Paleoclimatic Reconstruction and Archaeological Investigations
at Xcoch and the Puuc Region of Yucatan, Mexico in 2010:
Exploratory Research into Arctic Climate Change and
Maya Culture Processes

Michael P. Smyth
Foundation for Americas Research, Inc.

Ezra Zubrow
State University of New York at Buffalo

David Ortegón Zapata
Instituto Nacional de Antropología e Historia

Nicholas P. Dunning
Eric M. Weaver
University of Cincinnati

Philip van Beynen
University of South Florida

2010 Preliminary Report for the
EArly–Concept Grants for Exploratory Research
(EAGER, 0940183)

National Science Foundation
Arctic Social Sciences Program
Washington, D.C.
This report presents the results of the second year of research of an Early Concept Grant (NSF 0940183) for Exploratory Research (EAGER) that took place at the ancient Maya center of Xcoch and the Puuc region of Yucatan, Mexico in 2010. How data from the Puuc region relate to the nature of hydraulic systems and patterns of cyclical drought is being investigated and promises to shed new light on the processes of Maya response to cultural-environmental interplay and the rise and demise of early complex societies in the Northern Maya Lowlands.

A program of multidisciplinary research at the Maya center of Xcoch in the Puuc region of Yucatan, Mexico began in 2006 and remains ongoing. This work is focused on determining if the site had significant occupation during the Preclassic period, the size and density of settlement through Late Classic times, and the investigation of a deep water cave below the monumental center as well as numerous water control features distributed across the settlement. In 2009, the project initiated a study designed to begin reconstructing climate change and the human responses over the past 3000 years, especially emphasizing the phenomena associated with so-called Classic Maya collapse (800-900 AD). This time period is especially relevant to global climate researchers because it coincides with the Medieval Warm Period (AD 800-1300), when climatic conditions enabled Norse peoples to explore and colonize the North Atlantic Islands and reach the shores of America (Dugmore et al. 2007; McGovern et al. 2007). How climate change affected processes of cultural development and decline in the Maya Lowlands has the potential to inform us today regarding the far-reaching cultural-environmental impact of global climate change.

The results through 2010 continue to show that Xcoch was a large Prehispanic Maya center distinguished by a long occupation dating back to the Middle Preclassic period (~800-400 BC), or earlier, and peaking in the Late Classic period (600-800 AD) before general abandonment of the site, though the deep water cave continued to be visited up until modern times. Contextual and chronometrical archaeological data so far suggest that there were at least two periods of intense construction activity that correspond to contemporaneous episodes of cyclical drought. Based on climatic data from Lake Chichencanab, Yucatan, Belize, and elsewhere in the Caribbean Basin (e.g., Hodell et al. 2001; Haug et al. 2003; Webster et al. 2007; Moyes et al. 2009), one series of drought cycles may have occurred near the end of the Preclassic period around the 2nd century AD, or about the same time that massive efforts were made at Xcoch for rainwater capture in the form of hydraulic systems such as aguadas (water ponds), massive catchment surfaces, drainage canals, and chultuns (underground water cisterns). Excavations show that these efforts may have been in vain because stratigraphic evidence for a hiatus in occupation associated with the end of the Preclassic indicates that many site areas were abandoned at this time.

Near the end of the Early Classic period (~500 AD), Xcoch was reoccupied and settlement slowly began to build in a crescendo-like fashion to reach a maximum in the Late Classic. However, there is again evidence for another series of drought cycles (Hodell et al. 2001; Webster et al. 2007; Wahl et al. 2007; Media-Elizade et al. 2010) that may have pressured Xcoch populations to intensify water management by resurrecting and expanding old water control systems or by constructing new ones for capturing rainwater. Evidently, these efforts...
were again insufficient because the site shows settlement abandonment, perhaps abruptly, by the Terminal Classic period (~800 AD). Though clearly suggestive, previous climate change data in the Yucatan has been too course-grained and non-site specific for rigorous cultural interpretation at the site level. Much more localized and comprehensive paleoclimate and settlement data are required to properly assess the relationships between drought cycles and human responses at Xcoch and the Puuc region.

This report details the current settlement pattern research, including surface collection survey and architectural mapping, and a program of test excavation, ceramic analysis, and radiocarbon dating through 2010, and discusses the research into water management practices such as the aguadas at Xcoch as well as the related cave investigations and speleothem analyses carried out at the Xcoch and Vaca Perdida caves. These studies indicate that the site of Xcoch and vicinity were occupied at the beginning of Maya settlement in northern Yucatan and that the Puuc region was affected in the past by numerous drought cycles that had significant impact on human adaptation and culture process.

**Settlement Survey and Surface Collections**

Surface collection survey at Xcoch continued in 2010. Site-scale systematic interval sampling of the surface landscape was a major component of field research completed at the Puuc region sites of Sayil and Chac (II) approximately 20 km south of Xcoch. The purpose of such work was to document urban phenomenon and investigate human adaptations in the challenging tropical environment of the Puuc Hills and can provide important comparative region-wide variability in responses by the Maya to severe climate change in the prehispanic past.

The Xcoch Project to date has surface collected an area of about 100 hectares radiating out from the site center of Xcoch (Figure 1), including more than 30 hectares in 2010. The surface survey so far is composed of 857 3x3 m units spaced at intervals of 25 m of which 304 were collected and recorded in 2010. Within the central area of Xcoch, most architectural features were mapped at a scale to 1:200. The site-scale survey is anchored to a base line datum at N5000 E5000 near where the municipal border (mensura) runs east-west separating the municipal lands of Santa Elena from Ticul. From this starting point, main north-south brechas (trails) were opened to N6000 and south to N4700. The survey in 2010 has reached west to E4600 and to east to E5400 between N5400 and N4800. With the aid of a total-station EDM (Electronic Distance Measuring Theodolite) and GPS receiver, main breaches north-south were opened each 100-mts with 3x3 m collection units placed every 25 m.

Significant architectural and ceramic surface remains were found throughout the area around the central groups at Xcoch, including the dense settlement zone known as the Elite District east of the Great Pyramid and Grand Platform. Also, three groups south of the Gruta Xcoch and three groups to the west, including massive habitation platforms, an immense aguada (La Gondola), and the Chac-Na group. Though the exact settlement limits of Xcoch have not been determined, there is evidence for settlement radiating outwards in all directions more than 1 km, including pyramid groups, aguada features, and causeways both long and short.
The name “Cave Pyramid” was given to a prominent pyramid temple that sits immediately above the sinkhole (Xcoch Grotto) in which the entrance to Xcoch cave is located (Figure 1). The Cave Pyramid sits on the southwest edge of Xcoch Plaza, the apparent central point of the ancient community. There are at least two causeways that converge near the Pyramid to the west and southeast. The southeast causeway travels almost 1 km before arriving at a natural hill that supports three structures forming a triadic group placed upon an expansive leveling platform: two pyramids of the megalithic style without vaulted summit buildings and a vaulted range structure to the east. Less than 1 km to the south of this group are two aguadas (one is “Xcoch South Aguada 1” and the other is a deep depression over which a paved farm road passes) within
the mechanized parcels of the municipality of Santa Elena. From previous reconnaissance, we know that there are other pyramid groups and substantial settlement 1 km to the east of the Great Pyramid, other groups with substantial architecture in the intermediate zone, and habitation structures to the southeast. Eight hundred meters north of the Great Pyramid are numerous settlement groups including a number with pyramids at least one (Old Pyramid Group below) of which is dated to the Preclassic period.

Settlement at Xcoch is much more dense and extensive than originally anticipated when the project began. It is now estimated that Xcoch may cover 6 km², though this projection may be conservative because satellite imagery suggest that there are substantial structures beyond the current northern and eastern survey limits. The survey indicates that settlement is continuous to the north and could include another aguada 1.5 km to the northeast (Dunning 1992). Xcoch extends 1 km to the west where a shallow aguada was identified in 2010 and more than 1 km to the east because there is no evidence of any settlement drop-off beyond the areas of preliminary reconnaissance. This same kind of settlement pattern continues to the south indicating that Xcoch extends another 2 km in this direction. In fact, numerous habitation structures were located in 2010 within the newly cleared municipal parcels 2.3 km southeast of the Great Pyramid, which is clearly visible in the distance. Therefore, several more seasons of surface collection and settlement mapping survey are required to completely document the site.

Architectural Mapping and Site Description

The site of Xcoch is best known for a deep water cave, a tall megalithic pyramid, and a giant platform covering about 1 hectare that together stand more than 42 m above the ground surface. The survey work revealed that the Great Pyramid is the highest point of a massive multi-level acropolis incorporating at least 7 architectural groups covering more than 10 hectares, representing one of the largest architecturally integrated constructions in the Puuc region (Figure 1). Much of the acropolis is constructed in the early megalithic style, characterized by large shaped boulders with abundant chinking stones, and believed to be an indicator of Preclassic to Early Classic occupation. On the south side of the Grand Platform leading to the Great Pyramid are two megalithic staircases with treads and risers measuring up to 2 m in length. The central megalithic staircase is virtually identical to one recently consolidated at Xocnaceh, a relatively small site approximately 20 km to the east of Xcoch centered by an enormous Preclassic platform (Gallareta Negrón and Ringle 2004; Bey 2006). Atop the Megalithic Staircase at Xcoch are three stone buildings, one or more showing and the remains of early-style vaulted roofs. The Great Pyramid of Xcoch towers over the north end of the Grand Platform. Lower sections of this enormous terraced pyramid show megalithic characteristics, but the uppermost reaches are clearly formed by multiple Classic period constructions, now badly fallen.

Nearly 50 architectonic groups and topography, including more than 15 groups in 2010, have been mapped intensively at a scale of 1:200 using an EDM transit, compass and tape, and GPS receiver (Figure 1). Additionally, the remains of numerous other settlement groups also were located during reconnaissance surveys. Overall, the site is composed of many features, including platforms and multiple room buildings, >15 pyramids (5 to 30 m in height), the Great Acropolis, many adjacent plazas, and a causeway connecting the Acropolis to a hilltop pyramid group almost 1 km to the south. Chultuns are largely absent in the core area of monumental

---

4
architecture in the site center, but are increasingly prevalent in surrounding residential groups along with numerous stone basins (pilas). The architectural remains mapped in 2009 were concentrated in an area of more than 30-ha around central Xcoch and outside of the enormous Acropolis. In 2010, remains of other large settlement groups were found to the north, east, and south. The high quality and scale of construction indicate that Xcoch was a first-order settlement and among the largest sites in the Puuc region.

The largest architectural complexes are closely linked with the Great Acropolis. The “Elite District” is one of these settlement zones covering 6 hectares located to the east of the central Xcoch and contains numerous platforms, vaulted buildings, foundations for perishable houses (foundation braces), plazuelas, and at least four pyramid platforms. In the western part this district (N5100 E5200 and N5200 E5200) is the Residential Group, a high platform surrounded by foundation braces and a small central platform with a small altar to the south and a short plain stela to the north. To the southeast of this group is a multi-room, L-shaped vaulted building with a four column entrance and a linear pyramid platform highlighted by a single-room temple structure at the summit and two lower structures to the east. To the south of the linear pyramid platform are two chultuns within a plazuela. A 10 m tall pyramid somewhat rounded in appearance is nearby where 2010 test excavations show that both the pyramid and the associated plaza were originally Preclassic constructions. To the northwest is a plaza with two, four-room vaulted buildings on the south and west wings. These vaults have triangular-shaped stones and the rooms are of average height but show architectural characteristics of the Early Puuc style (Figure 2). Two megalithic stela, one standing upright and the other laying flat, are to the west and north of the vaulted buildings but there is a platform that probably supported another vaulted range structure on the north side. A parallel platform further north suggests that these two platforms could have formed a ballcourt alley but this has not been confirmed by test excavation.

Figure 2: The Eastern Elite District
To the north of the parallel platforms is a 7 m tall pyramid with possible stairs on the east side and a collapsed vaulted summit temple (Figures 1 and 2). A test pit 9 (Op. 38) at the western base in 2010 of this pyramid revealed Preclassic platform levels and suggests that the pyramid platform itself was originally a Preclassic structure. An adjacent long platform to the northeast shows apron molding decoration that supports a probable vaulted building with two lateral room wings on the west and east sides set between a long building with no internal room divisions. The decoration and the style of the rooms suggest the Proto-Puuc style dated to the Early Classic period. Two foundation brace buildings are to the south. To the north is another plaza and a vaulted building with a single column entryway on the west side. Further north is a large palace-type range structure with 5 rooms each of which had columned doorways and evidence of high vaulted roofs in the Classic Puuc style (boot stone vaults). The columns and door jambs were found out of their original places laying along the west part of the plaza. Within the plaza itself is a deep chultun, a columnar stone altar, and two large rectangular stone basins which appear to have been used for milling. A foundation brace structure and a vaulted building without room divisions is oriented north-south along the east side of the plaza. A large, high platform for a two story, multi-room building is also found to the east near N5200 E5300. Although poorly preserved, this building has a lower level of three small rooms on the west wing that must be a lower story for a larger room block near the center of the structure.

Further southeast, three additional feature clusters were cleared and mapped in 2010 (Figure 3). The nearest group is centered by a three-room vaulted building set upon a raised building platform fronted by an expansive plaza and altar platform to the west. Immediately to the south is the Cuevas Group which consists of 3 plazuelas, 5 chultuns, 6 pilas, one conical altar, and at least 15 buildings (9 appear to have been vaulted). Some of the buildings contain multiple rooms that show characteristics of the Proto Puuc and Early Puuc styles. The Proto Puuc buildings concentrate to the southeast and show a north orientation. The Early Puuc buildings are oriented east of north and many have column entryways. The Mensura Group located to the east, actually on the mensura, is a high platform supporting only megalithic-style foundation brace buildings. Feature clusters continue to the east and southeast.

Figure 3: Southeast settlement at Xcoch
Northeast of the Great Pyramid, between N5300 E5200 and N5300 E5300, is a settlement zone well exposed by a modern cornfield (*milpa*) consisting of four groups with platforms, buildings, and pyramids (Figures 1). The first group is a quadrangle situated on a high basal platform more than 7 m in height composed of a pyramid platform with megalithic stairs supporting a large un-vaulted single-room building. The quadrangle contains three other buildings (two are stone buildings without vaulted roofs). The south building is a three-room vaulted structure. About 50 m southeast, is a group of four platforms--three with collapsed building--surrounding a small plaza and the remains of a vaulted building to the south; a small pyramid is on this side as well. Two chultuns are located off-platform to the west and south and 3 pilas nearby suggest domestic residential activities. Less than 50 m northeast atop a 3 m high platform is a group with three vaulted buildings and a 6 m tall pyramid to the east. There is a chultun off-platform on the west side and a large foundation brace to the extreme southeast near where surface collections recovered Preclassic ceramics. A fourth group to the north was recorded in 2010 and is a small but high platform with a vaulted building on the west, several foundation brace structures and undistinguished platforms, as well as two circular foundations constructed of reused facing stones suggesting a possible post-occupation. No chultuns were seen on-platform.

Site survey benefited from milpa activity in 2010 just north of the Great Pyramid. This area was partly cleared and burned for planting corn and revealed settlement details of an expansive North Plaza and extension of the Great Acropolis that consists of numerous surface levels and platform structures spread over an area approaching one hectare (Figures 1 and 4). An upright megalithic stela in situ was found on the midline of the Great Pyramid approximately 150 m north. A group with an east facing vaulted building and a three-column doorway borders the North Plaza on the west. Just north of the megalithic stela is a very large and dense concentration of vaulted buildings that underwent surface collections but not intensive mapping. West of this settlement concentration is the “Old Pyramid Group.” Mapping revealed an archaic pyramid structure with no clear summit building surrounded by foundation brace buildings on its east and south sides. Test excavations at the base of the Old Pyramid date this structure to the Preclassic period, though pottery remains also suggest that many of the associated foundations were reoccupied during the Late Classic.
North of the Old Pyramid Group between N5550 and N5650 are two additional settlement groups with the remains of vaulted and un-vaulted buildings and chultuns but only represent a fraction of the feature clusters located along the E5000 and E5100 lines. In fact, based on surface collection survey and judging by the number of vaulted buildings, this area may be the most densely occupied sector of Xcoch and settlement zone associated with many of the highest ranking elite during the Late Classic period. Indeed, there are other settlement groups up to 1 km to the north including some with pyramidal structures of which at least one is a Preclassic structure that are scheduled to be mapped in 2011.

Settlement groups were also found during surface survey to the west of the E5000 line between N5300 and N6000. These groups appeared to be more domestic and residential in function given the predominance of foundation brace structures, chultuns, and pilas distributed on relatively low basal platform surfaces. Many of these foundation braces are constructed of megalithic stones, like those seen in other parts of Xcoch, and may be Preclassic house buildings as suggested by test excavation in a similar three-room megalithic foundation (Op. 35 near N5350 E 5000) and others near the Xcoch Grotto (see below). This megalithic building produced Preclassic
diagnostics below a thick stucco floor surface covered with a midden of Early Classic and Late Classic ceramic material and below floor cuts near the center of the east room burning was also evident. The implication is that this building was abandoned at the end of the Preclassic.

The Grotto Group is located near the sinkhole leading to the deep water cave to the north of the mensura dividing the lands of Ticul and Santa Elena (Figure 1) and is composed of both vaulted and un-vaulted buildings. There are three, three-room vaulted buildings one with a central column entryway situated around a small plaza; the South Pyramid of the Xcoch Plaza is located to the east. Also, to the west are two megalithic foundations oriented north-south that are a short distance from the grotto that clearly date to an earlier time period. Test excavation in 2009 showed Preclassic diagnostics associated with the lower floor of the north building while Late Classic materials are prominent near the surface suggesting that this structure was occupied continuously and included ritual activity associated with the cave. Test pits in 2010 sampled the adjacent platform area bordering the depression descending to the cave entrance and produced a wide range of Preclassic to Postclassic ceramics such as water vessels, incense burners, and figurines. These diagnostic ceramic are clearly associated with ritual activity related to the water cave both before and after the site was depopulated. To the west of the grotto is a 6 m wide causeway that runs approximately 100 m west towards the La Gondola Aguada passing two collapsed chultuns and one ring structure before arriving at two platforms each with multiroom foundation braces. In 2010, probing excavations within this causeway revealed two stucco floor surfaces beneath the causeway fill. Both the causeway and the stucco floors produced abundant Middle Preclassic ceramic materials indicating that these features were constructed at the beginning of formative occupation at Xcoch.

Near N5000 E5000 south of the mensura is the South Grotto Group situated atop the second terrace level of the Great Acropolis. The main building is a seven-room vaulted range structure oriented east-west with a wide north staircase. This building was constructed in the Classic style because there are “boot” stone vaults seen within the building collapse. Two vaulted buildings to the east are earlier and seem to be in the Proto-Puuc and Early Puuc styles respectively; the first structure is oriented north-south with single piece moldings and decorative stones carved with feather motifs. The other building has an entrance formed by a single column and two jambs and there is a conical altar at the center of a small adjacent plaza. Three foundations for buildings with perishable roofs show megalithic stones; one located to the north was tested by excavation and found to be Preclassic in date. There are two megalithic foundations to the south that display similar stonework and layout and must be contemporary. A megalithic staircase provides access to these early house foundations as well as the second level of the Acropolis. Another similar megalithic foundation lies along the south border of the first terrace of the Acropolis where three collapsed chultuns are found; two were covered with inverted pilas and platform fill. Another flight of megalithic stairs to the south clearly indicates that this complex settlement group must have been the principal southern access to the Great Acropolis and the Xcoch Grotto in Classic and Preclassic times.

Further south are two large terrace platforms that mark where the Great Acropolis begins (Figure 6). The west platform is a multilevel terrace built into the natural topography with two house foundations and three chultuns, two of which are well preserved, and three pilas that suggest a domestic residential function. The other terrace platform integrates with the Great Acropolis and
has four multi-room foundation brace structures, 3 chultuns, and numerous pilas. Immediately southeast is a depression with megalithic stone walls that suggest a former stone quarry site converted into a reservoir or mini aguada engineered to collect and store rainwater. There are a number of similar such features across Xcoch that will be the subject of investigation in 2011. The southeast causeway is a short distance to the west but it is still unclear how it articulates with the Great Acropolis, but it certainly passes between the south terrace platform and a pyramid group to the east. A probing excavation in a north section of this causeway indicates that it was constructed on relatively high bedrock in Late Classic times, though a Preclassic date for other sections cannot be ruled out.

Figure 6: South terraces and platforms near the SE causeway.

Some 200 m to the west of the Great Pyramid is the Chikin Mul group, an enormous 5 m tall basal platform measuring almost 100 m east-west and some 70 m north-south (Figures 1 and 7). This platform was machine mapped in 2010 and supports numerous foundation brace buildings, three with multiple rooms. A deep probing excavation near the center indicates that the platform itself was constructed in the Preclassic period with repeated reoccupation until the Late Classic. Surface structures are clearly habitations with many associated pilas but no on-platform chultuns. Deep test pits reaching over 4 m in depth, encountered a prepared soil surface that may represent a leveling for the platform and Middle Preclassic ceramic diagnostics above natural bedrock. A wood charcoal sample from the soil surface is radiocarbon dated to 2060 BC +/- 30 (uncorrected; Table 5 suggesting that this massive platform was constructed at least as early as the Grand Platform and may have been superimposed upon a Late Archaic-Initial Formative site occupation. Around the Chikin Mul group, particularly a small plaza group to the southwest, are several small platforms for foundation braces and chultuns and a ruined single-room vaulted building.
At the end of the west causeway between N5000 E4900 and N5000 E4800 is the Aguada La Gondola, an enormous apsidal-shaped depression constructed by the ancient Maya (Figure 1 and below). This aguada measures roughly 110-m east-west by 80-m the north-south and has a current depth of about 6 m (see Dunning et al. this volume). To the north of the aguada is an expansive platform surface that covers over one-half hectare constructed with cobble stones (chich) of various sizes. The Chich Platform slopes towards the aguada and seems to have been a catchment area to collect runoff rainwater. A lone foundation brace is the only associated structure located near the southeast corner. In all respects, these two massive constructions represent a tremendous effort by the ancient Maya to collect and store water at Xcoch.

The “Long Group” is located between of N5100 E4700 and N5200 E4700 represents another massive platform that measures 125 m north-south and 50 m east-west with a height of 4 m (Figure 1). In the center is a building platform with a megalithic staircase and a three-room stone walled building that may have not been vaulted. To the south is a group of foundation brace buildings and to the north a wide pyramid platform near a chultun with another structure of stone walls but no vaulted roof set upon a platform accessed by megalithic staircase on the north. The Long Group may have been another major area of Preclassic settlement.

The “Chac-Na Group” (between N4900 E4600 and N4900 E4700) is the westernmost group mapped so far at Xcoch (Figures 1 and 5), though residential settlement is known to continue further west. The group takes its name from a four-room Proto-Puuc style building still partially standing. This structure has a type of vault with roughly shaped slab stones. The exposed ends were tilted upward and were heavily plastered to approximate a smooth soffit and wall facing is of well-cut and well-fitted stones that are slightly smaller than normal (similar to a building at Cacabxnuc, Campeche; Pollack 1980). Another multiple room building to the southeast has an
L-shaped layout and is constructed in a similar style. A second L-shaped, but badly fallen, Proto-Puuc style building defines a plazuela including the Chac-Na building to the west and a higher platform with a megalithic staircase supporting an un-vaulted stone building on the east. There is another vaulted building to the south and three to the northeast that show columned doorways and are likely Early Puuc style structures. Also, there are four foundations braces to the northwest and three additional buildings to the north of the Chac-Na Group, as well as an apsidal-shaped foundation to the southeast that may be of historic age. Another small platform group with several foundation brace buildings is found to the south.

![Figure 8: The far west Chac-Na Group settlement.](image)

**Xcoch Aguadas**

In July 2010, excavations were conducted in two aguadas at the site of Xcoch, Yucatan. One unit was opened in the Xcoch East aguada and three units were excavated in Aguada La Gondola (Figure 9). The excavation units and profiles are described in this report. Results from laboratory analyses of soils, sediments, and artifacts are pending.
Xcoch East Aguada

The Xcoch East Aguada is a roughly circular depression with a diameter of about 65 m situated a short distance east of the monumental structures on the elevated Xcoch Plaza (Figure 10). The aguada is currently a very shallow depression just over a meter deeper in its center than surrounding terrain. Vegetation in the depression indicates that it occasionally retains surface water. The aguada is bounded by clear artificial berms on its north and south sides. On the west side the aguada abuts outcopping limestone that gives the appearance of having been quarried in ancient times. The east side the aguada is flanked by elevated plazas surmounted by monumental architecture. Several of these plazas appear to be interconnected and canted so that they would funnel rainwater into a clear sluiceway and thence into the aguada.
Xcoch East Aguada 2010 Pozo 1

Pozo 1 was a 2 x 2 meter unit excavated near the approximate center of the aguada. The unit reached a depth of 180 cm at which point it bottomed out in sascab. The north profile of the pozo is shown in Figure 11 and described in Table 1 below.

Based on this excavation and on the apparent quarry scars on the bedrock exposed along the western flank of the aguada the Xcoch East Aguada can be best interpreted as having originated as a stone or stone and sascab quarry, although it is possible that a natural depression existed in this spot and was deepened or widened by quarrying. At a currently undated time, the floor of the quarry was sealed with a layer of compacted (possibly tamped) clay. Ceramics found just above the floor suggest that the reservoir was in place by sometime in the Preclassic period. Clayey sediment began to accumulate after the floor was in place. It is not clear whether or not dredging occurred or whether sediment accumulation was uninterrupted.
Table 1: Xcoch East Aguada – 2010 Pozo 1 North Profile

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Color (Munsell)</th>
<th>OM (%)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>P (ppm)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-25</td>
<td>Very dusky red (2.5YR2.5/2)</td>
<td>5.8</td>
<td>10</td>
<td>8</td>
<td>82</td>
<td>211</td>
<td>1: A: clay (+/- 2% coarse sand); small crumbs</td>
</tr>
<tr>
<td>25-65</td>
<td>Dusky red (10R3/4)</td>
<td>2.6</td>
<td>5</td>
<td>6</td>
<td>89</td>
<td>195</td>
<td>2: Bt: Boundary with A1 is somewhat irregular due to in-filled cracks; some piedrine</td>
</tr>
<tr>
<td>65-140</td>
<td>Dark red (2.5YR3/6)</td>
<td>2.3</td>
<td>12</td>
<td>9</td>
<td>79</td>
<td>300</td>
<td>3: C1: clay (+/- 2% coarse sand); massive; slickensides</td>
</tr>
<tr>
<td>140-155</td>
<td>Dark red (2.5YR3/6)</td>
<td>2.0</td>
<td>9</td>
<td>11</td>
<td>80</td>
<td>398</td>
<td>4: C2: clay; massive; scattered large sherds; carbon</td>
</tr>
<tr>
<td>155-165</td>
<td>Dusky red (10R3/4)</td>
<td>2.5</td>
<td>10</td>
<td>4</td>
<td>86</td>
<td>245</td>
<td>5: clay; massive and highly compact; carbon; possible lining</td>
</tr>
<tr>
<td>165-180</td>
<td>Dark red (2.5YR3/6)</td>
<td>2.2</td>
<td>19</td>
<td>7</td>
<td>74</td>
<td>114</td>
<td>6: marly clay; discontinuous; located only in pockets within sascab</td>
</tr>
<tr>
<td>165/180+</td>
<td>Dark reddish brown (2.5YR3/4)</td>
<td>0.5</td>
<td>29</td>
<td>2</td>
<td>69</td>
<td></td>
<td>7: sascab and weathered limestone</td>
</tr>
</tbody>
</table>

Aguada La Gondola

Aguada La Gondola lies approximately 100 meters west of the Gruta Xcoch entrance and site center. It is a roughly rectangular depression about 110 m on its east-west axis, 80 meters on its north-south axis, though there is an embayment along the south side of the aguada making it
somewhat pentagonal in shape (figure 4). The aguada is currently about 6 meters deep. There are sluiceways leading into the aguada at its NE and NW corners. Low berms are visible around much of the outer rim of the aguada. Alignments of large stone blocks are visible at varying elevations on each of the interior walls of the depression. 2009 Pozo 1 was excavated across one such alignment situated about midway up the north wall of the aguada. Pozo 2 was begun in the floor of the aguada but was discontinued at a depth of 110 cm due to time constraints. 2010 Pozo 1 was excavated near the center of the aguada floor and carried to a depth of 330 cm. 2010 Pozos 2 and 3 were excavated into the berm along the northern rim.

Figure 12: 3D digital elevation model of Aguada La Gondola created by Eric Weaver. North is at the top of the image.

Aguada La Gondola 2010 Pozo 1

Pozo 1 was a 2 x 2 meter pit excavated near the center of Aguada La Gondola. The north profile of Pozo 1 is shown in Figure 13 and described in the Table 2 below.

The excavation revealed a possible badly decomposed floor/lining at a depth of 155 cm. Well preserved floors made of compact clay and sascab were exposed at depths of 250 and 310 cm. The sediment immediately above each of these lower floors contained abundant sherds and charcoal. The lowest floor was associated with only Preclassic ceramics suggesting that the reservoir was in place early in the site’s history. Late/Terminal Classic ceramics (Cehpech) found in the middle and upper strata suggest that the reservoir continued to be used and refurbished. Charcoal recovered from the lower floors is not yet dated.
Figure 13: Aguada La Gondola 2010 Pozo 1: north profile.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Color (Munsell)</th>
<th>OM %</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>P (ppm)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>Reddish black (2.5YR2.5/1)</td>
<td>4.8</td>
<td>8</td>
<td>9</td>
<td>83</td>
<td>308</td>
<td>1: A1 horizon</td>
</tr>
<tr>
<td>20-50</td>
<td>Dark reddish brown (2.5YR3/3)</td>
<td>2.5</td>
<td>7</td>
<td>7</td>
<td>86</td>
<td>218</td>
<td>2: AC: Boundary with A1 is highly irregular due to deep, in-filled cracks; slickensides</td>
</tr>
<tr>
<td>50-60</td>
<td>Reddish brown (2.5YR4/4)</td>
<td>2.0</td>
<td>5</td>
<td>6</td>
<td>89</td>
<td>191</td>
<td>3: C: massive; slickensides</td>
</tr>
<tr>
<td>60-70</td>
<td>Dark reddish brown (2.5YR3/3)</td>
<td>2.6</td>
<td>11</td>
<td>16</td>
<td>73</td>
<td>311</td>
<td>4: Ab?: scattered weathered sherds; carbon</td>
</tr>
<tr>
<td>70-100</td>
<td>Dark red (2.5YR3/6)</td>
<td>1.5</td>
<td>28</td>
<td>7</td>
<td>75</td>
<td>267</td>
<td>5: 5-10% limestone fragments; carbon; possible lining</td>
</tr>
<tr>
<td>100-155</td>
<td>Dusky red (10R3/4)</td>
<td>1.8</td>
<td>17</td>
<td>8</td>
<td>85</td>
<td>220</td>
<td>6: a few weathered sherds; carbon</td>
</tr>
<tr>
<td>155-165</td>
<td>Dark reddish brown (2.5YR3/4)</td>
<td>22</td>
<td>3</td>
<td>75</td>
<td>185</td>
<td>7: clay; massive; ±5% coarse sand; charcoal; sherds; possible lining</td>
<td></td>
</tr>
<tr>
<td>165-250</td>
<td>Dark reddish brown (2.5YR3/4)</td>
<td>2.8</td>
<td>9</td>
<td>6</td>
<td>85</td>
<td>336</td>
<td>8: clay; massive; few sherds except in lowest 10 cm where sherds and charcoal are abundant</td>
</tr>
<tr>
<td>250-257</td>
<td>Red (2.5YR4/8)</td>
<td>15</td>
<td>5</td>
<td>80</td>
<td>130</td>
<td>9: compact floor of sascab and clay; charcoal</td>
<td></td>
</tr>
</tbody>
</table>
Aguada La Gondola 2010 Pozo 2

2010 Pozo 2 was a 1 x 2.5 m trench excavated into the berm on the northern rim of the aguada at a point due north of Pozo 1. The east profile of Pozo 2 is shown in figure 5 and described in the Table 3 below.

**Table 3**

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Color (Munsell)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>Dark reddish brown (5YR3/4)</td>
<td>1: A1 horizon; clay</td>
</tr>
<tr>
<td>10-25</td>
<td>Red (2.5YR4/8)</td>
<td>2: AC horizon; sandy clay</td>
</tr>
<tr>
<td>25-35</td>
<td>Red (2.5YR4/6)</td>
<td>3: Decomposing floor of sascab and clay; sherds and charcoal</td>
</tr>
<tr>
<td>35-50</td>
<td>Reddish brown (2.5YR4/4)</td>
<td>4: Clay; massive; few sherds</td>
</tr>
<tr>
<td>50-55</td>
<td>Strong brown (7.5YR4/6)</td>
<td>5: Compact floor of sascab and clay; charcoal</td>
</tr>
<tr>
<td>55-70</td>
<td>Red (2.5YR4/8)</td>
<td>6: Sandy clay with gravel; massive; few sherds</td>
</tr>
<tr>
<td>70-85</td>
<td>Reddish yellow (5YR6/6)</td>
<td>7: Compact floor of sascab and clay in matrix of cobbles; charcoal and sherds</td>
</tr>
<tr>
<td>85+</td>
<td></td>
<td>Hard limestone bedrock</td>
</tr>
</tbody>
</table>

**Figura 14:** Aguada La Gónola 2010 Pozo 2: east profile.
Floors/reservoir linings were revealed at depths of 25, 50, and 70 cm; the upper floor was significantly decomposed whereas the lower two floors were still solid. These floors appear to have been associated with low boulder retaining walls, though in this place those walls have partially collapsed. The walls and floors were also exposed in Pozo 3, where these features were better preserved.

**Aguada La Gondola 2010 Pozo 3**

2010 Pozo 2 was a 1 x 2.5 m trench excavated into the berm on the northern rim of the aguada at a point about 12 m east of Pozo 2. The west profile of Pozo 3 is shown in figure 6 and described in the Table 4 below.

![Profile of Pozo 3](image.png)

**Table 4**

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Color (Munsell)</th>
<th>OM (%)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>P (ppm)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>Dark reddish brown (5YR3/4)</td>
<td>3.9</td>
<td>8</td>
<td>8</td>
<td>84</td>
<td>187</td>
<td>1: A1 horizon; clay</td>
</tr>
<tr>
<td>10-35</td>
<td>Red (2.5YR4/8)</td>
<td>2.0</td>
<td>16</td>
<td>7</td>
<td>77</td>
<td>164</td>
<td>2: AC horizon; sandy clay</td>
</tr>
<tr>
<td>35-45</td>
<td>Red (2.5YR4/6)</td>
<td>22</td>
<td>5</td>
<td>73</td>
<td>170</td>
<td></td>
<td>3: Decomposing floor of sascab and clay; sherds and charcoal</td>
</tr>
<tr>
<td>45-70</td>
<td>Reddish brown (2.5YR4/4)</td>
<td>2.1</td>
<td>11</td>
<td>7</td>
<td>82</td>
<td>201</td>
<td>4: clay; massive; few sherds</td>
</tr>
<tr>
<td>70-75</td>
<td>Strong brown (7.5YR4/6)</td>
<td>25</td>
<td>3</td>
<td>72</td>
<td>188</td>
<td></td>
<td>5: compact floor of sascab and clay; charcoal</td>
</tr>
<tr>
<td>75-115</td>
<td>Red (2.5YR4/8)</td>
<td>1.8</td>
<td>15</td>
<td>6</td>
<td>79</td>
<td>211</td>
<td>6: Sandy clay with gravel; massive; few sherds</td>
</tr>
<tr>
<td>115+</td>
<td>Reddish yellow (5YR6/6)</td>
<td>27</td>
<td>4</td>
<td>69</td>
<td>190</td>
<td></td>
<td>7: compact floor of sascab and clay in matrix of cobbles; charcoal and sherds</td>
</tr>
</tbody>
</table>
Floors/reservoir linings were revealed at depths of 35, 70, and 115 cm; the upper floor was significantly decomposed whereas the lower two floors were still solid. These floors are clearly associated with low boulder retaining walls which appear to have been embedded in the floors and likely served to help keep soil from washing into the reservoir. The lowest floor contained only Preclassic ceramics and likely articulates with the lowest floor exposed in the reservoir floor in Pozo 1. Late/Terminal Classic ceramics were recovered in mid to upper strata indicating that the reservoir had a long use history.

Aguada La Gondola 2009 Pozo 1

2009 Pozo 1 was a 1.5 x 1 m trench excavated across an alignment of large stones situated about midway up the north wall of the aguada. The trench revealed a former linear “bench” supported by a double retaining wall of large stones seated in a thick plaster reservoir liner, although much of the walls are now fallen (Figure 16). A possible interpretation of the stone alignments along the walls of the aguada is that these features were benches or steps created within the ancient reservoir so that people could more easily gain access to water as the water level within the reservoir was lowered during the course of the dry season. Weathered ceramics were recovered throughout 2009 Pozo 1.

Figure 16: Aguada La Góndola 2009 Pozo 1: west profile.

The lowermost floor (310 cm) of the reservoir produced a charcoal-based AMS date of 2040 +/- 25 B.P. (1 sigma calibrated range of 89 B.C. – A.D. 1), that is in the Late Formative, a finding consistent with weathered Sierra Red ceramics lying within and above the floor (Figure 17). The Middle Formative dates associated with the sacbé connecting the reservoir with the Xcoch Grotto that this location may have had ritual significance even before the first known floor was laid, perhaps as a natural sinkhole or pond. The floor at 230 cm depth produced a charcoal-based AMS date of 1750 +/- 45 B.P. (1 sigma calibrated range of A.D. 235 – 377), or Early Classic. The accumulation of 70-80 cm of sediment in the reservoir between these two floors show signs of a period of abandonment for which there are also indications elsewhere in the site. The exact dating of this apparent site abandonment is far from clear, but appears to have occurred towards the end of the Late Formative. The second century A.D. was a notable time of environmental
stress, including drought episodes across the Maya lowlands and witnessed site abandonments in many regions (Dunning et al., n.d.).

![Cross section of the north side of Aguada La Góndola.](image)

**Figure 17:** Cross section of the north side of Aguada La Góndola.

**Discussion**

Excavations were conducted in two aguadas at Xcoch in 2010: the large, roughly rectangular Aguada La Gondola situated west of the site core and the roughly circular and smaller East Aguada located on the east side of the site core. Both aguadas clearly functioned as urban reservoirs, with plaza pavement areas used to funnel rainwater into these depressions. The origins of the aguadas remain somewhat unclear. Either or both may have begun as natural karst depressions. Evidence in the form of apparent quarry scars on the western flank of the East Aguada as well as truncation scars revealed in the bottom of the depression by our single excavation indicate that substantial quarrying contributed to the creation of this depression before it was modified into a reservoir. It is also possible that quarrying contributed to the creation of Aguada La Gondola though we have yet to recover evidence of this activity there.

The East Aguada exhibits an apparently simple construction history with only one floor revealed in our excavation at a depth of about 155 cm. The current surface of the aguada is approximately one meter lower than the surrounding ground surface. Given the aguada’s approximate diameter of 65 m and an approximate total depth of 2.5 m, a very rough approximation of the reservoir’s
ancient water storage capacity is about: 8,300 m$^3$ or 8,300,000 liters. This capacity assumes that the reservoir was routinely cleaned of accumulating sediment. Elevated phosphate levels and sherds indicate that for at least the waning years of its use, maintenance of the reservoir in terms of cleaning was allowed to lapse and sediments accumulated.

Aguada La Gondola exhibits a more complex history with three episodes of floor construction. These floors or linings were constructed principally of a densely packed mixture of clay and sascab – a practice still in use in Yucatan today. The linings extended up the sides of the reservoir as revealed in our excavation in the low berm along the northern flank of the aguada where stone retaining walls were anchored in the floors and used to build up the berm. Although the maximum depth of the reservoir varied over time as floor and berm levels were raised over time, the average depth of the reservoir was approximately 9 meters. Given the roughly 80 x 110 m horizontal dimensions of the reservoir, an approximate estimation of its volume would be on the order of 79,200 m$^3$ or 79,200,000 liters. Using an average volume of 30,000 liters for the typical Puuc region chultun, the water storage capacity of the La Gondola Reservoir would have been equal to about 2,640 chultunes.

Terraces or benches are evident along the interior slopes of the aguada. Our excavation of one such bench on the north side of the aguada in 2009 revealed that it was constructed of roughly dressed stone, rubble and plaster. These benches are set at different elevations on each side of the aguada and likely functioned to allow access to water in the reservoir as levels dropped during the course of the dry season each year.

Mapping and excavations conducted by Michael Smyth in 2009 revealed that the large elevated plaza surface of the Great Pyramid acropolis was drained into Aguada La Gondola via a plastered sluice and canal. A large low platform was constructed immediately north of the reservoir apparently with the primary purpose of collecting rainwater and funneling this clean water into the reservoir (Figure 10).

Aguada La Gondola also clearly had a great ritual or symbolic significance for the people of Xcoch. A short sacbe connects the east side of the reservoir with the sinkhole in which is located the entrance to the Gruta Xcoch. The gruta was clearly a place of vital importance, most likely for rain god-related rituals for at least 2,000 years. At some point, the sacbe and reservoir were added as part of a ritual complex in which one can easily imagine sacred water being brought forth from the deep pool at the base of the cave and carried to the reservoir to symbolically renew the filling of the reservoir by the perceived combined actions of the shamen and rain gods. The antiquity of the reservoir’s lowest floor suggests that this ritual activity may have begun as early as

Cumulative evidence suggests that Aguada La Gondola represents a significant investment in human labor in its construction and maintenance and it obviously played an important role throughout much of the long history of urban Xcoch. This role clearly included an enduring ritual function as an element in water rituals that also involved the Gruta Xcoch, as well as a highly pragmatic function in the collection and storage of a large quantity of water in the seasonally arid Puuc region.
Xcoch and Vaca Perdida Caves

The 2010 cave project at Xcoch included Beth Cortright, Harry Goepel, Chasity Stinson, and Eric Weaver. Additional support was provided by Dr. Michael Smyth, Dr. Nicholas Dunning, Sebastian Smyth, and Eden Dunning. The primary goal in 2010 was to exhaust all possible leads at Actun Xcoch in an effort to locate speleothems for paleo-climate study and, if it was not possible to locate these at Actun Xcoch, to find a cave location in close proximity that does contain usable speleothems. The passages in Actun Xcoch that contained unexplored areas included the A, D, E, K, and H passages. The 2009 survey resulted in 120 stations with a surveyed length of 735.8 meters (2,414.2 feet). The 2010 survey added 88 additional stations for a total of 208. The total surveyed length of the cave increased by 551 meters (1,806 feet) making the cave 1.286 kilometers long (0.80 miles). While the depth of the cave did not change as a result of the new survey data, the outer perimeters of the cave did. The most southerly and furthest station from the entrance is E27 (170.5 meters, 559.5 feet). Station E27 is also the highest elevation in the cave at 47.796 meters (277.658 feet) Above Mean Sea Level (AMSL). This station is located 3.796 meters higher than the entrance to the cave. The most northerly station of the cave is now HI6.

Originally, the K passage had seemed to be the most likely passage to contain speleothems and was one of the first passages to be revisited. It very quickly diminished to a size impassable by humans and there was not enough new passage to warrant a survey of the passage to its terminus. The D Passage was explored with slightly more success. The passage was surveyed for an additional 19.6 meters and terminated in a large breakdown pile at an elevation of 37.403 AMSL. A few rocks in the breakdown pile appeared to have been carved (Figures 18 and 19).

Additionally, roots were noted at this location. A surface check of the above-ground coordinates of the cave did not find any indications of a cave entrance. There are a large number of human bones in the area at the beginning of the D passage and their locations were surveyed (Station DB1 and DB2). It was also noted that the altar at the junction of the D and E passages (Station SA1) appears to have been inverted.
The H Passage was surveyed to its terminus, which was 46.9 meters (153.9 feet) from where last year’s survey had stopped. A small assortment of speleothems were discovered in a small chamber at the terminus of the H Passage. The speleothems included stalagmites, stalactites, columns, and soda straws (Figure 20). With the exception of one soda straw, the formations did not appear to be active. Rock hammer-marks indicated that many other formations in this area had been removed by the Maya. Speleothems potentially useful for the paleo-climate research were collected.

![Figure 20]

The E Passage was the final and most eventful of the leads. Unfortunately, it did not provide any additional speleothems. The lead in the E Passage did not appear to hold much hope for expansions as the previous stopping point of the survey showed an increasingly lower ceiling with a relatively steep incline. However, further exploration resulted in the discovery of a significant amount of new cave passage. The total passage surveyed was 397.8 meters (1305 feet). The passage is very distinct from the rest of the cave in that it is comparatively larger, the air quality better, the temperature much cooler, and there is significant air movement present. While it is evident that the Maya had used this passage, there is no evidence of the same kind of ritual usage that is present in the rest of the cave. No evidence of footprints were encountered during the survey and few torches fragments were found as well as vines that may have been used to wrap torches. A few ceramics were located in the passage. The most prevalent sign of past usage was large cairns used to mark off the maze of side passages (Figure 21). The presence of the cairns is interesting as they do not appear elsewhere in the cave and their function is unclear.
Charcoal was noted in various areas of the E passage. Toward the terminus of the main passage in E and EK, it was evident that the floor was coated with a layer of charcoal. The E Passage is also interesting because it terminates several meters higher than the current entrance to the cave. This strongly suggests that the E Passage once had an entrance to the surface that may now be buried. This observation is further reinforced by the presence of a termite nest (Figure 22) as well as some leaves noted on the passage floor.

Using the coordinates based on the cave survey, a surface examination of the area was conducted. A ground feature was noticed in close proximity to the EK and E junction. This feature is a significant depression that appears to be ringed with shaped boulders. Later in the week, several workers were dispatched to attempt to locate an entrance to the E Passage by
digging in the surface feature (Op. 22, below). While a physical connection was not made with the surface, communication was established indicating very close proximity of the workers digging from the surface to the surveyors in the cave. Nick Dunning collected soil samples in the E Passage. One sample was taken near E17 (Station N1) and the other was taken at station E24.

Survey data for the cave was collected using Suunto instruments and fiberglass tape/Leica A3 for cross-section heights using standards derived from the Cave Research Foundation. La Cueva de la Vaca Perdida (discussed below) was surveyed using a DistoX. The above mean sea level elevations were derived from an electronic altimeter calibrated with a GPS altimeter to give an expected accuracy of +/- 3 meters. Calibration of the altimeter was done at a known elevation in Cancun. Depth data is also presented based on local depth starting at 0 meters. The zero datum for Actun Xcoch was established at the base of a tree at the top of the sink (44 meters AMSL). Zero datum was established at Cueva de la Vaca Perdida at the base of a tree at the top of the pit.

The other cave visited was named Cueva de la Vaca Perdida (Cave of the Lost Cow). The cave is 11.04 kilometers due east of Xcoch Cave. It was surveyed for a total length of 85.8 meters (281.85 feet). The depth of the cave was 32.1 meters (105.4 feet) and begins with an eight meter drop into a large chamber (Figure 23).

![Figure 23](image)

The upper layer of the cave consists of two primary chambers. The second chamber was separated from the first by a breakdown pile of massive boulders. The connection to this second chamber is a steep slope that traverses past a large breakdown pile. There appears to be a built-up wall next to steps cut in the floor to help negotiate the steep incline. Small quantities of ceramic sherds were noticed in the second chamber and have been identified as Yokat Striated and Chemax slateware water jars as well as sherds of a Chemax slateware bowl dated to the Late and Early Classic periods. An associated wood charcoal specimen produced an uncalibrated radiocarbon dated of AD 320 +/-30. Additional ceramics were found in an alcove that was only accessible by climbing a flowstone wall. A pila was found in the second chamber and it was included in the survey as Station A6Pila (Figure 24).
Near Station A8 was a second eight meter drop that was not explored due to time constraints. Safe descent of this pit will require placing bolts in order to rig a rope. A significant amount of airflow from the pit suggests a large amount of passage beyond. A coating of gypsum trails down a flowstone feature that stretches the entire length of the pit. Water drips from the formation approximately halfway down the pit and can be seen pooling at the bottom.

This cave once had a heavy concentration of speleothems; however, it appears that the majority of formations have been removed or damaged by the Maya. Three speleothems were found that appeared usable for the paleo-climate study (below). One was in the transition area between the first and second chamber (A1C), the other two (A6Dspeleo and A7) were in the second chamber. All of the formations were active. The formation A1C (names are based on survey station) is a short, stout formation that had calcified over a dirt floor, which allowed the base to stay intact. It was 22.641 meters from the entrance and 4.8 meters from the ceiling located at 67.564 AMSL and -7.417 meters from our zero datum point (top of pit entrance). A6Dspeleo was the longest speleothem collected. We were successful in removing this formation at its base. It was located 4.1 meters below the ceiling and 59.201 meters from the entrance. This speleothem appeared to be the most active, evidenced by a white calcite cap and water droplets. It is rather surprising that this speleothem had been left by the Maya. It was 58.729 meters AMSL and -16.252 meters below zero datum. The final speleothem, A7, was a broomstick stalagmite that was precariously perched on the edge of a massive boulder. While attempting to remove the speleothem, it broke 4.8 centimeters from the base during the extraction process. It was also an active formation and was 3.2 meters from the ceiling. It was located at 55.101 meters AMSL (-19.881 meters from zero datum) and 55.58 meters from the entrance.

Another goal of the project was to locate significant artifacts and ceramics in Actun Xcoch. The locations were added into the survey and, when necessary, removed for further study. There were several new discoveries. A pila was noticed in the A Passage at Station A11. It was designated as Station MU1. After a heavy rainstorm, it was noted that the water that came in from the entrance drained directly to the pila. Within this vicinity, in close proximity to Station A10, two apparent protoglyphs were scratched in the ceiling and photographed and then sketched by Nick Dunning. What appears to be a wooden beehive was discovered in a small side passage adjacent to the large room in the A Passage at Station A14 (Figure 25). This survey location was at
Station BH2. Nearby, a Teotihuacan hollow slab support was recovered and is identified as Hunabchen Naranja, an Early-Middle ceramic likely of foreign origin (Figure 26).

Another goal of the project was to locate significant artifacts and ceramics in Actun Xcoch. Artifact locations were added into the survey and, when necessary, removed for further study. There were several new discoveries. A pila was noticed in the A Passage at Station A11 and was designated as Station MU1. After a heavy rainstorm, it was noted that the water that came in from the entrance drained directly to this previously unnoticed pila. Within this vicinity, in close proximity to Station A10, two apparent protoglyphs scratched in the ceiling were photographed and sketched by Nick Dunning. What appears to be a wooden beehive was discovered in a small side passage adjacent to the large room in the A Passage at Station A14 (Figure 25). This survey location was at Station BH2. Nearby, a Teotihuacan hollow slab support was recovered and is identified as Hunabchen Naranja, an Early-Middle ceramic likely of foreign origin (Figure 26).

The room connecting the A Passage (Station A15) and the H Passage (Station H1) revealed a significant amount of pottery and bones underneath a large rock. This area was designated as the CC Survey. The bones of at least one child and infant were located in this area (Station CC2). A large circular ornament identified as hematite mirror was also found in this location atop on substantial amount of wood charcoal and beneath several large Yokat Striated sherds (Station CC3). The apparent ritual offering shows burning and an uncalibrated radiocarbon dated of AD 700 +/-24.

In the H Passage, an obsidian blade discovered during the previous year was relocated and collected between Stations H3 and H4. Several rounded out areas in the rock floor provided ceramic and charcoal samples, which were brought out of the cave for further analysis. Ceramics were also collected at a location between Stations A12 and F1 and nearby human bones were located and identified during the survey (Station AB1).

Material collections were made in the lower cave chamber containing the water source near Stations A38 and A39. These collections focused on specific areas of interest: a fire pit, a stone basin (perhaps a metate), and the water source. Charcoal samples also were taken from the fire pit (Figure 27). Significant quantities of ceramic sherds was removed from the area as well.
These samples provided a number of painted ceramic pieces, among them including Chac polychome and Chemax slateware jars as well as Preclassic diagnostics. Additionally, an attempt was made to assess the depth of the ceramic deposits in this area (Figure 28).

The antechamber that housed the stone basin (Station A34B) provided several interesting artifacts. A circular stone was found that may represent a griddle, or comal. Close to the circular stone, a decorated tube-like item with incised decoration was found that appears the an ultra thin rim portion of a blackware (Dzitya negro) miniature vessel. Incised decoration near the top of the rim shows a horizontal line circumventing the rim and three connected u-shaped design with vertical lines dangling from the top and may be a motif representing a cave. A second incised line is below that shows three sets of two inverted curved lines that do not intersect that may be water symbols resembling grecas. Near the miniature vessel rim were a piece of coral and shell. These items appear to be components of a necklace. Quantities of ceramics was also removed in this area. The water source (Station A38) was also sampled with surface collections. One brown ware sherd from large bowl or basin shows a blackline painted fish motif that has not been identified but may be a Preclassic ware.

It would appear that the survey has exhausted all leads at Actun Xcoch in regards to the search for speleothems (Figures 29a-d). There remains a wealth of information contained within Actun Xcoch that can help us understand its connection with the surface architecture and the utilization of the cave by the Maya. It is amazing that a cave that contains so many archaeological resources could be so well known, but yet so largely ignored. This brings about the question what other caves in the area, known and unknown, may contain. La Cueva de la Vaca Perdida is another example of a previously unknown cave that is not even known by most local residents. It was only explored in the last days of the project because of the limited success at Actun Xcoch in obtaining speleothem samples for the paleo-climate study. At La Vaca Perdida we had great success in locating and obtaining speleothems; additionally, it was discovered that the ancient Maya had reached this cave despite the 8 meter drop at the entrance pit. A second 9 meter pit was discovered during the survey. The mouth of the pit had a glowing, white calcite crust coating a flowstone formation that stretched to the floor of the pit. Water continuously dripped from the flowstone into pools of water and a strong, cold wind bellowed out. The surveyors were certain
that this pit had also been negotiated by the Maya. As time was limited and the primary goal to obtain speleothems, this intriguing pit had to be left unexplored.

Figure 29a: Map of Cueva la Vaca Perdida.

Figure 29b: Profile of Cueva de la Vaca Perdida with station number, elevation, and distance from entrance.
Figure 29c: Profile of Cueva de la Vaca Perdida with walls, station number and elevation.

Figure 29d: Lineplot of Actun Xcoch that includes the 2010 data.
Stratigraphic Excavations

Test pit operations (Op.) consisting mostly of 2 x 2-m units were excavated in levels following natural or cultural stratigraphy in architectural contexts at many settlement localities across Xcoch (Figure 1). Most excavations produced typical Cehpech ceramics (800-1000 AD) in the upper levels. Nevertheless, significant quantities of ceramic diagnostics such as Late-Middle Classic Motul (600-800 AD), Early Classic Cochuah (300-600 AD), and Preclassic Mamom and Tihosuco complexes (800/700-400/300 BC) were found in stratigraphic association with early architecture. Excavation data supported by radiocarbon dating clearly demonstrate that Xcoch had a large occupation during the Preclassic period.

Stratigraphic excavations continued in 2010. Ops. 24, 25, and 27 sampled a settlement area known as the Cuevas Groups located about 500 m southeast of the Great Pyramid (Figure 3). Stucco floors surfaces were found in Op. 24 adjacent to a conical altar and in all units Cehpech ceramics predominated with moderate amounts of Early Classic wares in the lower levels. Ops. 26 and 30 sampled the Chikin Mul Group and probed the platform center and south retaining wall (Figure 4); both units contained significant quantities of Preclassic diagnostics within architectural fill. Ops. 29 and 31 were deep stratigraphic cuts between the Chich platform and the north berm of the Aguada La Gondola. Op. 29 clearly showed that the Chich Platform's cobblestone surface slopes southward towards the aguada and was constructed upon a prepared surface composed of a >1 m layer of finely sifted, compacted red kancab soil. Op. 31 revealed a 15 m stone-free zone between the Chich Platform and the aguada berm that consists of a thick layer of red kancab-alkache clay lining mottled with white sascab. This clay lining, identical to the lining found inside the aguada, was very hard and water tight and clearly engineered to seal the ground surface so rainwater could flow parallel to the aguada berm and discharge into the aguada at its corners; there is no evidence of any drain hole or sluice gate penetrating the north berm wall. In both units Cehpech ceramics predominate in the upper levels but Preclassic wares associate with the lower levels suggesting that both features were originally Preclassic constructions.

Ops. 33 and 34 sampled the platform surface immediately south of the Xcoch Grotto, an area forming a terminus for the West Sacbe (Figures 30a-b). These units produced a wide variety of Preclassic to Postclassic ceramics, most notably water jar and incense burner forms, including Early Classic Chac Polychrome, and Postclassic Chichen and Mayapan diagnostics. Ops. 36 and 37 sampled the West Sacbe itself about 50 m west of the Gruta to show that this causeway was constructed during the latter part of the Preclassic period (Figures 312a-b). Sacbe fill was superimposed upon three preserved stucco floors associated with Middle Preclassic potsherds as well as marine shell and serpentine flakes. A wood charcoal sample taken from beneath the lowest stucco floor dated to 640 B.C. (Table 5). These data indicate the space adjacent to the cave was paved even before the Preclassic construction of the West Sacbe and part of a west extension of the Great Acropolis.
Ops. 35, 38, and 39 were probes into the plaza surfaces east and southeast of the Grand Platform. Two units, Op. 35 and 38, were placed to the west of two pyramid structures that are part of the settlement zone known as the Eastern Elite District (Figures 32a-b and 33a-b). Both pyramid contexts contained numerous stucco floor surfaces. Op. 38 had two stucco floors while Op. 35 produced five stucco floors set upon leveled bedrock with 2-3 m layers of large and medium size boulders and cobblestones. Ceramics indicate that the upper floors date to the Late-Early Classic periods while the lowest floors and original plaza surfaces were Preclassic. A wood charcoal sample below Floor V of Op. 35 produced a radiocarbon date of 570 +/- 30 BC (Table 5). Indeed, it seems that both pyramids were probably Preclassic structures with only the northeast pyramid (Op. 38) showing later reutilization in the form of a vaulted temple building erected on its summit. The southeast pyramid (Op. 35) supported some form of non-vaulted roof building. Op. 39 sampled the edge of the Grand Platform's southwest wing and it too produced quantities of Preclassic diagnostics.
Op. 41 was a 2 m wide trench extending from the cave entrance to 12 m west (Figure 34). This trench exposed the original descending staircase that, surprisingly, shows many of its original megalithic treads and risers in situ and still usable as an access into the cave itself. Clearly, there must have been a U-shaped megalithic stairway integrated into three sides of the depression or sinkhole descending into the cave entrance. Because of the downsloping surface, the thousands of the ceramics recovered, have little stratigraphic integrity. Preclassic to Postclassic sherds and even some modern debris, however, demonstrate that this water cave has been continuously visited over the past 3000 years, if not earlier.
Ops. 42 sampled the Old Pyramid Group’s pyramid platform on the west and Op. 43 probed the north side of the Chac-Na Group's Proto-Puuc building. Op. 42 produced no recognizable floor surface but plenty of Preclassic ceramic diagnostics associated with unusual foundation stones set as upright boulders. It seems likely that the pyramid and its associated platform as well as many of the house foundations are Preclassic, though there was clearly a substantial Late Classic reoccupation. The Chac-Na operation (43) recovered an Early-Middle Classic Say slateware chultunera buried deep within level 1 that must have been a dedicatory offering for the nearby Proto-Puuc building (Figures 35a-b). Associated with the chultunera were a number of Early Classic diagnostics and a preserved stucco floor below. This stucco floor yielded pure Preclassic pottery and strongly suggests that much of the Chac-Na group was built upon a Preclassic basal platform.
Figuras 35a-b: Photos of the Chac-Na building, Op. 43, and a Early Classic Say Slateware chultunera offering.

Ceramic Analysis

The 2006, 2009, and 2010 field seasons at Xcoch recovered 53,934 ceramic sherds that were analyzed using the type-variety classification system, employed by most Maya ceramists in the Yucatan during the last four decades. Adapted for the identification and comparison of analytical units from different sites, this system allows one to infer cultural relations between different sites of the Maya area through time (Sabloff 1975: 3; Robles 1990:25). Modified type-variety classifications and formal ceramic analysis employed at Sayil, Chac II, and now Xcoch are also designed to extract behavioral information from analyzed pottery using surface collections and test excavations. In addition to ceramic types, which can provide the relative age and cultural affiliation, the ceramics are also classified according to vessel type which provide vessel form assignments and functional information on vessel assemblages related to cooking, serving, and storage activities.

In most excavations the ceramics recovered near the surface are identifiable as typical of the Cehpech ceramic complex of the Late–Terminal Classic period including Yocat striated, Muna slate, Ticul thin, Teabo red, and Holactun. There are, nevertheless, significant numbers of Early Classic types including polychromes such as Chac, Timucuy, and Dos Arroyos within the middle levels. In almost every test pit, the lower levels produced Preclassic diagnostics such as Chancenote striated, Chunhinta black, Joventud red, Sierra red, Dzudzuquil cream to buff, Muxanal red on cream, among others. Within the Xcoch cave, there are the remains of at least three large hemispherical vessels with cylindrical monopod supports and long narrow necks identified as Yotolin Patterned Burnished, among the earliest ceramics of Yucatan, (Brainerd 1958; Smyth and Ortegón 2008). There is no agreement on the dating of these mysterious ceramics only found near Mani, Sacalum, Loltun Cave, Tzucacab, and now Xcoch. It it is largely
agreed, however, that Yotolin Patterned Burnished dates to the early Middle Preclassic thought some have argued for an Early Preclassic date (Brainerd 1958; Folan 1968; cf. Andrews V 1990). Its finding underneath the Cave Pyramid in the middle of a Preclassic center is very significant and importantly suggests that the producers and the consumers of this early ceramic ware lived nearby.

The presence of early ceramics in many surface units cannot be a random pattern. The surface survey collected 14,067 sherds from 869 3x3 m collection units resulting in an average of 16.2 sherds per collection unit. As expected, most surface ceramics are of the Cehpech complex; almost all are Yokat striated and Muna slate types without decoration and there are few fine paste wares (150 sherds or ~ 1%). This pattern is very unusual given the fact that the majority of the collections have come from in and around the central monumental zone of Xcoch, including the Eastern Elite District and the North Brecha where there is much monumental architecture. These same kinds of contexts produced significant quantities (~5%) of fine paste ceramics in the previous surface surveys of Sayil and Chac II (Smyth et al. 1995; Smyth et al. 1998). Also at Xcoch, the frequencies of Muna slate are greater than the frequencies of Yokat striated (water jars). At Sayil and Chac II, and presumably other major Puuc sites, Yokat striated comprises more than 60% of all the ceramics found on the surface. So far, Early Classic and Preclassic ceramics at Xcoch are found within 32 different surface units and, approximately 1 Preclassic sherd for every 43 squares. These surface patterns suggested a major Preclassic occupation during the 2006 season (Smyth and Ortegañon 2008) and have been absolutely confirmed by test excavation and radiocarbon dating in 2009 and 2010. Indeed, the surface survey at Sayil produced very few Preclassic ceramics within 5,261 squares and at Chac II there were no Preclassic sherds from 3,970 collection units.

The stratigraphic test pits at Xcoch collected 53,910 sherds many associated with stucco floors, architectural stratigraphy, and wood charcoal samples. Within upper level contexts (Late Classic), a total of 46,539 sherds (86%) were recovered, though a certain percentage may be transitional types such as Yokat striated that may have begun in the Early Classic period. However, 5,128 Late Classic sherds came from Chultun 2 (Op. 15) and 5,527 sherds were from the Gruta Xcoch staircase trench (Op. 41) and because of considerable mixing of these deposits skew representative ceramic samples at the site level. Removing the ceramic totals from Chultun 2 and the cave trench leaves 3,317 sherds (9%) in the middle levels diagnostic of the Early-Middle Classic periods. In the lowest levels Preclassic 3,410 sherds (10%) of which the majority appear to be Middle Preclassic were recovered. These data show that the center of Xcoch had a significant occupation during Middle Preclassic, a time when many of the site's largest monuments were constructed or at least initiated. In most test pits clear hiatus zones are seen between the upper and lower levels indicated a general site abandonment at the end of the Late Preclassic period. The ceramics also suggest that site was reoccupied later in the Early Classic period. In fact, both ceramic and architectural data converge to show Preclassic occupation at nearly all settlement areas covered by survey or almost 1 square kilometer. Excavations at Xcoch also have been attuned to identify Preclassic ceramic diagnostics comparable to Early and Late Nabanché phase (Xanilá Complex) materials. In addition to Yotolin Pattern Burnished, long-neck monopod water jars, like those found in the Xcoch cave (above), other early diagnostic forms encountered at Xcoch include temocates (neckless hemispherical jars) and
everted, outward-sloping flanged bowls typical of early Nabanché ceramics at Komchén on the northern coastal plain. The ceramic analysis, of course is a work still in progress.

**Radiocarbon Dating**

Twenty-eight wood charcoal samples were submitted to the National Ocean Accelerator Mass Spectrometry Facility (NOSAMS) for radiocarbon dating in 2009 and 2010 (Table 5). These samples were recovered from Ops. 4-8, 15, 26-27, 32, 35, 36, the South Aguada, the Gondola Aguada, the East Aguada, the Gruta Xcoch, and La Vaca Perdida Cave (11 km east). Four samples are modern or Historic and are likely the result of contamination, four are Colonial, seventeen samples were prehispanic, and two samples are in progress. The most notable were seven Middle Preclassic dates from the lower levels of the Grand Platform, Xcoch Plaza, the Grupo Residencial, the East Pyramid Plaza, and the West Sacbe, all associated with Middle Preclassic diagnostic ceramics. These dates clearly show that much of the central architecture at Xcoch was constructed between the 5th and 8th centuries BC and represent among the earliest and largest monumental constructions in northern Yucatan. A Late Archaic to Initial Formative date came from deep within the Chikin Mul platform (Op. 26). One Late Preclassic date is from the La Gondola Aguada. Four Early Classic dates were associated with the La Gondola Aguada, South Aguada, Chultun 2 (Op.15), and the Vaca Perdida cave, a time when Xcoch was being reoccupied after initial abandonment in the Late Preclassic period. Three Postclassic dates from the Gruta Xcoch indicate that the cave was still being visiting long after major site abandonment in the Terminal Classic. No radiocarbon assays so far date to between 800 and 1000 AD, a finding that is consistent with the lack of certain Terminal Classic diagnostic ceramics at the site.

Table 5: Radiocarbon dates from Xcoch, Yucatán. All dates were calculated using the Accelerator Mass Spectrometer (AMS) technique from the National Ocean Accelerator Mass Spectrometry Facility (NOSAMS) and the Calib Radiocarbon Calibration Program.

<table>
<thead>
<tr>
<th>Field Specimen</th>
<th>Lab Num.</th>
<th>Conventional NOSAMS C-14 Age BP</th>
<th>Uncalibrated Calendar Date</th>
<th>Calibrated C-14 BC/AD (2 sigma, 96% probability)</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>20013</td>
<td>78754</td>
<td>1460+/-.25</td>
<td>490 AD</td>
<td>560-646 AD</td>
<td>Aguada S, Pozo 1(200 cm)</td>
</tr>
<tr>
<td>20020</td>
<td>78755</td>
<td>305+/-.30</td>
<td>1645 AD</td>
<td>1488-1603 and 1609-1651 AD</td>
<td>Aguada Gondola, Pozo 2 (100 cm)</td>
</tr>
<tr>
<td>20045</td>
<td>78756</td>
<td>2520+/-.30</td>
<td>570 BC</td>
<td>716-792 and 593-695 BC</td>
<td>Grand Platform, Op. 4, Lev. 6 - Piso V</td>
</tr>
<tr>
<td>20046</td>
<td>78757</td>
<td>2550+/-.30</td>
<td>600 BC</td>
<td>743-800, 663-689, and 549-647 BC</td>
<td>Grand Platform, Op. 4, Lev. 7 - Piso VI</td>
</tr>
<tr>
<td>20076</td>
<td>78761</td>
<td>330+/-.25</td>
<td>1620 AD</td>
<td>1483-1641 AD</td>
<td>Grp. Residencial, Op. 8, Lev. 3 - Piso II</td>
</tr>
<tr>
<td>20078</td>
<td>78762</td>
<td>Modern</td>
<td></td>
<td></td>
<td>Grp. Residencial, Op. 8, Lev. 5 - Piso IV</td>
</tr>
<tr>
<td>20088</td>
<td>78765</td>
<td>625+/-.25</td>
<td>1325 AD</td>
<td>1291-1331, 1338-1397 AD</td>
<td>Chultun 2, Op. 15, Lev. 4 (270 cm)</td>
</tr>
<tr>
<td>20089</td>
<td>78766</td>
<td>1420+/-.30</td>
<td>530 AD</td>
<td>581-660 AD</td>
<td>Chultun 2, Op. 15, Lev. 5</td>
</tr>
<tr>
<td>20124</td>
<td>84303</td>
<td>1750+/-.45</td>
<td>200 AD</td>
<td>139-160, 165-196, 209-398 AD</td>
<td>Aguada Gondola, Pozo 1 (230cm), Lev. 5</td>
</tr>
<tr>
<td>20126</td>
<td>84304</td>
<td>2040+/-.25</td>
<td>90 BC</td>
<td>135-159, 114 BC-24 AD</td>
<td>Aguada Gondola, Pozo 1 (310cm)</td>
</tr>
<tr>
<td>20131</td>
<td>84305</td>
<td>Modern</td>
<td></td>
<td></td>
<td>E. Aguada, Lev. 2</td>
</tr>
<tr>
<td>20168</td>
<td>84307</td>
<td>1280+/-.30</td>
<td>670 AD</td>
<td>662-779,794-801 AD</td>
<td>Grp. Cuevas, Op. 27, Lev. 7</td>
</tr>
</tbody>
</table>
Speleothem Analysis

The speleothem paleoclimate reconstruction component of this study attempted to provide a more detailed understanding of the variability of precipitation for the Xcoch and Puuc Region of the Yucatan, Mexico. As mention above, the Terminal Classic Period, 800-950 C.E. or 1200-1050 year BP (before present) is the time span of interest. The BP chronological terminology will be used hereafter. In 2010 speleothems were initially collected from Xcoch Cave below the archaeological site. Upon closer examination, these formations were found to be portions of stalactites and other secondary calcite deposits which could not be used for the paleoclimate reconstruction. After corresponding with Dr. Michael Smyth, new speleothems were collected from a nearby cave, the Vaca Perdida (VP). These three stalagmites were of varying length and the two most complete speleothems were selected for the paleoclimate study. The samples were then analyzed for their periods of deposition and stable isotope composition. It was hoped that this analysis could shed light on how potential abrupt precipitation changes, such as prolonged droughts, for this particular site may have been partially responsible adding pressure to the Maya people of this region.

Figure 36 (1) below shows the location of the Xcoch study area in the Yucatan Peninsula, Mexico. The other locations shown are either other archaeological sites or where paleoclimate studies have been conducted. Of particular interest are the Tecoh Cave and Lake Chichanacanab sites which will both serve as records that will help create a chronology for our speleothem record and its interpretation.

Methods

Sample Selection

The two stalagmites, VP-10-1 and VP-10-2 were collected from Vaca Perdida Cave which is ~11.04 km east of Xcoch Cave. The cave is entered through an 8 m shaft which ends in a large chamber where many of the speleothems had been removed or damaged by the Maya. These two formations appeared to be active in that water was dripping of their terminuses. VP-10-1 is ~450 mm in length and was located 60 m from the entrance and appeared to have recent deposition as evidenced by the presence of a white calcite cap and water droplets. VP-10-2 is a boss stalagmite ~ 150 mm long and was collected 23 m from the entrance. In the laboratory each
speleothem was cut along its c-axis, and then polished. Fourteen and seven 300 mg samples of calcite were removed along each growth axis of VP-10-1 and VP-10-2 respectively, using a computer-controlled micro-drill equipped with a dental burr. These samples were then analyzed for their ages using U-series dating (see below section). The same micro-drill was then used to remove 200 μg samples at 5 mm intervals along the growth axis for each speleothem. These were needed for stable isotope analysis.

Figure 36

**Dating Techniques**

Uranium series dating techniques, specifically $^{234}$U-$^{230}$Th, were used in order to determine accurate dates for each speleothem and completed at the Radiogenic Isotope Laboratory at the University of New Mexico. 50-150 mg of carbonate powder for the samples were dissolved in nitric acid and spiked with a solution of $^{233}$U and $^{229}$Th of known concentration. These were then dried, redissolved in nitric acid and perchloric acid. The samples were again dried, dissolved in nitric acid, and added to anion resin columns to separate the thorium and uranium. Once separated, the thorium and uranium from each sample was run through the ICP-MS. Due to the low counts of $^{234}$U and $^{230}$Th, the more sensitive SEM is used to measure the amounts of these isotopes.

**Stable Isotope Measurements**

Once the calcite samples were collected from the speleothems, they were weighed to ~200 μg for stable oxygen isotopic analyses. The calcite was then placed in individual reaction vessels, subjected to anhydrous phosphoric acid in the Keil III carbonate-extraction system coupled to a
ThermoFinnigan DeltaPlus XL mass spectrometer. The standard used with conjunction with the cave calcite was the NBS-19 standard which allowed a precision of <0.1‰.

Results

*U*-series dates

The ICP-MS ages for each speleothem are given in Table 6. Despite the best efforts of Anna Leech (my research assistant) and Dr. Victor Polyak (UNM), accurate ages for the speleothems could not be obtained. However, the top and base dates for VP-10-1 appeared to be usable due to the low detrital Th and the fact that they were chronological order. The top date for this speleothem also agreed with the top date of VP-10-2, hence this was used for the date that the speleothems cessation of deposition. The construction of the age model for VP-10-1 was simply based on the linear interpolation between the top and base dates. This age model was then used to create a time series for the VP-10-1 stable isotopes values (see Figure 37(2). With the poor chronological control, a comparison to another, well dated, nearby speleothem record (Tecoh Cave, Medina-Elizalde et al. 2010) was used to help constrain our age model.

Table 6. ICPMS ages for VP-10-1 and VP-10-2.

<table>
<thead>
<tr>
<th>Speleothem</th>
<th>Distance from Top (mm)</th>
<th>Age (yr BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VP-10-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>589± 224</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>278± 273</td>
</tr>
<tr>
<td></td>
<td>57</td>
<td>-2± 364</td>
</tr>
<tr>
<td></td>
<td>91</td>
<td>2791± 1746</td>
</tr>
<tr>
<td></td>
<td>121</td>
<td>-6363± 5293</td>
</tr>
<tr>
<td></td>
<td>140</td>
<td>1703± 221</td>
</tr>
<tr>
<td></td>
<td>173</td>
<td>2346± 327</td>
</tr>
<tr>
<td></td>
<td>182</td>
<td>975± 232</td>
</tr>
<tr>
<td></td>
<td>217</td>
<td>801± 262</td>
</tr>
<tr>
<td></td>
<td>257</td>
<td>816± 218</td>
</tr>
<tr>
<td></td>
<td>339</td>
<td>551±476</td>
</tr>
<tr>
<td></td>
<td>425</td>
<td>449±346</td>
</tr>
<tr>
<td></td>
<td>435</td>
<td>811±144</td>
</tr>
<tr>
<td></td>
<td>450</td>
<td>2026±387</td>
</tr>
<tr>
<td>VP-10-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>580± 88</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>-19607± 9306</td>
</tr>
<tr>
<td></td>
<td>58</td>
<td>1616± 1242</td>
</tr>
<tr>
<td></td>
<td>89</td>
<td>-14644± 9715</td>
</tr>
<tr>
<td></td>
<td>106</td>
<td>319± 156</td>
</tr>
<tr>
<td></td>
<td>127</td>
<td>298± 99</td>
</tr>
<tr>
<td></td>
<td>153</td>
<td>1677± 215</td>
</tr>
</tbody>
</table>

*Oxygen isotope record for VP-10-1*

Figure 37 (2) show the time series for the oxygen isotopes for VP-10-1. The $\delta^{18}O$ values for speleothems in the tropics and this region have been found to record changes in precipitation. The cause of this variability in the $\delta^{18}O$ is due to the amount effect (Lachniet et al. 2004). Consequently, more (less) depleted values in the speleothem are indicative of wetter (drier) conditions. As found in the speleothem c-axis profile, there were numerous hiatuses in the top third of the speleothem. The more prominent of these are marked on Fig. 37 (2). $H^2$ and $H^3$ are
two very pronounced events where two and three hiatuses occurred in rapid succession. Cessation in deposition is normally induced by drought conditions.

Comparison with other Yucatan paleoclimate records
To check the accuracy of the VP-10-1 chronology and our reconstruction of precipitation variability, two different proxies were used. The first is a speleothem record from Tecoh Cave (Chaac δ¹⁸O record, Fig. 38(3)a) which is north of our field site (Figure 36(1)). Once again, the Chaac δ¹⁸O isotopic values are interpreted as wetter conditions. Both speleothems, VP-10-1 and Chaac, are plotted on the same y-axis and possess not only very similar δ¹⁸O values but also similar amplitudes. Consequently, our linear interpolation for VP-10-1 appears to be quite accurate when compared to the well dated Chaac chronology. Any differences in the timing of abrupt changes in the δ¹⁸O values can be attributed to the frequent hiatuses in our speleothem, differing growth rates and data resolutions between each record. The Lake Chichanacanab δ¹⁸O record (Hodell et al. 2001) further solidifies both the accuracy of our chronology and our precipitation reconstruction (Fig. 38(3)b).
Terminal Classic Period (TCP)

The TCP is of great interest to paleoclimatologists since it was suggested that major droughts may have contributed to the Maya collapse during this interval. Medina-Elizalde et al. (2010), while not being the first study to investigate this question, has the most detailed and quantitative analysis of this period to date. The authors demonstrated the possible impact of decreasing precipitation on the Maya society in their region of the Yucatan. They suggest precipitation may have been 300 mm below the long term average for their region (Figure 39(4)).
A subsection of the Chaac speleothem record is highlighted in Figure 39(4) showing precipitation changes for the Tecoh Cave region during the TCP. Medina-Elizalde et al. (2010) detailed depiction of the TCP demonstrates both rapid changes in precipitation and pronounced droughts, which coincide with pivotal demographic changes for the Maya. One overlying objective of this study is to determine whether these abrupt shifts in precipitation shown above were local or more widespread. Precipitation amounts in the Yucatan can vary greatly, even across relatively short distances. In addition, even if the same climate shift occurred across the Yucatan, would its magnitude be uniform or vary locally? For example, could a locale in the...
same geographic area, such as the Yucatan, experience a different magnitude of change in rainfall compared to another?

In a preliminary attempt to address these questions, Figure 40 displays the Chaac reconstruction of precipitation compared to that of VP-10-1. It is readily apparent that there is a great difference in the resolution of data between the two records. However, there are still several pertinent observations that can be made from this comparison. First, the major changes in precipitation measured at Tecoh Cave (Chaac), especially the prominent droughts, are also found at Vaca Perdida (VP-10-1). Second, the magnitude of change in rainfall at Vaca Perdida appears to be somewhat subdued when matched with the Chaac record. However, it should be noted that this observation may simply be an artifact of the lower resolution of the Vaca Perdida speleothem record.

Summary

The preliminary nature of this pilot study must preclude any definitive conclusions about the magnitude and timing of precipitation changes at the Vaca Perdida region of the Yucatan over the last 2000 years. The low resolution of the oxygen isotopic record and the issues with the chronology are two major reasons for this tentative approach. However, if the observations outlined in this report have some validity, then an expanded study is warranted. This could entail a higher resolution stable isotope record, possible $^{14}$C dating constrained by the two reliable U-series dates, and even investigating the possibility of annual laminae in the speleothem. This last
mode of study can help to create greater precision for the chronology, a technique long undertaken in dendrochronology. There are very clear laminations throughout the speleothem. Consequently, although there are obstacles to overcome, further study may well show subtle, yet potentially important differences in climate change in the Yucatan Peninsula.

Discussion

The beginnings of sedentary farming communities, complex societies, and early community organization in the Puuc region are being be addressed by the multidisciplinary work at Xcoch and vicinity. Multiple data sources are helping identify patterns of Preclassic chronology, community structure, and culture process: indigenous development versus in-migration or some combination thereof. We believe that there is evidence at Xcoch for in-situ development of key northern ceramic traditions but in-migrations of outside traditions and the people that they represent cannot be ruled out at this point. Multiple data sources are addressing Middle Preclassic community organization for the Puuc hills region by documenting contextual information on architecture and reconstructing the settlement and artifact landscapes across Xcoch. The survey data indicate that the site was indeed a large Preclassic Maya center as supported by the presence of megalithic monumental architecture and Preclassic ceramics. Similar finds at other Puuc sites such as Kiuc, Hunitchmul, Paso de Macho, and Xocnaceh show evidence that sedentary farming communities were already established in the Puuc region (Robles Castellano and Andrews 2003; Bey 2006). With the possible exception of Xocnaceh, which may have been a special purpose center of religious significance, these sites, however, are not regional centers as some researchers have been argued for the site of Xtobó in northwest Yucatan (Anderson 2004); Xcoch may have been a Preclassic center for the Puuc hills of special importance because it contained one of the three known water-bearing caves in the region. Other early sites such as Komchen, Dzibilchaltun (El Mirador Group), and Poxila to the north, Xtobó to the northwest; Yaxuná, Izamal, and Acanceh to the east, Oxlintok and Siho to the west, and Edzna and Santa Rosa Xtempak to the southwest imply the existence of a Preclassic regional settlement hierarchy across Northern Yucatan that included the Puuc hills.

Water is a vital resource in the Puuc region and aguadas and other hydraulic features for water retention or the lack thereof may have fundamentally shaped the development of Maya culture as well as it demise during certain periods of Maya prehistory (e.g. Dunning 2003a; Ford 1996; Harrison 1993; Scarborough 1993, 1998; Wahl et al. 2007). Xcoch is providing important new environmental data on climate change, especially rainfall, as a site that experienced a long occupation and appears to have been a major Maya center with massive monumental architecture as early as the Middle Preclassic period and was based upon an agricultural economy with complex social organization until the Late Classic period. Xcoch is particularly well suited to investigate climate change because of its long span of occupation and because it appears to have experienced multiple collapses; one in the Late Preclassic and another in the Late Classic perhaps brought on, in part, by recurring cycles of intense drought. The site also had a sophisticated hydraulic system of water retention including multiple depression features (aguadas and reservoirs), canal systems, and chultuns constructed to store vast amounts of rain water for domestic consumption, irrigation, perhaps trade, likely in response to reoccurring drought cycles beginning in the Preclassic period.
The material remains within the Xcoch cave indicate that the rulers of the overlying ancient settlement, or ritual specialists acting on their behalf, participated in and manipulated a belief system that highlighted their special relationship with the rain gods. Through ritual, this power would have been publicly expressed as zuhuy ha (sacred water) was likely brought forth annually from the home of the rain gods and poured into the great western reservoir (Aguada La Gondola) helping to initiate the onset of life-giving rains. The physical manipulation of surface flow off of the plastered buildings and plazas of the site center would have further demonstrated their control over water in a more pragmatic manner as well. In the seasonally arid, river-less and cenote-less Puuc, reservoirs would, of course, have had tremendous practical importance as community water catchment and storage facilities providing water for domestic uses as well as perhaps facilitating some localized irrigation farming. The creation of large bodies of water within the site center would have also had further potent symbolic meaning as well. A significant feature of Maya cosmology is the role of water as a transformative boundary, simultaneously connecting and separating cosmic planes. The boundary of the underworld is manifest as a watery surface, reflective of events past, present, and future (Dunning et al. 1999; Isendahl, n.d.; Scarborough 1998). The creation or enhancement of such surfaces within an ancient Maya community undoubtedly had tremendous symbolic power replicating cosmic structure at the hands of rulers.

The central reservoirs also gave the rulers of Xcoch tremendous practical leverage over the urban population. As noted above, the reservoirs could have supplied a critical back-up supply of water useable to supplement or refill chultuns or to enhance urban gardening and farming. Puuc Maya rulers may also have attempted to control population distribution by restricting the constructions of chultuns – the water catching/storing cisterns vital to the domestic life of the region’s residents. Notably, many “rural” (intersite) hamlets and farmsteads lack chultuns suggesting that these places were only seasonally occupied and that the rulers of Maya communities may have attempted to control population dispersion by dictating that chultuns could only be constructed in controlled community space (Dunning 2003b, 2004). The later expansion of reservoirs into the outlying portions of Xcoch would have allowed the extension of water-based social control more effectively into the site’s hinterland, perhaps analogous to the system of “water hole group” political control apparent in the Copán Valley.

Climate change, surface survey, mapping, and excavation data are providing important insights into human ecodynamics among the ancient Maya of the Puuc region. This exploratory research is addressing compelling cultural issues regarding adaptation to rapid climatic change that can be potentially traced to climate changes in other world regions such as the Arctic. This transformational work engages the global community because it is becoming increasingly apparent that climate changes have global culture-environmental impacts. Also, this work brings to the forefront a tangible example of how tropical and Arctic climate processes may be interrelated and helps liberate researchers from 19th century regional boundary paradigms to contemplate and appreciate the dynamics of global climate and sociocultural change past and present. Continued work at Xcoch and the Puuc region will certainly enhance and advance understanding of the origins the Maya in northern Yucatan and human ecodynamics of climate change and past cultural response.
Acknowledgments

We wish to recognize the many individuals and institutions that have supported the Xcoch Project. This work was funded by a grant from National Science Foundation (#0940183). We are especially indebted to Anna M. Kerttula, Director of the Arctic Social Sciences Program, for her strong support and encouragement. This project worked with the permission of Mexico's Instituto Nacional de Antropologia e Historia. We are also grateful to Dra. Nelly Margarita Robles García (Presidente), of the Consejo de Arqueología of the Instituto de Antropología e Historia, Eduardo López Calzada Dávila (Director), and José Huchim Herrera (Coordinator) of the Centro INAH Yucatán. The municipalities of Santa Elena and Ticul must be praised for providing the project with strong logistical support. We would like to thank Dustin Keeler and Karen Crissy of the University at Buffalo for their services administering the NSF grant. Radiocarbon dating was provided by The National Ocean Sciences Accelerator Mass Spectrometry Facility (NOSAMS) at the Woods Hole Oceanographic Institution. We also want to express our deep gratitude to Daniel Griffin, Pilar Suárez Smyth, Sean-Michael Suárez Smyth, Sebastián Suárez Smyth, Harry Goepel, Beth Cortright, Chasity Stinton, Humberto Bonilla Mían, Manuel Bonilla Camal, Marisol Dzul Tuyub, Karina Dzul Tuyub and the local Maya workers of Santa Elena for their dedicated service. And finally, a special thanks to the people of Santa Elena and Muna for their friendliness, patience, and good humor which helped to make this project a success.

Bibliography

Anderson David S.

Andrews, E. Wyllys V.


Bey, George J., III

Bey, George J., III and Rosanna May Ciau
México.

Brainerd, George W.

Dugmore, A. J., Keller, C. and McGovern, T. H.

Dunning, N. P.


Dunning, Nicholas, Vernon Scarborough, Fred Valdez Jr., Sheryl Luzzadder Beach, Timothy Beach, and John G. Jones

Dunning, N. P., J. G. Jones, T. Beach, and S. Luzzadder-Beach

Folan, William J.

Ford, Anabel

Gallareta Negrón, Tomás and William M. Ringle
Harrison, Peter  

Haug, Gerald H., Detlef Gunther, Larry C. Peterson, Daniel M. Sigman, Konrad A. Hughen, and Beat Aeschlimann  


Hodell, D.A., Curtis, J.H., and M. Brenner  

Isendahl, Christian  


Lozano-Garcia Maria del Socorro, Margarita Caballero, Beatriz Ortega, Alejandro Rofriquez, and Susana Sosa  

Martín Medina-Elizalde, Stephen J. Burns, David W. Lea, Yemane Asmerom, Lucien von Gunten, Victor Polyak, Mathias Vuille, Ambarish Karmalkar  

Medina-Elizalde, Martín, Stephen J. Burns, David W. Lea, Yemane Asmerom, Lucien von Gunten, Victor Polyak, Mathias Vuille, Ambarish Karmalkar  

Mercer, Henry Chapman  

Moyes, Holley, Jaime J. Awe, George A. Brook, and James W. Webster


Smyth, Michael P.

Smyth, Michael P., Christopher D. Dore, and Nicholas P. Dunning

Smyth, Michael P., José Ligorred P., David Ortegón Z., and Pat Farrell

Smyth, Michael P. and David Ortegón Zapata


Stanton, Travis W.,
2000 Heterarchy, Hierarchy, and the Emergence of the Northern Lowland Maya: A Study of Complexity at Yaxuna, Yucatan, Mexico (400 BC-AD 600). Ph.D. dissertation, Department of Anthropology, Southern Methodist University, Dallas.

Wahl, D., T. Schreiner, R. Byrne, and R. Hansen
2007 A Paleoecological Record from a Late Classic Maya Reservoir in the Northern Peten. Latin American Antiquity 18:212-222.


Zubrow, Ezra B. W., Michael P. Smyth, David Ortegón Zapata, Nicholas P. Dunning, and Eric M. Weaver
2010 "Paleoclimatic Reconstruction and Archaeological Investigations at Xcoch and the Puuc Region of Yucatan, Mexico: Exploratory Research into Arctic Climate Change and Maya Culture Processes." Report to the National Science Foundation, Washington, D.C.