emerged as a prominent site for paleontological and paleoanthropological research, offering valuable insights into the lives and adaptations of early human populations. The unique geological features, particularly the karst cave systems, have significantly influenced human activity and settlement patterns over millennia, highlighting the crucial role these natural formations played in the survival and cultural evolution of these early groups.

A notable discovery in the region is the skeleton of Eva de Naharon, which represents the first human fossil identified in the Yucatan Peninsula and, with a dating age of 13,721 years cal BP (Stinnesbeck, et al., 2017), Eva de Naharon is currently the oldest human fossil known in the Americas. The finding was made and reported in 2002 to the National Institute of Anthropology and History (INAH) by Octavio Del Río, in collaboration with Eugenio Aceves, as part of an initial archaeological project titled 'Archaeological Catalog of Cenotes and Submerged Caves of Quintana Roo' (Del Río, O., SAS/C INAH Q. ROO, 1998-2002) (Del Río, 2018). This project aimed for the first time to systematically and scientifically document cultural and paleontological evidence found within the region's cenotes and submerged caves.

Initiated in 1998, this pioneer underwater archeological project received significant endorsement and academic support from Adriana Velazquez Morlet, director of C INAH Q. Roo from 1995 to 2018 and currently director of the C INAH Campeche, as well as from Pilar Luna Erreguerena (RIP), who was the founder and director of the Underwater Archaeology Subdirectorate (SAS/INAH) since 1985 to 2018, and Luis Alberto Martos López, the current director of the Archaeological Studies Direction (DEA/INAH). Due to the significance of its findings and research results, the project expanded in 2003 into a broader initiative encompassing the entire Yucatán Peninsula, titled Archaeological Atlas of Cenotes and Caves in the

Peninsula of Yucatán (González, A., Rojas, C., and Del Río, O. SAS/INAH, 2003).

More than two decades after the initiation of the archaeological project that led to the discovery of Eva de Naharon, advancements in digital forensic science have allowed researchers to reconstruct her facial features using 3D modeling techniques. This reconstruction is based on the skull bones recovered along with approximately 80% of her skeleton. Digital craniofacial reconstructions, combined with extensive prior analyses, including anatomical characteristics and chronological dating, have significantly deepened our understanding of early human physical traits, migration patterns, and the lives and fates of some of the earliest inhabitants of the Americas.

This research and its findings not only enhance our understanding of human history in the Americas but also underscore the Yucatán Peninsula's significance as a critical area for ongoing archaeological and paleontological exploration.

BACKGROUND

Tracing the Footsteps of the Earliest Americans

Human skeletons in the Americas older than 10,000 years are exceedingly rare, with fewer than 30 individuals identified in North America and only 12 directly dated. In contrast, South America has reported around 20 skeletons from the same period (Neves, 2013). Among these, only two specimens predate 13,000 years: the Arlington Springs skeleton, dated to 13,010 – 12,710 CalYrBP (10,960 +/- 80 ^{14}C CalYrBP) (Johnson, 2002), and Eva de Naharon in Tulum, México, dated to 13,721 CalYrBP (Stinnesbeck, 2017). In the rest of Mexico, there are few directly dated early humans older than 10,000 B.P.: Peñón III Woman, dated at 10,755 ± 75 ^{14}C CalYrBP (12,700 calibrated years); Tlapacoya Man, dated at 10,200 ± 65 ^{14}C CalYrBP (12,000 calibrated years); Texcal Man, dated to 7,480 ± 55 ^{14}C years B.P., and the San Vicente Chicoloapan skull, dated to 4,410 ± 50 ^{14}C CalYrBP (Ardelean, 2020).

Research in the Mayan area indicates that the first humans likely arrived around 13,000-10,000 years B.P. (Stinnesbeck, 2017; Chatters, 2014). Los Tapiales, a small hunter's camp in the Quiché basin of Guatemala, has been radiocarbon dated to 10,700 B.P. (Brown, 1980; Velázquez, et al., 1988). In coastal Belize, archaeologists, including Richard S. MacNeish and his team, identified sites that may date back to 9,000 B.C. (MacNeish, 1980). Additionally, flaked stone tools found in the cave of Loltún are believed to be associated with Pleistocene animal bones (Velázquez, 1980; Alvarez, 1983). Recent discoveries of human bonfires in the submerged cave of Aktun Ha were dated to 9,154 ± 74 ^{14}C years B.P., calibrated to 8,560 to 8,230 B.C. (López, 2020). Overall, this evidence suggests that humans penetrated the region thousands of years before the emergence of any Mayan cultural traditions (Martos, 2008).

From the Tulum region, there exist a Paleoamerican human catalog consisting of ten human fossils. This collection is particularly significant as it includes some of the oldest known human remains in the Americas. Among these, Eva de Naharon, the oldest known in the Americas, is dated to 13,721–13,354 CalYrBP (11,670 ± 60 RCYBP); Naia, dated to 12,910–11,750 CalYrBP (10,976 ± 20 RCYBP) (Chatters, 2014); Las Palmas, dated to 12,000–10,000 B.P. using U/Th techniques; El Pit I, dated to 11,396–11,150 CalYrBP; Chanhol II, dated to 10,500 CalYrBP; and Chanhol I, El Pit II, and El Templo, dated between 10,000 and 8,000 CalYrBP (González, et al., 2008; Hering, 2018). Radiometric dating places all these skeletons in the late Pleistocene to early Holocene at the end of the Last Glacial Maximum (Seltzer, et al., 2021).

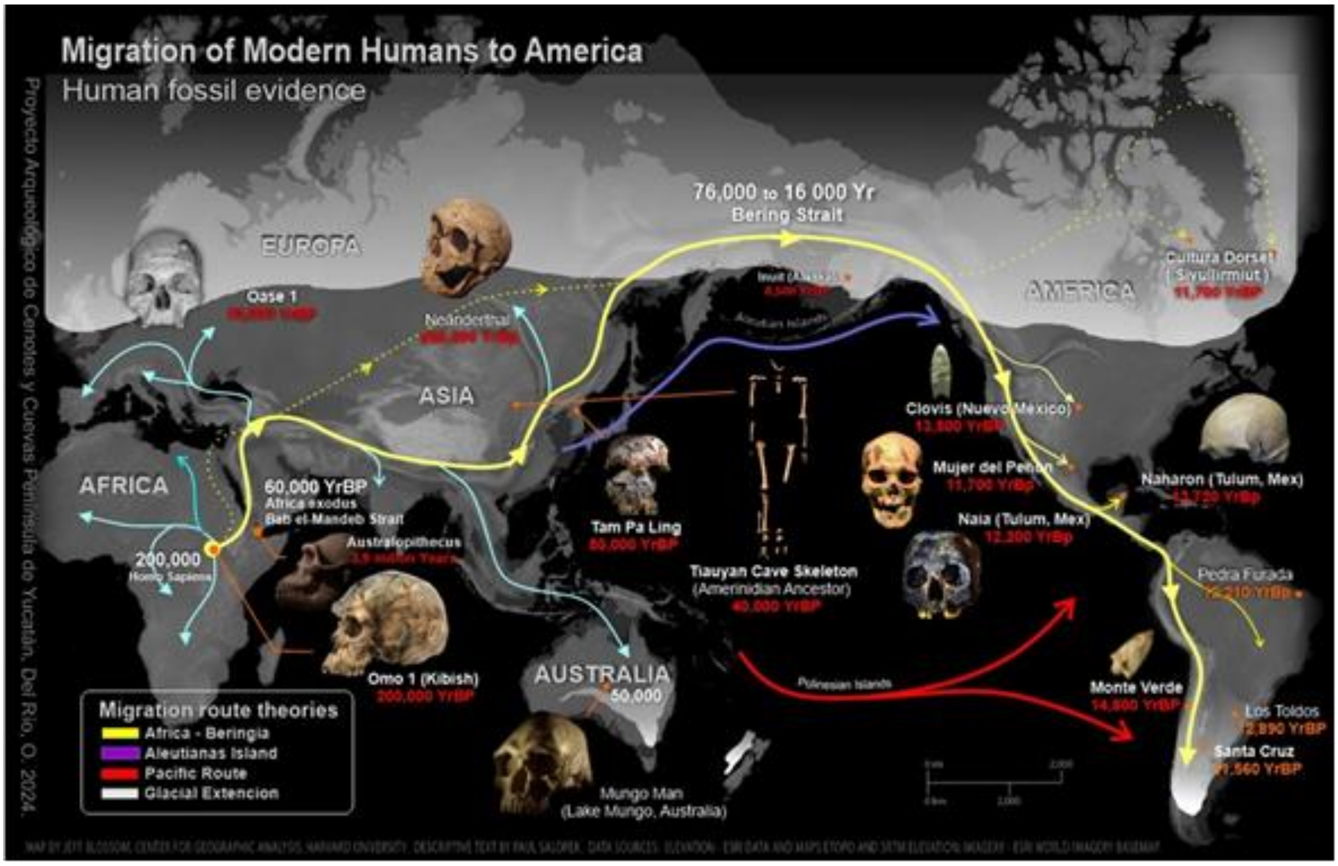
The human fossil evidence and anthropological findings from Tulum, including hearths and a diverse late Pleistocene faunal assemblage, have significantly enhanced our understanding of human migration and settlement patterns across the Americas. These discoveries underscore the importance of the Tulum caves for early human survival and cultural evolution.

Early Human migration to Tulum

An established thesis in anthropology postulate that the Paleoamerican populations emerged from multiple migrations through the Bering Strait and along the Pacific Ocean coast (Figure, 1). This theory is substantiated by archaeological findings that demonstrate the expansion and settlement of early inhabitants along the Pacific coastal pathways (Erlandson, 2007). Recent research proposes that early populations may have also migrated along the Pacific coast, utilizing maritime routes to reach various regions of the Americas Pacific coast and interior lands (Jones, et al., 2018).

A noteworthy aspect of these migration patterns is the deviation toward the Atlantic Ocean along the northeastern coast of the Yucatán Peninsula, particularly in the Tulum region. This geographic area spans approximately 65 km, extending from the town of Pamul to south of Tulum, and reaching up to 12 km inland to the Holbox geological fracture, which plays a crucial role in influencing groundwater flow and the ecological dynamics of the surrounding areas (Cejuo, et al., 2021). The region's unique geological and geographical features, which host some of the longest cave systems in the world, made it a focal point for early settlers who established long-term camps in these now-submerged caves (Bedows, 2022).

Figure 1. Migration route theories of modern humans to America.



Note. Elaborated by Del Río, O. based on original findings.

Evidence from these early populations found in the Tulum caves underscores the vital role these natural formations played in the survival and cultural development of these first American and Tulum settlers. The caves provided essential resources and shelter, while their relatively stable interior conditions significantly contributed to the inhabitants' resilience. This stability aided their adaptation to the extreme environmental changes that occurred during the transition from the Pleistocene to the Holocene periods, at the end of the Last Glacial Maximum (Zhuang, et al., 2012; Fairbanks, 1990).

Archaeological explorations in Tulum's caves have unveiled a remarkable human presence in the area that spanned approximately 5,000 years, from 13,700 to 8,000 years before present (BP) (González, 2002). This timeline coincides with significant climatic changes, including the end of the last Ice Age, which ultimately led to the flooding of these caves (Light and Stuckenbath, 1982; Blanchon and Shaw, 1995). The catalog of ten individuals discovered to date highlights not only their existence but also the rich tapestry of life that once thrived in this unique environment. DNA studies and the craniofacial characteristics of these human fossils reveal striking similarities to individuals from South Asia, suggesting a shared Asian ancestry that deepens our understanding of human evolution and migration patterns across the Americas.

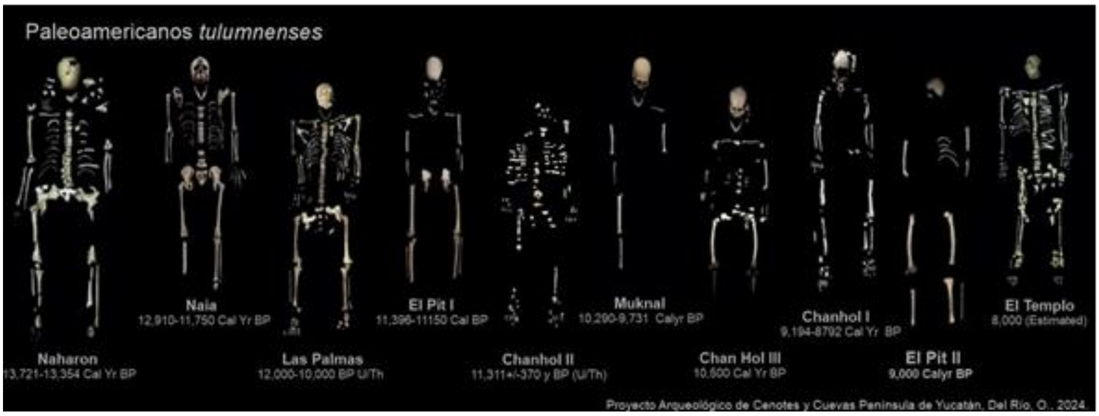
Paleoamericans in Tulum

The caves from Tulum offer refuge and sustainable environment during the geological transition from the Pleistocene to the Holocene, a period of significant environmental change. This shift included the extreme cold of the Younger Dryas, around 12,900 to 11,700 years BP (Peltier, et al., 2006), which marked the end of the Last Glacial Maximum. The subsequent warming of the planet led to the extinction of megafauna that were unable to adapt, while rising sea levels eventually submerged the caves to their current levels around 8,000 years ago (Blanchon and Shaw, 1995), prompting human migration to higher lands.

These now-submerged caves, among the longest in the world, offered a stable environment essential for the adaptation and survival of these groups during the extreme climatic changes at the end of the Ice Age (Toscano and Macintyre, 1978; Fairbanks, 1998), provided refuge and protection from large predators, along with access to vital water, especially crucial due to the area's scarcity of rivers. Additionally, these caves served as shelters in life and sites for mortuary deposits in death.

The region's unique geological features profoundly influenced human activity and settlement patterns over millennia, highlighting the essential role these natural formations played in the survival and cultural practices of early populations.

Figure 2. Homogenized radiometric ages of human remains discovered in submerged caves of Quintana Roo, México.



Note. *Naia skeleton date directly from >12 ka from which a DNA has been extracted (Chatters, 2014).

Eva de Naharon, along with nine other human fossils documented in the area (Figure 2), provides crucial insights into the origins of the first settlers in the Americas. Studies in physical anthropology conducted on Naharon (13,721–13,354 CalYrBP) and Las Palmas (12,000–10,000 B.P. U/Th), reveal that their craniofacial characteristics exhibit striking similarities to the physiognomy of native inhabitants from South Asia and Indonesia (Hubbe, et al., 2020). Notably, mitochondrial DNA (mtDNA) from Naia (12,910–11,750 CalYrBP), derived from a D1 haplogroup linked to Beringia**,** supports an Asian origin. This analysis indicates a lineage shared only with Native Americans, suggesting that the craniofacial differences observed between Paleoamericans (up to 8,000 years ago) and contemporary Native Americans likely resulted from in situ evolution rather than separate ancestral lines (Chatters, 2014).

METHODS

The geological characteristics of the karstic platform in the Yucatán Peninsula, along with fluctuating water levels during the late Pleistocene and early Holocene, provide valuable insights into the dynamic relationship between early human settlements and the natural landscape. The analysis of Eva de Naharon and other Paleoamericans remains found in the Tulum region enhances our understanding of the importance of these caves for early human, reveling how they were carefully selected as shelters and resource hubs but also as significant cultural sites. This contributes to a richer narrative about the lives, beliefs, and practices of the region's first inhabitants and expands our understanding of human history in the Americas.

Naharon: Insights into Early Human Settlement

Eva de Naharon was discovered in Cenote Naharon (Figure 3), with her name derived from both the cenote where she was found and the fact that she was the first human fossil uncovered in the region and the oldest in the Americas. Cenote Naharon, also known as Cenote Cristal for its stunning clear waters, is located 4 km south of downtown Tulum, adjacent to Highway 307. It lies about 6 km inland from the eastern coast of the Yucatán Peninsula, nestled between the prehispanic cities of Muyil and Tulum in Quintana Roo. The cenote is one of the over 150 natural entrances to the Ox Bel Ha cave system, which translates to "Three Water Ways" in Maya. This remarkable system stretches 338,976 m (1,112,125.98 ft) and has formed through the dissolution of limestone over millennia, making it the second longest cave system in the world after Sac Aktun, which is 376,101 m (1,233,927.16 ft) long (QRSS, 2017).

Figure 3. Cenote Naharon entrance to the cave system. Photo by Del Río, O.

Note . Photo by Del Río, O.

Naharon cenote description and route to the site

The Naharon cenote is open-pit and elongated, with a maximum distance between the longitudinal edges of about 45 meters, and about 30 meters in the widest part. It is surrounded by exuberant vegetation characteristic of the low subperennifolia jungle, with the body of water surrounded by the vegetation. The entrance to the water from the outside is almost at ground level. The open part of the cenote is no more than 4 meters deep and is covered by a green microalgae that provides refuge and food to hundreds of freshwater fish, as well as some macroscopic invertebrates and crustaceans that inhabit the cenote.

The water clarity in the Naharon Cenote also named Cenote Cristal is extraordinary, allowing visibility all the way to the bottom at a depth of 4 meters and providing a comprehensive view of the entire perimeter of the cenote, where a cavern serves as the access point to the extensive Ox Bel Ha cave system. The entrance to this cave system is characterized by a slope that descends from the cenote opening, transitioning from a depth of 4 meters at the bottom to the cavern zone at 12 meters deep, occurring just a few meters from the open section.

Following a northeasterly direction into the interior of the cave, the space narrows into a tunnel with particularly dark walls. This peculiar darkness is present in some sections of the cave systems and is caused by chemical reactions involving manganese oxidation and iron, facilitated by microbial activity and the unique hydrological conditions of the region's eogenetic karst systems (Cruz and Mendez, 2018). The cave is richly decorated with speleothems (stalactites and stalagmites) that are superimposed throughout the journey into the cave. The organic sediment at the bottom of the cavern, produced by the washing of natural debris by the rain towards the interior of the cenote, diminishes the more it penetrates into the cave, and gives way to an abrupt rocky bottom generated by multiple fractures and landslides, a result of Karst erosion, which also generates a very fine limestone sediment that remains on the bottom of the cave.

The route inside the cave to where Eva de Naharon remains were located is through a relatively wide tunnel formed by several geomorphology chambers, different in size and the numbers of speleothems. The first 170 meters of the 367.48 meters distance that has to be traversed to where fossil remains were found, are at a relatively uniform depth of around 12 m, which travels among formations and collapses that sometimes restrict passage in smaller spaces. Throughout this initial journey, there are several branches to other arms that make up the cave system, one of which must be taken to enter the southwest towards a passage that leads to where the remains were located. This second passage descends at a greater slope, from 12 to 18 meters in very little distance and from there it continues descending gradually until reaching 22.4 meters depth at 367.48 meters distance from the cenote, where Naharon's skeleton was found. This second tunnel is considerably narrower, fluctuates between 2 and 3 meters in width from wall to wall, and 1 meter to 2.5 meters height, and the speleothems and collapses during the route additionally confine the space even more (Del Río, 2018).

Skeleton location and description

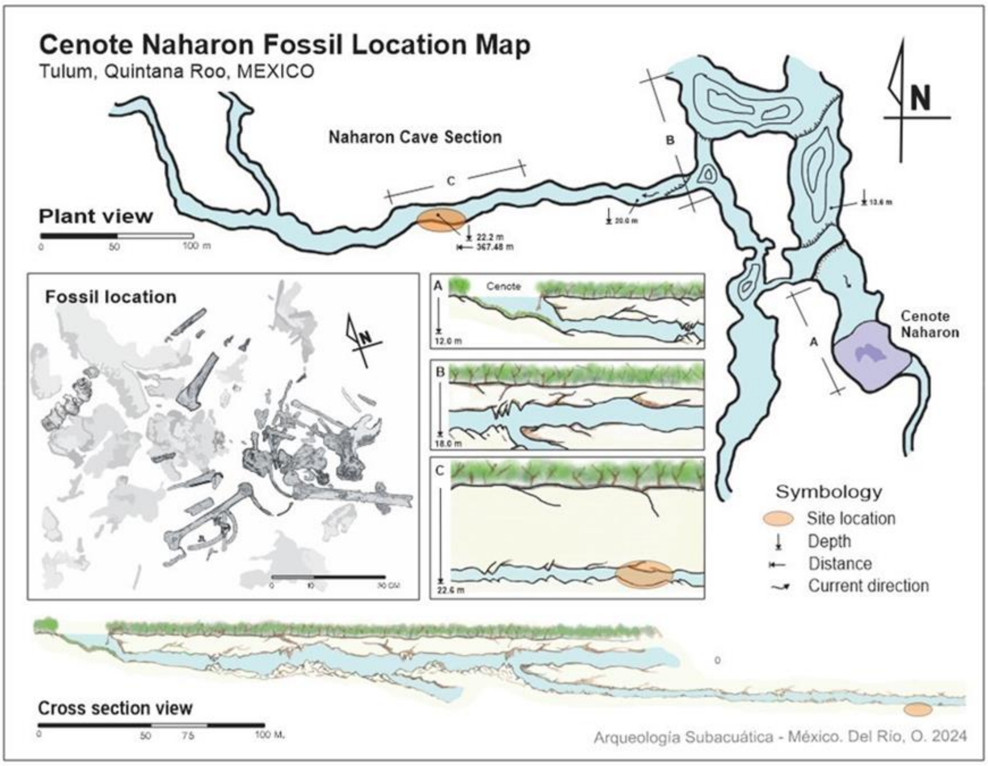
The skeleton was located 367.48 meters (1,223.7 feet) from the entrance of the cave and at a depth of 22.6 meters (74 feet) (Figure 4). It was situated in a narrow space within one of the branches of the cave. Due to its location and its positioning, it is assumed that Eva de Naharon was placed there by her loved ones after death, to protect her remains from potential intruders that could disturb her eternal rest and peace. Approximately >80% of the remains were collected during the years 2002 and 2003 (González, et al., 2004, 2008; Del Río, 2018).

Over millennia, erosion and sediment deposition occurred at varying rates, with faster processes when the cave remained dry, accelerating taphonomic processes and skeleton degradation. When water levels flooded the caves, conditions stabilized, but the rising water contributed to additional deposition processes that gradually dispersed the remains over an area of 3 by 2 meters along one side of the cave. Only a few articulated vertebrae, tarsals, and phalanges remained in their anatomically correct positions (Gonzalez, et al., 2004, 2008). Additionally, the site appears to have been disturbed by cave divers, who may have altered the archaeological context. The skull and facial bones were discovered in a small niche in the cave wall a couple of meters from the main deposition site. This placement may have been an attempt to hide the skull remains for protection, although it inadvertently compromised the integrity of the archaeological context. Such disturbances can significantly impact the interpretation of the site (González, 2004).

Understanding the conditions surrounding the presence of these remains raises important questions: Was this a burial site, as a result of a funerial ceremony where the body was deposited, or did she die there? Both possibilities exist. It is conceivable that she became lost and ran out of fuel for her torch while searching for water, which at that time was approximately 30 meters below the current level (Fairbanks, 1990).

This scenario highlights the challenges faced by individuals in ancient environments and the potential for tragic outcomes in such perilous conditions.

Figure 4. Map of Naharon's fossil location inside the cave



Note. Developed by Del Río, O.

Fossil dating

The skeleton was dated in the Radiocarbon Laboratory of the University of California, Riverside (UCR) and Beta Analytic laboratory, Florida (Beta) by acceleration mass spectrometry (AMS), and direct methods through ^{14}C isotope analysis, resulting in an age of 13,721–13,354 years cal BP (11,670±60 ^{14}C years BP) (Stinnesbeck, 2017).

Physical anthropology analysis

Physical anthropology analyses (Figure 5) were carried out by Martha Benavente and Alejandro Terrazas at the Institute of Physical Anthropology of the National Autonomous University of Mexico (2006).

The remains from Naharon are estimated to belong to a young adult female who was between 25 and 28 years old at the time of her death. These remains currently represent the oldest skeletal findings in the Tulum caves and in the Americas.

The bone remains were demineralized, having also lost most of the organic material; the bones are light, brittle, and highly fragmented. The cranial vault is preserved. The frontal bone is almost complete and intact. The right parietal bone broke into three parts, and the left parietal into four; the occipital bone only retains the posterior region; the right temporal bone is almost complete and articulates with the parietal, while the left temporal bone cannot be articulated to the skull; only fragments of the sphenoid are preserved.

A fragment of the maxillae left upper arch was recovered, containing two premolars and the first molar. From the mandible, a fragment from the right side was recovered, preserving part of the fractured body along with the neck, coronoid and condylar processes intact, as well as two molars. Despite the fractures, it was possible to assemble the neurocranium, noting that there is virtually no post-mortem plastic deformation.

Based on the physical anthropology analysis (Terrazas and Benavente, 2006), it was determined that:

- **Body metrics**: Based on the analysis of the left radius and right humerus, it has been determined that the individual stood approximately 140 cm tall and weighed around 53 kg.
- **Age**: To estimate Naharon's age, it was considered the auricular surface, a fragment of the pubic symphysis, and the long bones that had completed the epiphyseal fusion process the partial obliteration of the sutures of the skull of the long bones, along with fully erupted adult dentition, and in accordance with the morphology of the auricular surface of the left innominatum, it is concluded that the individual was an adult between 25-30 years at the time of death.

- **Sex**: The sex was determined based on the shape of the sciatic notch, with an angle greater than 90°. In the skull, the mastoid process is small and rounded, while the digastric groove is well-defined; the supraorbital ridges are small, and the upper edges of the orbits are slightly rounded. For all these reasons, it is assumed that the individual was female.
- **Pathology**: The individual demonstrated complete fusion of the second and third cervical vertebrae, which may have been a congenital condition identified as Klippel Feil type II syndrome. The third lumbar vertebra shows an osteophytes rim, a product of work stress. In the skull, the region of lambda shows porotic hyperostosis and the roof of the orbits have a little-marked cribra orbitalia. The frontal bone has evidence of fracture and an associated infectious process, completely healed at the time of death.

3D model generation

The use of 3D reconstruction techniques has significantly advanced the ability of researchers to visualize and analyze the anatomical features of ancient remains, enhancing our understanding of individual physical characteristics and potential appearances. For the reconstruction of Naharon's skull, the process involved meticulous work based on the recovered skull and jaw bones, along with the rest of the >80% of the skeleton unearthed during the 2002 and 2003 excavations. This comprehensive approach not only aids in visualizing Naharon's appearance but also contributes to a deeper understanding of the physical traits of early inhabitants in the region.

Skull reconstruction

To create an accurate 3D model replica of Naharon's skull, it was essential to restructure the surviving articulated bone parts and other fragments, including a highly fragmented and fragile cranial vault. The frontal bone was almost complete and intact. The right parietal was broken into three parts that could be reunited, but the left parietal broke into at least four pieces that could not be reunited.

The occipital retained only the posterior region and the entire base of the skull was missing. The right temporal that articulates with the parietal was also almost complete, the left temporal was present, although it was not possible to physically articulate it to the skull, and only fragments of the sphenoid were preserved (Terrazas and Benavente, 2006).

The reconstruction utilized parts of both jaws, which included some teeth. Specifically, the upper jaw's left quadrant retained two premolars and the first molar in place, while a broken portion of the left jaw included the condyle and neck, along with the first and second molars still in place and intact.

Forensic facial digital techniques

Once the original pieces of Naharon's skull were joined by the anthropologist, a 1: 1 scale printed replica was produced. This printed model of the skull was used for processing photogrammetry images, which, with the aid of sophisticated software tools, were utilized to generate a virtual 3D model of the skull. To address the missing areas of the skull, the reconstruction process involved cloning the mirror counterparts from the existing bone structure to fill in the gaps. In cases where no suitable counterpart was available, a donor skull with a compatible structure was employed to ensure accuracy in the reconstruction (Kälin, 2018; Hines, et al., 2010). This innovative methodology not only aids in creating a lifelike representation of Naharon but also enhances our understanding of the physical characteristics of early inhabitants in the region.

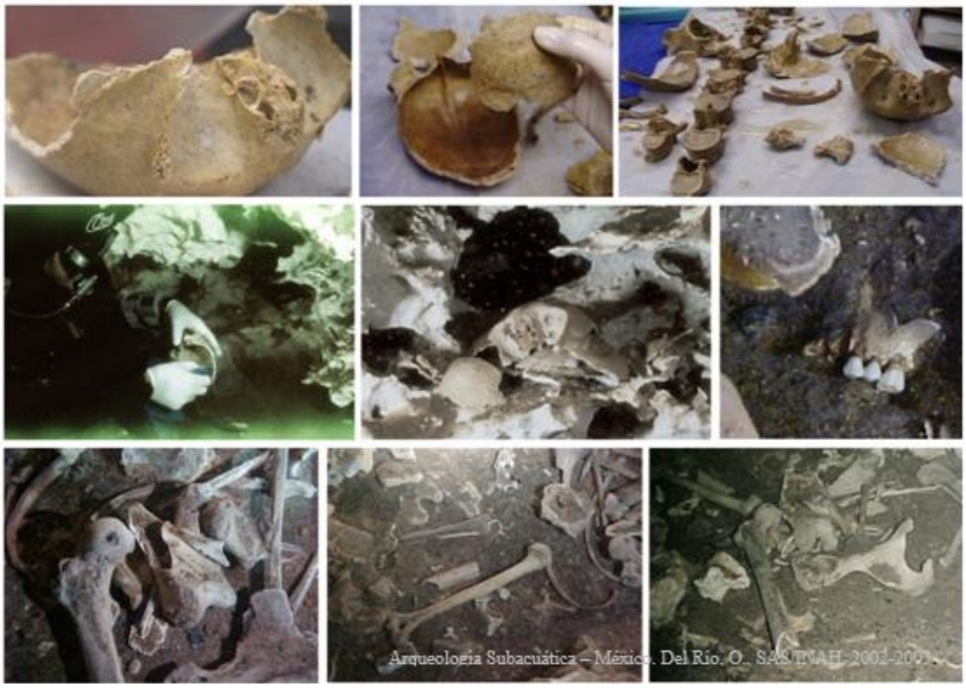
3D modeling and face reconstruction

The application of advanced techniques of digitalization and methodologies based on forensic facial reconstruction managed to obtain a reliable reproduction of the face using a replica of the original skull through photogrammetry (Hines, et al., 2010). As part of our research, facial approximations of Naharon and Las Palmas have been reproduced using digital techniques, which have proven to be a more accurate and efficient method compared to traditional techniques.

The craniofacial reconstruction of Eva de Naharon (Figure 6) and Las Palmas Woman (Figure 7) was conducted by Cisero Moraes, a specialist in digital forensic reconstruction. These advancements in digital reconstruction provide a clearer understanding of the physical characteristics of these early individuals.

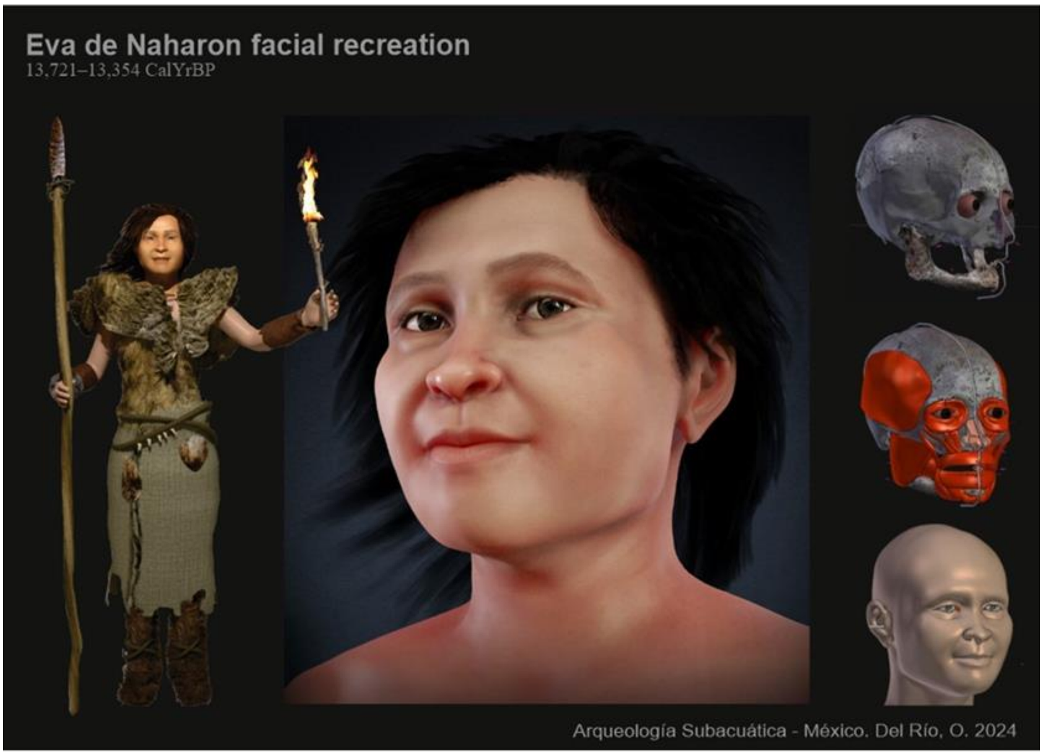
This process involves the use of craniometric landmarks to estimate the thickness of soft tissue at 21 different anatomical points, which is crucial for accurately recreating facial features. The thicknesses of the soft tissue and the lengths of the markers used in the reconstruction are determined based on factors such as ethnicity, sex, height, and available anatomical and demographic information. This data supports the forensic approaches required for each case study (Miranda, et al., 2018).

Figure 5. Naharon fossil location site and collecting



Note. Photos by Acevez, E. and Del Río, O.

Figure 6. Naharon facial recreation

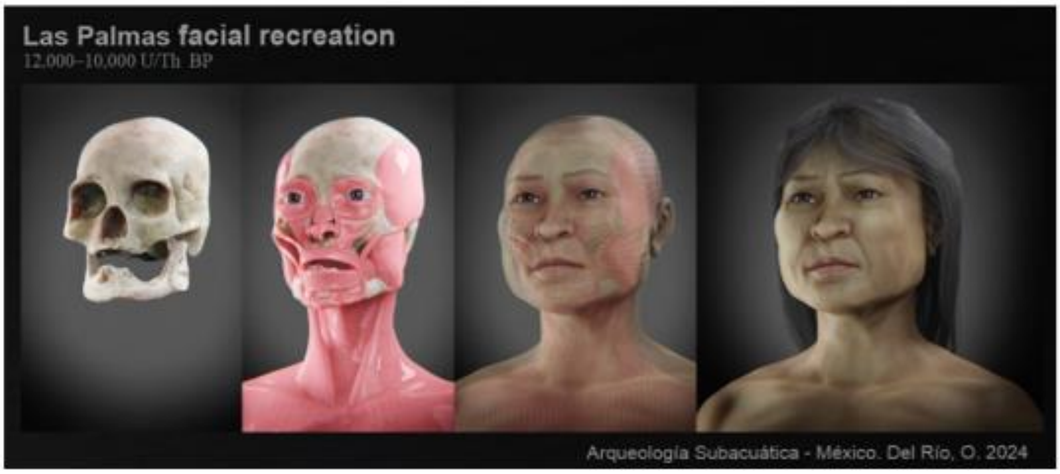


Note. Developed by Moraes C. and Del Río O.

Las Palmas Woman: A quick insight from a sacred burial site

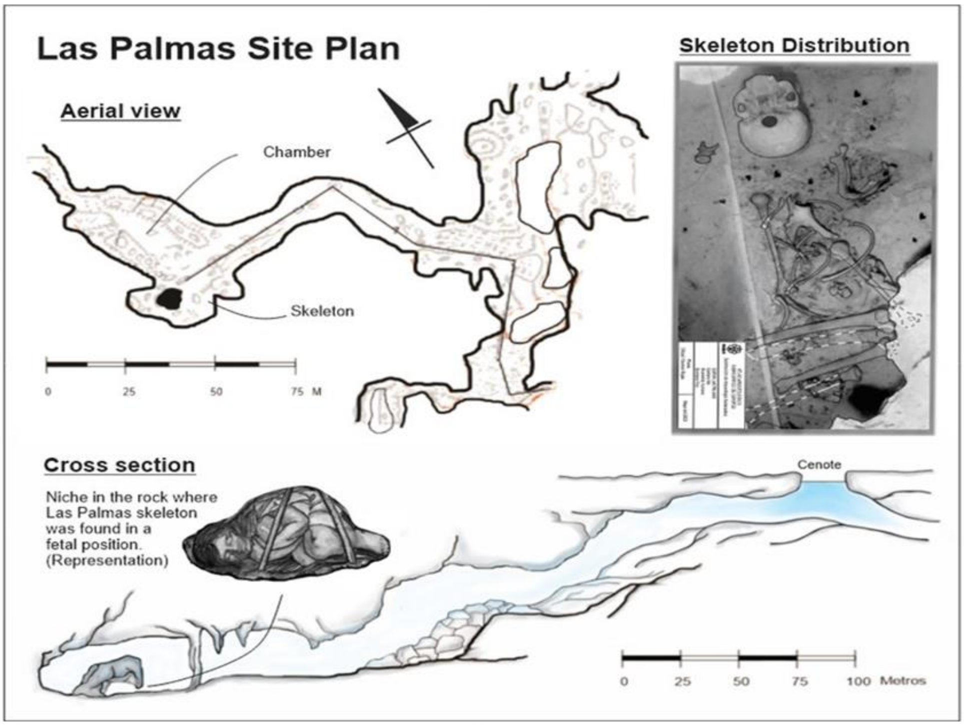
Las Palmas fossil remains belong to a woman dated to 12,000–10,000 BP using U/Th techniques (8050 ± 130 RCYBP) and are estimated to have been around 55 years old at the time of her death (Gonzalez, et al., 2008, 2014). Her anatomically articulated skeleton was found in fetal position, placed inside a niche on a rock at a depth of 22.6 meters, within a large a chamber far from the entrance. This suggests that the site was chosen as a funerary deposit, underscoring the cultural significance of these underground environments as sacred burial spaces for early human populations in the region. Over 90 percent of the Las Palmas skeleton was recovered, and it was found in excellent preservation conditions.

Figure 7. Las Palmas facial



Note. recreation by Moraes C

Figure 8. Las Palmas Site Plan



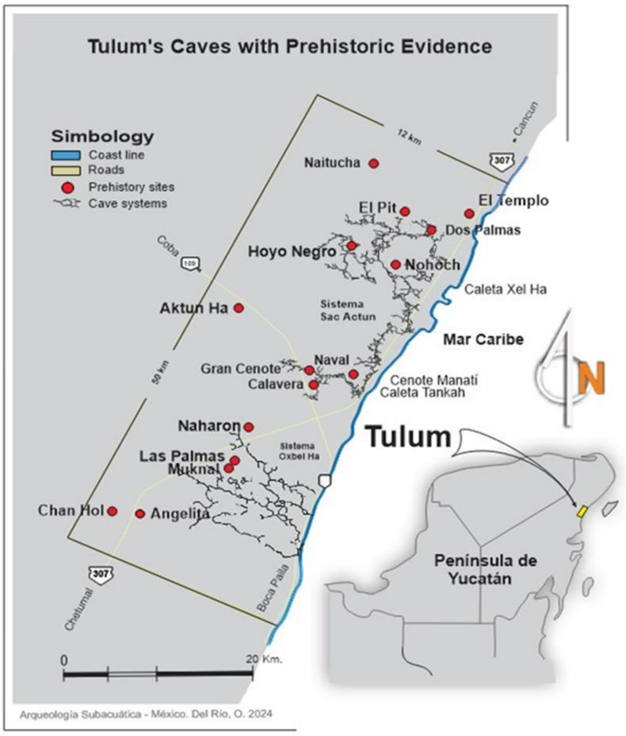
Note. Drawn by Octavio Del Río

RESULTS

Paleoenvironment and Geological Characteristics of the Tulum Region

The development of caves in the Tulum region is intricately linked to glacio-eustatic sea level changes, which have influenced the region's geological landscape. These changes create conditions that facilitate the formation of extensive cave systems through active water flows. The karst geology led salt and rainwater to filter through the soil. When saline water flows through the interior of the systems, it enhances mineral dissolution, facilitating the removal of carbonate and actively enlarging the submerged passages. This condition is aggravated when saline water comes into contact with fresh water, creating a physical division called halocline, which produces greater acidity and accelerates the dissolution of the strata. Another condition arises from the effects of fresh water produced by rain filtering through the rock, which eliminates and arrests uncemented sediments. These constant conditions eventually lead to a loss of support, resulting in rock collapse and the creation of fractures and natural entrances to cave systems known as cenotes.

Figure 9. Tulum prehistoric evidence located inside the cave systems in the region



Note. Elaborated by Del Río, O.

The Tulum region is characterized by a vast network of underground rivers that has resulted in interconnected channels that predominantly run parallel to one another and perpendicular to the coastline. [(53)]. This area is notable for housing the two most extensive flooded cave systems on the planet: Sac Actun, which extends 376 km, making it the longest in the world, and Ox Bel Ha, which extends 339.17 km (QRSS, 2017). Together, these systems contain around 380 cenotes, which are the entrances to some of the cave's systems where the remains were discovered (Figure 9).

In addition to the caves and cenotes, this region contains the highest concentration of coves, bays, inlets, and other geographical features, including linear depressions where underground rivers flow and discharge rainwater into the ocean. These include Caleta Tankah, Yalku, Xel-Há, Bahía Solimán, and Xcacel, all characteristic of the eastern coast of the Yucatán Peninsula. This particular geological predisposition of the area generated the ideal conditions for the creation of shallow and very long caves (Smart, et al., 2006; Coke, 2004). The rock collapses and fractures in the ground, along with the collapsed vegetation, formed natural bridges providing relatively easy access to the underground passageways, first through a zone of natural light into the cavern zone and then to the penumbra towards the interior of the cave.

Paleoambience

Besides human fossils found in Tulum, there is significant paleontological evidence of Ice Age megafauna in the region and the rest of the peninsula de Yucatán (Figure 9). Both humans and these large animals engaged in hunting and gathering, competing for resources. Among the notable megafauna were large predators such as the saber-toothed tiger (Smilodon fatalis), bears (Carnivora, Ursidae, Tremarctinae Arctodus simus), puma (Felis concolor), wildcat (Lynx rufus), coyote (Canislatrans) and herbivores such as the giant armadillo and other species of glyptodonts (Cingulata, Glyptodontidae, Glyptotherium, G. floridanum), American horse (Perissodactyla, Equidae, Equus conversidens), tapir (Tapirus bairdii), pecari (Tayassupecari), white-nosed coati (Nasuanarica), Proboscidea (Proboscidea, Comphotheriidae, Cuvieronius) and other large mammals such as giant sloths (Nothroteriops shastensis, Xibalbaonyx oviceps, Megatheriidae, Megalonychidae) (Alvarez, et al., 1983; González, et al., 2008,2014; Polaco, et al., 1982; McDonald, et al., 2017) (Figure 10).

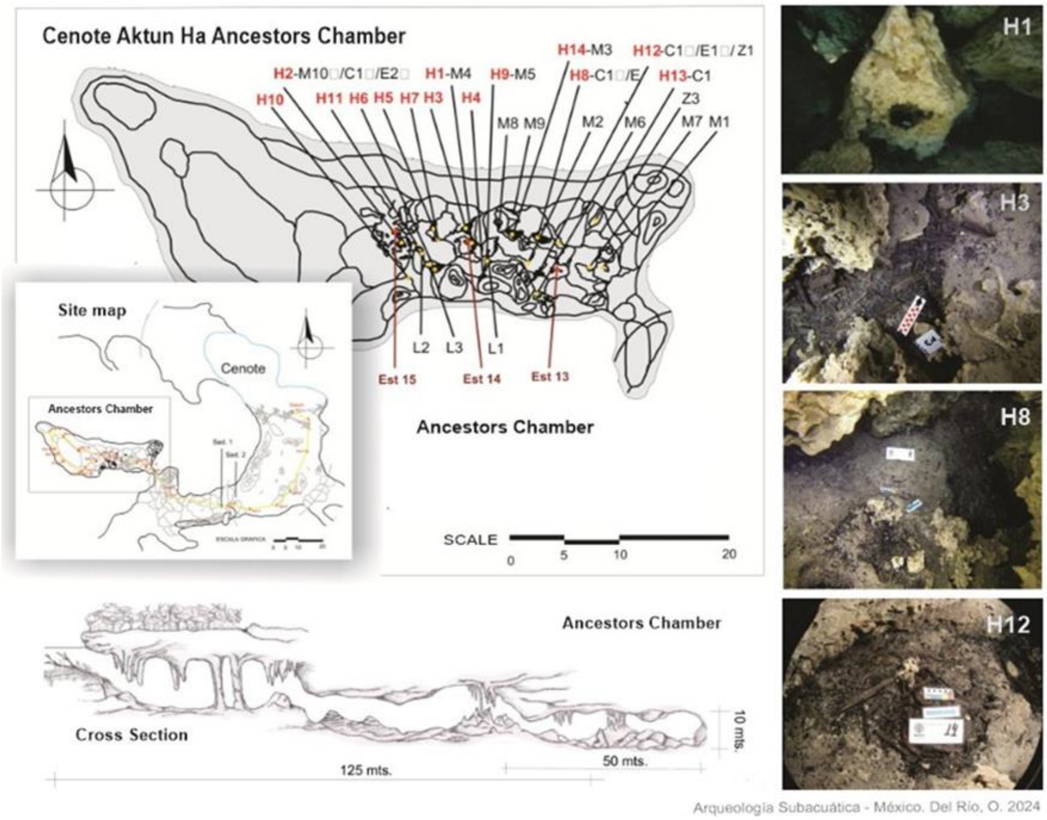
In related studies, and as part of our research, a direct association between animals and humans has been identified in certain caves within the region. In Taxma Ha cenote, the remains of a camelid (Hemiauchenia macrocephala) were found with cut marks and burns associated with an archaic bonfire where it was cooked and consumed (González, et al., 2008, 2014).

At the Ancestors Chamber, located 130 meters inside Cenote Aktun Ha at a depth of 30 meters, sediment and charcoal samples were collected from charcoal accumulations that suspected to be hearths, which were dated from 10,740 to 10,250 cal yr BP (Gonzalez, et al., 2008; Lopez, et al., 2020) (. The carbon stable isotope ($\delta^{13}C$) values, which accompanied the results from Beta Analytic, were -24.5 and -25.8‰. These values provided evidence of vegetal tissues of C3 species in the burned material (fuel), suggesting environmental conditions at the time. Samples may correspond to the genus of *Cedrela* (MELIACEAE), *Metopium* (ANACARDIACEAE) or *Casimiroa* (RUTACEAE) (Pérez et al., 1980, Miller & Détienne 2001, Moya 274 et al., 2013) predominant in steppe or savannah environments, among other types of edible vegetation such as the Avicennia germinans (Acanthaceae), Sideroxylon (Sapotaceae), Casearia javitensis (Salicaceae), Bauhinia divaricata (Leguminosae) (López, et al., 2020).

Figure 10. The Late Quaternary Mammal Fauna in Mexico

Note. Instituto Nacional de Antropología e Historia. *Bases de datos SNIB-CONABIO proyecto No. G012.* México D.F. Arroyo, J., Polaco, O.J., Johnson, E

Figure 11. A total of 14 charcoal accumulations were recorded (H1 to H14), with 4 selected for sampling (H8, H12, H13, 130 and H14).



Note. Developed by Del Rio, 2024.

Rock sample analysis taken from inside the Ancestor Chamber was conducted by Rafael López at the Institute of Geology of UNAM in search of the macro characteristics of fire modifications in the rocks, identifying changes in color, angular cracks and their association with charcoal accumulations. The use of multiproxy methodology provides strong evidence of the in situ anthropogenic production of the charcoal accumulations assigned to hearths being used inside the Ancestor Chamber, either for illumination and/or heating porpoises (López, et al., 2020).

The human occupation of Tulum at the end of the glacial age

The Tulum region is significant for its archaeological evidence of human's occupation during the transition from the late Pleistocene to the early Holocene. These humans occupied the caves of Tulum for approximately 5,000 years, from 13,000 to 8,000 years ago. This period coincided with the Würm or Wisconsin glaciation, which began around 110,000 years ago and ended with the Younger Dryas, a final glacial phase lasting from 12,700 to 11,500 years (Fairbanks, 1989; Elsevier, 2013). During this time, sea levels were approximately 30 meters below current levels (Lighty and Stucknernrath, 1982; Toscano and Macintyre, 1987), rendering the caves dry and habitable until the onset of the Holocene period, a geological transition that included three major events: the end of the Ice Age (Faibanks, 1989), the flooding of the caves and the extinction of megafauna during that time (Peltier and Fairbanks, 2006). It was during this stage of prehistory, under extreme and changing environmental conditions, that Eva de Naharon and other Paleoamericans from Tulum survived and evolved.

Rising Sea Levels and their implications for early human settlements

It is no coincidence that the Paleoamerican inhabitants of Tulum chose to settle in an area with the most extensive network of underground passages in the Yucatán Peninsula. Evidence suggests that these individuals existed over 13,000 years ago, a time when sea levels were approximately 30 meters below current levels, making cave occupation a viable option. This unique geological context likely provided shelter, resources, and strategic advantages for early human populations in the region.

Radiometric dating of skeletal remains and geological studies of rocks and soils altered by fire indicate that the caves were occupied at the end of the Pleistocene, prior to their inundation in a timeline transition between 8,000 and 4,000 years ago (López, et al., 2020). This timeline aligns with the melting of glaciers at the end of the Ice Age, which significantly impacted the environment and available resources. The unique karst landscape of the Yucatán, characterized by its cenotes and cave systems, provided essential shelter and resources for these early inhabitants, allowing them to thrive under extreme environmental conditions.

Sea-level history in the Caribbean has been discussed by Lighty et al., 1982, Fairbanks et al., 1989, Pelter et al., 2006, Toscano and Macintyre, (1978), Blanchon and Shaw (1995). These studies have utilized a comprehensive dataset to establish the sea level curve for the Caribbean-Atlantic region, primarily based on the presence of fossil reefs from the species Acropora palmata. This species is a dominant component of contemporary Caribbean reefs, typically forming monotypic colonies in waters deeper than 5 meters and often greater than 17 meters (1978). Based on these studies, the sea level on the coast of Quintana Roo may have been more than ~30 m below the current level around 10,000 years before present. The static rise in sea level caused by the deglaciation at the end of the Pleistocene between 13,000 and 7600 RCYBP was considered "catastrophic" by Blanchon and Shaw, 1995. The sea level increased in that time period from 30 m below the ground to its current level.

The transition from the Pleistocene to the Holocene brought significant environmental changes that likely influenced human populations in the Tulum region. As the caves began to flood at the end of the Pleistocene, populations may have been compelled to seek refuge in higher, drier caves and more fertile lands. This shift would have been a response to the changing landscape and the need for safer living conditions. No evidence has been presented to date for human settlement on the Peninsula de Yucatan during the ~5000-year interval between 8000 and 3000 years ago.

This is remarkable as the settlement in other areas of southeastern Mexico (e.g. Chiapas, Tabasco) and in Guatemala was apparently continuous [18]. Recent investigations carried out by the archaeologist Luis Alberto Martos López in the cave of Puyil in Tabasco (INAH,2018) , south of the Yucatan peninsula, found not only sumptuous Mayan burials of the Late Classic period (650 to 900 AD), but also the remains of three individuals considered the oldest ancestors of contemporary Tabasco people, one from the Early Pre-classic period (2500 to 1200 BC) and two from the Archaic period (8000 to 2500 BC). These studies seem to infer that the cavern was used for mortuary purposes from the Archaic period (8000 to 2500 A.C.), and reinterpreted centuries later by the Late Classic Maya (650 to 900 AD). These individuals could be the link between the settlers who migrated from the east of the Yucatan Peninsula to southern Mexico and Central America (2018).

The caves of Quintana Roo, much like those in Tabasco and various other parts of the world, were deliberately selected for a range of activities and purposes by early human populations. The geomorphology of caves significantly influenced their selection for various uses by ancient peoples. For instance, the narrow entrances leading to deep chambers, such as the "Chamber of the Ancestors" at Cenote Aktun Ha in Tulum and the "Chimney" inside Cenote Taxma Ha in Xpu-Ha, exhibit geomorphological characteristics that enhance ventilation. These features function effectively as natural chimneys, allowing smoke from hearths—used for cooking, warmth, light, or social gatherings—to travel upward and exit the chamber. This natural ventilation system would have been crucial for maintaining air quality within the living spaces, and its use underscores the importance of geomorphological considerations in the selection for different social activities in life or as funerary deposits in death.

Naharon´s skeleton and sea level curve

The correlation between the distance and depth from the cave entrance to the location of the Naharon skeleton—367.48 meters from the entrance and at a depth of 22.6 meters—along with the sea level elevation curve at that time, indicates that the cave must have been dry when Eva de Naharon died or was deposited at the site. The sea level was approximately 30 meters below present levels (Fairbanks, 1990), allowing for the occupation of the caves.

Genetic and Craniofacial Analysis

Physical anthropology analyses suggest that the recovered skeleton from Eva de Naharon comprised about >80% of the original structure of a woman who was 140.9 cm tall, between 20 and 25 years of age at the time of her death, and had an estimated weight of 53.5 kg (González, et al., 2008, 2014). Facial reproductions created using digital techniques of forensic anthropology applied to individuals found in Tulum such as Eva de Naharon and Las Palmas, reveal similar craniofacial characteristics to those of individuals from South Asia and Indonesia (Chatters, et al., 2014; Hubbe, et al., 2020). Furthermore, studies involving mitochondrial DNA (mtDNA) confirms that the genetic lineage of early American populations can be traced back to Asian ancestors. Comprehensive DNA analysis performed on the remains of Naia further supports this conclusion, reinforcing the idea that the first settlers of the Americas likely migrated from Asia (Chatters, et al., 2014).

DISCUSSION

The skeleton of a woman, dated to 13,721 CALYBP (11,670 ± 60 14C yr BP) (Stinnesbeck, et al., 2017) reported to the National Institute of Anthropology and History in 2002 by Octavio Del Río (Del Río, 2002) is, to date, the oldest human fossil found in the Yucatán peninsula and in the Americas.

Bone remains of Eva de Naharon

The discovery of the skeletal remains of Eva of Naharon was a significant achievement that required extensive effort over an 18-month period, involving hours of archaeological systematic exploration within the cave system based on vague hints of bones' existence. A map created by Jim Coke, a founding member of the Quintana Roo Speleological Society (QRSS), who initially mapped the cave system in 1998 (QRSS, 2017), which includes the Naharon cenote, provided the cartography orientation for systematic research. In 2002, I, Octavio Del Río, along with my partner and photographer Eugenio Acevez, located the bones, marking the first archaeological record of the site and reporting the finding to the National Institute of Anthropology and History (INAH) (Del Río, 2002, 2018). This meticulous effort led to the identification of one of the oldest human skeletons in the Americas, offering valuable insights into early human life and migration patterns.

The Naharon bones were found in the rocky bottom at the narrow end of one of the cave branches, covered with a small layer of sediment. The bones, which were fragile and very eroded, were scattered over an area of approximately 2 by 3 meters. Only some vertebrae were anatomically connected, while the rest of the bones were dispersed throughout the area. This scattering may have resulted from taphonomy processes or disturbances caused by flooding in the cave, as well as potential intrusions by cave divers. Of all the of bones found, the ribs, some clavicles and the vertebrae pointed towards the sacrum bone. Fractures and the fragility of their conditions were evident in the long bones, particularly the femoral epiphyses and the humerus, which stood out due to their size.

Notably, the left humerus was remarkably complete and featured the presence of the olecranon fossa perforation, an anatomical characteristic commonly associated with the female sex (Jing, et al., 2015). The jaw and one of the skull fragments were found later hidden in a niche in the rock, approximately 1.5 meters from the rest of the bones. These were completely disarticulated, suggesting they may have been placed there for protection by a cave diver.

At that moment, we knew that that the remains belonged to a human skeleton, likely female. Given the distance from the cenote entrance of 367.48 meters (1,223.7 feet) and the depth of 22.6 meters (74 feet) within the cave, it was determined that the individual must have arrived there when the cave was still dry, approximately 10,000 years ago (Del Río, 2018). This discovery marked the first preceramic human found in the Yucatán Peninsula and it was later recognized as the oldest human fossil recorded in the Americas.

What brought Eva de Naharon to that place?

The question of what led Eva de Naharon to such a remote and challenging location within the cave may never be definitively answered. However, some theories can be explored based on the evidence and the context in which she was found.

The remains of Naharon indicate a human presence in a remote section of the cave when it was still dry. To reach this point, she would have had to navigate through massive chambers and tunnels, predominantly shrouded in imposing darkness. The black walls and sediment absorb light, regardless of its source, whether from an archaic torch or a modern diver's flashlight, creating a disorienting atmosphere. Additionally, the cave bifurcates into numerous tunnels, and in some sections, it is necessary to bend over or even crawl to progress into wider chambers. This challenging subterranean landscape emphasizes the resilience and adaptability required by early humans as they explored these intricate cave systems for shelter or resources.

The Search for Water

At that time, obtaining water required finding a way into the cave and descending as deep as 30 meters to reach the vital liquid. Traveling through the cave alone with just the light of a torch in search of water would have been an extraordinary journey. If this scenario were true, it must have been a highly stressful situation, not only due to the fear of solitude in such a hostile environment, which was gloomy, desolate, completely dark, damp, and predominantly cold, but also because of the physical effects on the mind and body caused by fatigue and a lack of fresh air. These conditions could have led to confusion, impairing her ability to think clearly and causing disorientation despite her intention to return to the surface. Eventually, she may have run out of fuel and fire on her torch, taking refuge in the cave's solitude until she finally succumbed to her fate.

Mortuary Deposit Theory

Another theory, perhaps more likely, is that Naharon's remains represent a mortuary deposit; it is conceivable that her loved ones brought her into the cave, seeking a secluded place where she would not be disturbed in her eternal rest. Although no other materials or offering elements were found to confirm that it was a funeral ceremony, the position and location of the skeleton, along with the natural characteristics of the cave, in the most distant and narrowest section, could have been intrinsic factors in a ritual, possibly manifesting one of the earliest post-mortem rituals recorded on the continent.

Although we still do not know what happened to Naharon or why her remains were found in this place, nearly two decades after her discovery and over 13,700 years after her death, we now know what her face looked like. Traditional facial reconstruction techniques have been replaced by specialized software that generates 3D virtual models with greater precision, allowing for the identification of her facial characteristics. The reconstruction was performed by Brazilian designer Cicero Moraes, who utilized advanced forensic methods and anthropological information to create a virtual representation from her skull, effectively recreating her ethnic traits.

Considerations in radiocarbon dating

It is important to remember that there are challenges when obtaining ages using direct methods. The analysis of C-14 isotopes in ancient human bones can be imprecise, especially in areas with high concentrations of dissolving carbonates, such as cenotes and flooded caves where these remains were found. During fossilization, bones lose organic matter and mineralize, which reduces the amount of residual collagen available for dating. This often necessitates generating calibrations based on the fluctuation curve of radiocarbon, known as "wiggles." Adjusted dates are designated as CALYBP (calibrated years before present). For Naharon, direct dating yielded 11,670 ± 60 14C years, which calibrates to 13,721 CALYBP.

Naharon's research encapsulates significant insights into her entombment within a cave, the intricacies of fossilization, and the challenges associated with accurate dating methods. These suggest various scenarios for the deposition of her remains, influenced by cultural, environmental and geological processes and factors. The application of C-14 isotope analysis, while sophisticated, reveals the inherent difficulties in obtaining precise age estimates, particularly in carbonate-rich environments that hinder organic preservation. Moreover, the advancements in facial reconstruction exemplify the progress in archaeological methodologies, enabling a more nuanced understanding of prehistoric individuals. Collectively, this research not only shed light on Naharon's identity and historical context but also underscores the ongoing pursuit of knowledge in the field of human antiquity, balancing the strides in scientific inquiry with the complexities of interpretation.

CONCLUSIONS

We assess some of the most relevant individuals discovered in the area, including Eva de Naharon, who may have died in the cave or whether she was placed there after death during a time when the cave was dry. We conclude that: (1) this skeleton is to date the oldest human fossil found on the Yucatán Peninsula, Mexico, and in the Americas; (2) the reconstruction created using digital techniques of forensic anthropology to Eva de Naharon, which have been applied to other individuals found in Tulum, corroborates an Asian descent. In 2018, almost two decades after her discovery and 13,721 years after her existence, we finally knew what this woman looked like.

Pleistocene groups of hunter-gatherers likely used the caves as refuges from extreme environmental conditions and large predators of the epoch. These caves also provided essential resources such as water, due to the lack of rivers in the area, and served as sites for mortuary deposits. The caves in the Tulum region provided a stable environment that facilitated adaptability essential for the survival of Pleistocene hunter-gatherers and the evolution of their culture as they navigated the changing landscapes and ecosystems of the era.

REFERENCES

Álvarez T, (1983) Restos de mamíferos recientes y pleistocénicos procedentes de las grutas de Loltún, Yucatán, México. Cuadernos de trabajo 2. Departamento de Prehistoria, Instituto Nacional de Antropología e Historia, México.

Ardelean, C.F., Becerra-Valdivia, L., Pedersen, M.W. et al. Evidence of human occupation in Mexico around the Last Glacial Maximum. Nature 584, 87–92 (2020).

Bedows, P. (2022). "Hydrological Impacts on Archaeological Sites in the Yucatán Peninsula: The Case of Tulum." *Journal of Hydrology*, 603, 127-138. doi:10.1016/j.jhydrol.2021.127138.

Blanchon P, and Shaw J, (1995) "Reef Drowning During the Last Deglaciation: Evidence for Catastrophic Sea-level Rise and Ice-sheet Collapse", Geology 23:4-8

Bonnichsen R and Turnmire KL. (Eds.) (1999) Ice Age Peoples of North America: Environments, Origins, and Adaptations of the First Americans. Corvallis, Oregon: Center for the Study of the First Americans, Oregon State University Press, 536 pp.

Brown KL (1980) "A Brief Report on Paleoindian-Archaic Occupation in the Quiche Basin, Guatemala", American Antiquity 45(2):313-324.

Chatters, James C, Douglas J. Kennett, Yemane Asmerom, Brian M. Kemp, Victor Polyak, et al., (2014). Late Pleistocene Human Skeleton and mtDNA Link Paleoamericans and Modern Native Americans.Science344,750-754

Coke J. (2004) "Geography of Caves in Quintana Roo" Association for Mexican Cave Studies Activities Newsletter, 27, 93-97.

Cruz, J. V., & Méndez, J.** (2018). "Hydrological dynamics in eogenetic karst systems: Implications for microbial communities." *Hydrology and Earth System Sciences*, 22(5), 2601-2615. doi:10.5194/hess-22-2601-2018.

Del Río, O. (1998-2002) Proyecto Catálogo Arqueológico de Cenotes y Cuevas de Quintana Roo, C INAH Q ROO / SAS. Infrome Técnico. Archivo C INAH Q ROO / SAS.

Del Río, O, (2018). "Eva de Naharon", Arqueología Mexicana, núm. 157, pp. 70-77.

Elsevier BV. (2013) The Younger Dryas Climate Event A E Carlson, University of Wisconsin, Madison, WI, USA

Erlandson, J. M., Rick, T. C., & Vellanoweth, R. L. (2007). "The Role of Maritime Societies in the Peopling of the Americas." American Antiquity, 72(4), 703-726.

Fairbanks RG. (1989) "A 17,000-year Long Glacio-Eustatic Sea Level Record: Influence of Glacial Melting Rates on the Younger Dryas Event and Deep-Ocean Circulation", Nature 342: 637-642

Fairbanks RG. (1990) "The Age and Origin of the "Younger Dryas Climatic Event" in Greenland Ice Cores", Paleoceanography 5:937-948

González A, Del Río O and Rojas C. (2004) Informe Atlas Arqueológico para el Estudio, Protección y Conservación de los Cenotes y Cuevas de la Península de Yucatán, Informe Técnico, SAS/INAH.

González, AH., Rojas, C. and Del Río, O. (2002) Underwater Archaeology in the Cenotes of the Yucatán Peninsula, paper presented at the 35th Conference on Historical and Underwater Archaeology, annual meeting of the Society for Historical Archaeology, Mobile, Alabama.

González AH, Terrazas A, Stinnesbeck W, Benavente ME, Avilés J, Rojas C, Padilla MJ, Velásquez A, Acevez E, and Frey E (2014) Chapter 19, The First Human Settlers on the Yucatan Peninsula: Evidence from Drowned Caves in the State of Quintana Roo (South Mexico).

González González, Arturo & Sandoval, Carmen & Terrazas, Alejandro & Sanvicente, M.B. & Stinnesbeck, Wolfgang & Avilés, Jerónimo & de Los Ríos-Paredes, María & Acevez, E. (2008). The arrival of humans on the Yucatan Peninsula: Evidence from submerged caves in the state of Quintana Roo, Mexico. Current Research in the Pleistocene. 25. 1-24.

Hammond N (1982) Ancient Maya Civilization. Rutgers University Press, New Brunswick, New Jersey.

Hering F, Stinnesbeck W, Folmeister J, Frey E, Stinnesbeck S, Acevez E, González A, Terrazas A, Benavente ME, Rojas C, Velázquez A, Frank N, Zell P and Becker J (2018) "The Chan Hol cave Near Tulum (Quintana Roo, Mexico): Evidence for Long-lasting Human Presence During the Early to Middle Holocene", Journal of Quaternary Science 33(4) 444-454

Hines W, Ramsey C, Meadows Jantz L, Jantz RL, Hughes J and Wood B (2010) Improving Facial Reproduction Using Empirical Modeling, Final Technical Report.

Hubbe M, Terrazas Mata A, Herrera B, Benavente Sanvicente ME, González González A, Rojas Sandoval C, et al. (2020) Morphological variation of the early human remains from Quintana Roo, Yucatán Peninsula, Mexico: Contributions to the discussions about the settlement of the Americas. PLoS ONE 15(1): e0227444.

INAH (2018). Hallazgos en la cueva de Puyil, en Tabasco, enriquecen el conocimiento sobre el mundo maya en México: Boletin de Prensa - Secretaría de Cultura | 07 de agosto de 2018 | Comunicado.

Jiménez López, JC, Serrano Sánchez C, González González A and Aguilar Arellano FJ (eds.) (2011) IV Simposio Internacional: El hombre temprano en América. Instituto Nacional de Antropología e Historia, Universidad Nacional Autónoma de México, Instituto de Investigaciones Antropológicas y Museo del Desierto, México, D. F.

Jing LI, Qinghua MAO, Wenyuan LI, Xiaoyan LI, (2015) "An Anatomical Study of the Supratrochlear Foramen of the Jining Population", Turkish Journal of Medical Sciences

Johnson J, Stafford Jr T, Ajie HO, Morris DP (2002) Santa Barbara Museum of Natural History - Arlington Springs Revisited, in Proceedings of the Fifth California Islands Symposium pp541-545

Kälin, J., & Schmid, T. (2018). "Photogrammetry in Forensic Anthropology: A New Approach to Facial Reconstruction." Journal of Forensic Sciences, 63(4), 1125-1132. doi:10.1111/1556-4029.13690.

Lighty RG, Macintyre IG and Stuckenrath R. (1982) "Acropora Palmata Reef Framework: A Reliable Indicator of Sea Level in the Western Atlantic for the Past 10,000 Years", Coral Reefs 1: 125-130.

López-Martínez, Rafael & Solleiro-Rebolledo, Elizabeth & Chávez-Vergara, Bruno & Díaz-Ortega, Jaime & Merino, Agustín & Trabanino, Felipe & Velazquez-Morlet, Adriana & Río-Lara, Octavio & Martos-López, Luis & Terrazas, Alejandro. (2020). Early Holocene charcoal accumulations in the Aktun Ha cenote: Evidence of fire used by the first settlers of the Yucatán Peninsula, Mexico. Geoarchaeology. 35. 10.1002/gea.21797.

MacNeish RS, Jeffrey S, Wilkerson K and Nelken-Terner A (1980) First Annual Report of Belize Archaic Archaeological Reconnaissance. Andover, Mass: Robert S. Peabody Foundation for Archaeology.

Martos López, Luis Alberto, (2008) "Underwater archaeological exploration of the Mayan Cenotes". Museum Int. 60 (4), 100-110.

McDonald, H. & Chatters, James & Gaudin, Timothy. (2017). A new genus of megalonychid ground sloth (Mammalia, Xenarthra) from the late Pleistocene of Quintana Roo, Mexico. Journal of Vertebrate Paleontology. 37. e1307206. 10.1080/02724634.2017.1307206.

Miranda GE, Wilkinson C, Roughley M, Beaini TL, Melani RFH. Assessment of accuracy and recognition of three-dimensional computerized forensic craniofacial reconstruction. PLoS One. 2018 May 2;13(5):e0196770. doi: 10.1371/journal.pone.0196770. PMID: 29718983; PMCID: PMC5931631.).

Moraes, Cicero & Kimura, Ricardo & Bezzi, Luca & Bezzi, Alessandro. (2022). Fotogrametria com Limpeza de Pontos, Alinhamento e Redimensionamento Automáticos no OrtogOnBlender. 10.6084/m9.figshare.19450283.

Neves, WA, et al. (2013) Paleoamerican Odyssey, Graff KE, Ketron CV, Waters MR (Eds). Center for the Study of the First Americans, College Station, TX, pp. 397-412.

Peltier WR and Fairbanks RG. (2006) "Global Glacial Ice Volume and Last Glacial Maximum Duration from an Extended Barbados Sea Level Record". Quaternary Science Reviews 3322-3337.

Polaco OJ. 1982 [1983] Restos de moluscos recientes y pleistocénicos procedentes de Loltún, Yucatán, México, en T. Álvarez y O.J. Polaco (eds.), Restos de moluscos y mamíferos cuaternarios procedentes de Loltún, Yucatán, México. Departamento de Prehistoria, inah, México, pp. 37-41

Seltzer, Alan M.; Ng, Jessica; Aeschbach, Werner; Kipfer, Rolf; et al. (2021). "Widespread six degrees Celsius cooling on land during the Last Glacial Maximum". Nature. 593 (7858): 228–232. Bibcode:2021Natur.593..228S. doi:10.1038/s41586-021-03467-6.

Smart P, Beddows P, Cook J, Doerr S, Smith S, and Whitaker F. (2006) "Cave Development on the Caribbean Coast of the Yucatán Peninsula, Quintana Roo, Mexico" Geological Society of America Special Paper 404

QRSS (2018) List of Long Underwater Caves in Quintana Roo Mexico. Quintana Roo Speleological Survey. National Speleological Society (NSS). May 1, 2017.

Stinnesbeck W, Becker J, Hering F, Frey E, González AG, Fohlmeister J, et al. (2017) The earliest settlers of Mesoamerica date back to the late Pleistocene. PLoS ONE 12(8): e0183345.

Stinnesbeck, Wolfgang; Becker, Julia; Hering, Fabio; Frey, Eberhard; González, Arturo González; Fohlmeister, Jens; Stinnesbeck, Sarah; Frank, Norbert; Terrazas Mata, Alejandro; Benavente, Martha Elena; et al., (2017-08-30). Petraglia, Michael D. (ed.). "The earliest settlers of Mesoamerica date back to the late Pleistocene". PLOS ONE. 12 (8). Public Library of Science (PLoS): e0183345.

Terrazas A and Benavente M (2006) Estudio preliminar de tres cráneos tempranos procedentes de cuevas sumergidas de la costa este de Quintana Roo. 2° Simposio Internacional el Hombre Temprano en América.

Toscano MA and Macintyre IG. (1978) "Corrected Western Atlantic Sea-level Curve for the Last 11,000 years Based on Calibrated 14C Dates from Acorpora Palmate Framework and in16. Geology 6, 713-715.

Velázquez Morlet A, López de la Rosa E, Gaxiola González M and Casado López (1988) Historia prehispánica del estado de Yucatán, Zonas Arqueológicas: Yucatán, MP, pp. 28-31. Instituto Nacional de Antropología e Historia, México.

Velázquez, Valadez R (1980) Proyecto Loltún. Informe de los trabajos de campo, realizados en las excavaciones de la gruta de Loltún, Yucatán, durante el período de junio a diciembre de 1978. Manuscript. Instituto Nacional de Antropología e Historia, México.

Zhuang, Q., & Giardino, J. R. (2012) "Ocean Cooling Pattern at the Last Glacial Maximum." *Advances in Meteorology*, vol. 2012, Article ID 213743, 2012. doi:10.1155/2012/213743

.