Exploratory Research into Arctic Climate Change and Ancient Maya Response: Paleoclimate Reconstruction and Archaeological Investigation at the Puuc Region of Yucatan, Mexico

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
Jane E. Slater
University of Cincinnati

Philip van Beynen
University of South Florida

2011 Preliminary Report for the EArly–Concept Grants for Exploratory Research (EAGER, 1132061)

National Science Foundation
Arctic Social Sciences Program
Washington, D.C.
This report presents results of an Early Concept Grant (NSF 1132061) for Exploratory Research (EAGER) that took place at the ancient Maya center of Xcoch in the Puuc region of Yucatan, Mexico in 2011. How climate change affected the Puuc region and particularly Xcoch and vicinity relate to the nature of hydraulic systems and patterns of cyclical drought and shed new light on the processes of Maya response to cultural-environmental dynamics and the rise and demise of complex societies in the Northern Maya Lowlands.

A program of interdisciplinary research at the Maya center of Xcoch in the Puuc region of Yucatan, Mexico began in 2006. This work has determined that Xcoch was a large Maya center with a significant occupation during the Preclassic period, an even larger and more dense settlement through Late Classic times, and included 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 2011 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 peaked 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 suggest at least two periods of intense construction activity that correspond to contemporaneous episodes of cyclical drought. Based on climatic data from Lake Chichancanab, 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 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, water tanks and reservoirs, 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.

Xcoch was reoccupied at the end of the Early Classic period (~500 AD), and settlement slowly began to build to reach a maximum in the Late Classic. However, there is again evidence for another series of severe drought cycles (Hodell et al. 2001; Webster et al.
2007; Wahl et al. 2007; Media-Elizade et al. 2010; Media-Elizade and Rohling 2012) that may have pressured large 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 outset Terminal Classic period (~800 AD). Though clearly suggestive, previous climate change data in the Yucatan has been too course-grained and not closely tied to individual sites necessary for rigorous cultural interpretation at the site level. 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 2011, and discusses the research into water management practices such as the aguadas and water tanks 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.

Site Survey and Surface Collection

To further document urban phenomenon and investigate human adaptations in a semi-arid tropical environment, the 2011 Xcoch Project continued site survey of a 30 ha zone of the southern and southwestern zones of Xcoch (Figure 1). The surface collection survey consisted of 380 3x3 m collection units spaced at intervals of 25 m. Within this surveyed area, most architectonic features were mapped in detail at a scale to 1:200. The site-scale surface collections continued near the site access about one kilometer south of the N5000 E5000 base line where the municipal mensura runs E-W separating the lands of Santa Elena and Ticul. Main-line N-S brechas (trails) were opened 1000 m to the south of N5000 between E4800 and E5300. With the aid of a total-station EDM (Electronic Distance Measuring Theodolite) and GPS receiver, main breaches north-south were opened each 100 m with 3x3 m collection units placed every 25 m (Figures 2a-d).
Figure 1. Architectural and topographic map of Xcoch showing the settlement zones mapped up to and including the 2011 field seasons.
Significant architectural and ceramic remains were found across more than 30 hectares to the south and southwest of the main group at Xcoch, including a very dense settlement atop a high hill called the Southwest Huitz Group about 800 m south of the Great Pyramid. Also, there are groups to the south of the mensura near an apiary, and several groups with pyramids to the south near the South Aguada and the agricultural parcels of Santa Elena (Figure 1). Although the actual settlement limits of Xcoch could not be determined this season, there is evidence of settlement radiating in all the cardinal directions including large and small pyramid groups, aguadas, and causeways long and short. The southeast causeway travels almost 1 km before arriving at a natural hill that supports three structures forming a triadic-like group upon an expansive leveling platform: a pyramids of the megalithic style crowned with a low vaulted building. Less than 1 km to the south of this group, there are two aguadas within the mechanized parcels of the municipality of Santa Elena.

Clearly, settlement at Xcoch is more dense and extensive than we previously estimated. Xcoch covers more than 8 km² and perhaps as large as 10 km². The survey indicates that settlement is continuous up to 2 km north of the Great Pyramid and there is settlement...
near two large depressions (aguadas) 1.5 km to the northeast and the southeast. (Dunning 1992). Xcoch extends at least 1 km to the west and far more than that to the east. Settlement was found well to the south and more than 2 km to the southeast (Figure 3c).

Figures 3a-d. Photos of the Great Pyramid and a megalithic stela on the North Plaza (a), and near the edge of the site about 1 km south (b), two Preclassic vessels (a Sierra red plate y Ciego composite vase) found on the pyramid platform near N5500 E5200 (c), and the remains of a megalithic platform at N5400 E5300 after a field burning (d).

Settlement Survey

The site of Xcoch is most recognized for a deep water cave and a giant pyramid more than 40 m in height set upon a huge platform about 1 hectare in area. A massive multi-level acropolis with at least 10 architectonic groups covering more than 10 hectares is part of the pyramid platform and is one with the largest structures in the Puuc region. The acropolis also extends about 200 m to the north incorporating a plaza leveling and an upright megalithic stela, a possible water feature, and several building groups (Figures 2 and 3a-b). Constructed in an early megalithic style, an indicator of Preclassic to Early Classic occupation, the Grand Platform of the Great Pyramid contain large pillow-shaped boulders set in dry masonry with abundant chinking stones. This megalithic stonework is virtually identical to a structure recently consolidated at Xocnaceh, a relatively small site with an enormous Middle Preclassic platform approximately 20 km to the east of Xcoch (Gallareta Negrón and Ringle 2004; Bey 2006).

In 2011, 12 large architectonic groups were intensely mapped at a scale of 1:200 using a Topcon total-station EDM supplemented by compass and tape and a GPS receiver.
Additionally, the remains of several other groups settlement groups also were located. The settlement data of general site features show many platforms and multi-room vaulted and un-vaulted buildings, >20 pyramids (5 to 30 m in height), the Great Acropolis, many plazas, a 6 m wide causeway running from the Great Acropolis to a pyramid group almost 1 km to the southeast, and a limited number of chultuns of which some are shallow depth and archaic in construction, and several stone pilas apparently used to grind maize (Figure 1). The architectural remains mapped in the 2011 were concentrated in an area of more than 30 hectares of southwestern Xcoch and the north zone of the Great Acropolis, although there are substantial settlement remain remains outside the surveyed area. The extraordinary scale of the construction indicate that Xcoch was a settlement of first rank in size and importance.

To the northeast of the Great Pyramid between N5300 E5200 and N5300 E5300 was a zone of settlement within a milpa field with three platform groups of buildings and pyramids mapped in 2009 (Figure 1). Surveyed in 2010 is a fourth group to the north on a small but high basal platform with a vaulted building to the west, several structures with stone foundations and undistinguished platforms, and two circular stone foundations with reused facing stones suggesting a possible post-occupation. No chultuns were seen on this basal platform.

In 2010, the Project benefited from milpa activity north of the Great Pyramid. At the time, the milpa field was recently burned and cleared for maize planting. The clearing of the area allowed us to observe the patterns of settlement such as an expansive plaza to the north and extension of the Great Acropolis that consists of different surface levels and numerous surface structures on a platform that covers an area of about one hectare (Figures 1 and 3a). Also, an megalithic stela in situ was found standing upright and roughly aligned with the midline of the Great Pyramid approximately 150-m to the north. In 2011, farmers burned a broader zone to the northeast that revealed another substantial group that consists of a high and ample platform with an archaic building along the north side and several foundation brace structures on the south end (Figures 3d and 4a). About 50 m to the south is depression that probably served as a water collection and storage reservoir.
A vaulted building group with the remains of a with a three-columned entrance is located on the west end of the North Plaza. To the north near the megalithic stela is a dense concentration of vaulted buildings that underwent surface collections in 2010 and mapping in 2011 (Figures 4a-b). This group contains 5 vaulted buildings, 8 buildings without vaults, a foundation brace with 5 rooms, a ring structure, 5 chultuns (black dots), and four pilas (stone basins). To the northeast are two pyramid platforms; the first pyramid is 4 m in height near N5475 E5200 and shows a single-room building in the megalithic style with a central entrance and megalithic stairs to the south. To the north at N5500 E5200 is the other pyramid which is 2.5 m in height with a stair access on the west and a collapsed foundation atop the platform. During the clearing of this pyramid, the fragmented remains of two Preclassic vessels were near the surface and have been identified as a Sierra red plate and Ciego composite vase (Figure 3c); both are ceramics diagnostic of Late Preclassic and demonstrate that this pyramid dates to the Preclassic period. Stratigraphic excavations near the base of this pyramid confirmed the dating of this structure.

To the north between N5700 and N5900 and E5000 and E5400 are several additional settlement groups with vaulted and non-vaulted buildings and chultuns within a zone of zacate grass (Figures 5a-f). One group near N5800 E5200 is a quadrangle of four structures set upon a high platform with a pyramid and temple vaulted to the east, another vaulted building to the north, and two un-vaulted buildings to the west and the south. On the level of the lowest platform to the south is a building with two rooms and a one-column entrance and a foundation brace. There are two chultuns along the west and southwest sides of the lower platform. Another platform 75 m to the east exhibits an unvaulted structure with three rooms and one frontal chultun. Two other quadrangles are to the northwest. The first quadrangle this near N5875 E5175 and has two vaulted multroom buildings, one is set upon a high platform with four collapsed non-vaulted buildings and two chultuns. The other quadrangle is near N5925 E5100 and consists of five structures upon a platform with four vaulted buildings including a pyramid structure and foundation brace to the south. A vaulted building with three rooms and central column and another non-vaulted building is on the northwest side of the quadrangle. The
other group is within the zacate zone near N5725 E5450. This group does not have any vaulted buildings except one four-room building 20 m to the south that clearly is a later structure of the group. Upon a basal platform are 6 buildings and three of them are upon high building platforms and at least one is a pyramid structure. The building and platform to the north has megalithic stairs. Also, there are two structures one with three rooms to the northwest side the platform. Another settlement group was found during the surface collection survey on the E5000 line between N5900 and N6000. This group has a 5 m tall pyramid platform to the north of a quadrangle with vaulted buildings to the west and the south sides and two chultuns near the center periphery.

Figures 5a-f. Maps and a photo of the North zone of zacate grass with the settlement groups between N5800 E5300 and N5900 E5450 showing the northwest group (a), a quadrangle to the north (b), a group to
the south (c), another group to the west (d), and a group at N5775 E5200 (e) and a photo of the zacate zone (f).

About 200-m southwest of the Xcoch grotto is the Candelero Group, a 4 m high basal platform (Figure 6a-b) 60-m east-west by 60 m the north-south. This platform was surface collected intensively in 2011 and has numerous building foundations and a pyramidal platform in the central south part of the platform. On-platform test excavations indicate that the platform was constructed in the Preclassic period with a light reoccupation in the Late Classic period. Thirteen visible surface structure foundations are clearly rooms for perishable buildings with only one pila associated and no chultuns. Nevertheless, to the north and south sides are two deep depressions up to 10 m in depth that surely served as water reservoirs. Stratigraphic excavations reached to bedrock and contained significant quantities of the Middle Preclassic ceramics suggesting that this habitation group was one of the earliest at the site of Xcoch.

Near N4800 E4900 south of the mensura and next to a modern day apiary is a basal platform called the Apiary Group (Figure 7). The main structure is a Proto-Puuc-style
vaulted building with three rooms oriented east-west. Aside from this, there are several non-vaulted structures including simple and multi-room foundation braces and two apsidal-shaped foundations, and linear platforms. A conical, megalithic altar was found near the northeast corner and a plain stela lying on the ground near the southwestern corner. Stairways to access the platform are found on the north and west sides. To the east is a platform for a chultun located near the platform center. On the west side of the Apiary Group is another high platform with eight foundation brace buildings surrounding a central plaza. Although located but not mapped, about 50-m to the west, is a pyramid set upon the east end of a substantial platform with a sascabera in front of a small cave that 2012 explorations show connects to a deep cave system but not one that is or ever was accessible by man.

![Figure 7. Map of the Apiary group platforms between N4775 E4800 and N4725 E4900.](image)

Three groups near the site road between N4750 and N4600 E5000 and E5050 are all residential groups (Figure 8a-c). The group to the north is constructed upon a low rise that only shows a three-room building without vaults, two simple platforms or two archaic structures, and a chultun. To the south is another quadrangle group with two vaulted buildings, three foundations braces, a put simple platform upon the southwestern corner of the basal platform. Two multi-roomed buildings without vaults are attached to north side. Both groups contain two chultuns and 8 pilas. Another platform 50 m to the east has a three-room building without vaults and an accumulation of stones near a platform extension to the south.
To the south on a high hill and ridge between N4500 and N4400 E4800 and E4900 is the Southwest Huitz Group that consists of at least 7 large platform-terraces surrounded by the agricultural parcels of the municipality of Santa Elena. This expansive settlement group represents the leveling of an enormous area covering more than a hectare (Figures 9a-f). The central quadrangle has a panoramic view the valley of Xcoch and to the south of the main plaza is a pyramid with a building without a vaulted roof but high stone walls and a stairway access to the north. To the west set near the base of the pyramid is a stone slab that measures one meter in length that shows to an eroded and abstract bas relief figure. Though difficult to discern, the figure appears to show growing and luxuriant (maize?) vegetation, perhaps representing an abundant harvest. An un-vaulted building is on the plaza's west side and two platforms are found to the north and east with a cylindrical altar near the center of the plaza. North of the plaza are four more terraces with four collapsed megalithic un-vaulted buildings with multiple rooms and two chultuns. To the west is another platform with three foundations for perishable-walled and perishable-roofed buildings, 7 pilas, and one collapsed chultun on the west border of the hill. One of the buildings is similar to “C” structures found in many late Puuc sites but
with jambs constructed as pilasters forming a very wide north entrance. Further north is another platform with a two-room foundation brace, two bare platforms, one intact chultun and one collapsed chultun, one pila, and the remains of a wide staircase on the east side. To the south of the plaza of the pyramid, there are two large terraces at a lower level with two megalithic foundations for each, the nearer terrace has with one-room buildings and the other more distant terrace with two-rooms buildings and a wide staircase on the north side.
Figures 9a-f. Maps of the Southwest Huitz Group between N4350 E4800 and N4550 E4900 (a-c), and photos of the pyramid (d), the south platforms (e), and the view of the group from the south (f).

**Stratigraphic Excavation**

In the 2011 season, stratigraphic test pits (Operations) were excavated in 10 to 20 cm levels (following natural or cultural stratigraphy when possible) within the North Zone, the Candelero Group, the Apiary Group and platforms to the south, and the Southwest Huitz Group (Figure 10). These excavations produced typical Cehpech ceramics (800-1000 AD) in the upper levels. Nevertheless, there were ceramics and vessels of Motul (600-800 AD) and Cochuah (300-600 AD) complexes and significant quantities of ceramics from the Preclassic (Mamom and Tihosuco 800/700-400/300 BC) from stratigraphic contexts and early architecture. These data provide further evidence that Xcoch had a large occupation during the Middle Preclassic period.
Figure 10. Architectural map of the site of Xcoch showing the locations of the stratigraphic test pits (Ops. 1-16) in 2011 and the location of the depression near the “Old Pyramid Group (Op. 1),” the Preclassic
pyramids in the north, the Candelero Group, the Apiary Group, the Southwest Huitz Group, and new locational data of the Southeast Causeway.

Operations 1 and 2 were 2 x 2 m units in the north zone located within a depression to the south of the “Old Pyramid” Group and a pyramid platform where the remains of two Preclassic vessels were recovered. Operation 1 (Op.) probed the depression to determine if this feature could have been used as a reservoir for the storage of water. Passing through 8 levels, the first 3 levels contained a partial metate and high numbers of Cehpech ceramics mixed with Motul, Cochuah, Tihosuco, and Mamom ceramics. Within level 4 at 140 cm b.s. (below surface) was a very thick sascab (marl) floor (~20 cm) that suggests a sealing surface for a water reservoir (Figure 11a). Level 5 began at 210 cm b.s. and level 8 reached 300 cm b.s. and in between were dense concentrations of sascab. Also, the ceramics types were of the Motul, Cochuah, Tihosuco, and Mamom complexes with significant amounts of the Preclassic wares, including the top portion of a Dzudzukil cream-on-buff jar (Figures 11b-c). The unit continued below 300 cm b.s. but it was clear that this depression had multiple uses over many centuries beginning as a quarry for construction, followed by a reservoir for water, and finally as a refuse dump.

![Figure 11a-c. Photos of the Op. 1 within a depression south near the “Old Pyramid Group” showing the bottom of the unit, the top of a vessel, and floor for a water reservoir (a), a close-up view of the vessel top (b), and the same vessel which is a Dzudzuquil cream-to-buff jar, a type dating to the Middle Preclassic period (c).](image)

Op. 2 was located by a pyramid platform where two Preclassic vessels appeared near the surface (Figures 12a-b). In level 1 mostly Cehpech ceramics were recovered with some Preclassic sherds as well as more sherds from one of the vessels (Ciego composite vase)
found previously. In level 2 between 60 and 90 cm b.s. are quantities of Preclassic ceramics and a layer of sascab with few stucco fragments. In level 3 there is a stone surface of chic and medium size stones (bak pek) with fewer ceramics at 220 cm b.s. In level 4, we encountered a preserved stucco floor at 230 cm b.s. and clearly the original surface of this pyramid platform. Beneath Floor I was construction fill and ballast set upon bedrock at 250 cm b.s. The ceramics associated with floor I were early types of the Tihosuco and Mamom complexes and below Floor I in level 5 were solely Mamom complex ceramics of the Middle Preclassic period.

Ops. 3 to 7 were 2 x 2 m units located on the expansive Platform of the Candelero Group 200 m southwest of the Xcoch cave. Ops. 3 and 4 were located to the southwest and south center of the platform (Figures 13a-b). In levels 1 and 2 of both units were a mixture of the Late Classic, Early Classic, and Preclassic ceramics within the first 50 cm b.s. Level 3 revealed the only prepared surface of the platform which consisted of a stone layer of chic, bak pek, and sascab between 60 and 70 cm b.s., but we did not detect any stucco floor fragments. Below the prepared surface was more chic, bak pek and large boulders (buk) that clearly comprise the construction fill of the platform at 180 and 200 cm b.s. Levels 4 and 5 contained pure Preclassic pottery, including a monopod support of Yotolin patterned burnished water jar like those found in the Xcoch cave; the first time this rare pottery has ever been reported in a stratigraphic test pit or outside of a cave context.
Ops. 5, 6, and 7 were located to the east, the north, and the south of the pyramid platform (Figures 13c-j). Op. 5 was within a surface level adjacent to a retention wall seen to the north. At 59 cm b.s., stone surface and sascab was found containing a mixture of the Cehpech, Cochuah, and Tihosuco-Mamom ceramics above floor and pure Preclassic ceramics below floor at 100 cm b.s. Op. 6 probed the south side of the platform where a megalithic wall was detected. The large boulder stones were coarsely shaped and probably were the treads and risers of a megalithic staircase on the south flank of the platform for the Candelero Group leading to the south reservoir. Although there was no floor surfaces encountered, the ceramics were clearly Cehpech types in levels 1 and 2 but Preclassic ceramics starting in level 4 until bedrock at 56 cm b.s. In Op. 7 there was also a sascab floor at 50 cm b.s. and Cehpech and Cochuah ceramics above floor and Middle Preclassic ceramics below floor to bedrock at 160 cm b.s.
Ops. 8 to 11 were 2 x 2-m units located at the Southwest Huitz Group 800 m southwest of the Great Pyramid (Figures 14a-i). Ops. 8 and 9 were located near the center of the main plaza where there is a cylindrical altar and pyramid to the south with westside stone tablet showing amorphous figures in bas relief (Figure 14d). Op. 8 showed no base for the altar indicating that the altar was not in situ and obviously moved. In the only level of the unit was Cehpech ceramics. Between 40 and 50 cm b.s., a plaza floor of chich, bak pek, and buk appeared below level 2 that produced abundant sascab and Motul ceramics as well as Preclassic types clearly indicating that the leveling of this basal platforms and the construction of many of its buildings took place during the Preclassic period. Bedrock appeared between 133 and 159 cm b.s. Op. 9 found stone alignments that appear to be part of a leveling surface for the pyramid. In levels 1 and 2 were a mixture of Cehpech ceramic types, Preclassic wares, and bedrock between 108 and 123 cm b.s.

Ops. 10 and 11 were located in front of the pyramid on the north side and near Structure 2, a foundation brace with three rooms in the north edge part of the plaza. Op. 10 encountered the same floor surface found in the Op. 8 and passed through the same construction fill as that of the plaza. An oval cist appeared near the first row of stair steps for the pyramid but produced nothing significant. All ceramics are identified as Cehpech types and only a single sherd was Preclassic. Op. 11 recovered a large number of ceramics and several partial vessels of the Cehpech complex. A very fragmented stucco floor appeared at 30 cm b.s. and in level 2 there were the remains of a substructure along
the north wall of the unit and chich and bak pek at 80 cm b.s. In this context were Preclassic sherds and bedrock at 180 cm b.s.

Figure 14 a-b. Photos of Op. 8 on the Southwestern Huitz Group looking south showing the location of the unit in the plaza near the pyramid (rear) (a), and the pit, the altar, and floor I of the plaza between 40 to 50 cm b.s. (b). Preclassic ceramics were found beneath the floor. The altar is not associated with the floor nor its location on the plaza.

Figure 14c-d. Photos of Op. 9 showing the west wall of the pyramid of the Southwest Huitz Group showing the platform leveling and position of a stone slab with bas relief (c), and a close-up view of the slab with the bas relief showing an abstract and eroded figure (d).
Figure 14e-f. Photos of Op. 10 of the Southwest Huitz Group looking south showing the unit in front of the hypothetical stairs of the pyramid (e), and the unit showing an stone cist feature between 40 and 80 cm b.s. in the northwest portion of the unit and a surface of stones and sascab to the east at 80 cm b.s. (f).

Figures 14-i. Photos of Op. 11 near Structure 2 of the Southwest Huitz Group (a) and the west profile (b) showing fragments of a stucco floor 35 cm b.s. that is superimposed upon construction fill and bedrock, and the remains of a megalithic substructure in to north half of the unit (c).

Ops. 12 to 16 were 2 x 2 m units located within the Apiary Group, a group of three platforms and several mapped buildings (Figures 15a-e). Op. 12 was to the north-center of a three-room vaulted building in the Proto-Puuc style. Between 25 and 40 cm b.s., an offering of two complete vessels, a Say slateware chultunera and Chemax slateware painted bowl (Figures 15d-e), was found near the northeast corner of the unit. These vessels are of the Motul complex and date to the Middle Classic period and surely are contemporay with the vaulted building. Along the south wall appeared a surface with small areas of intact stucco between 16 and 18 cm b.s. that represents the building platform surface. The ceramics of the upper levels are of the Cehpech and Motul complexes. The lower layers within the original platform of the group show types typical of the Tihosuco and Mamom complexes suggesting a construction date that began in the Preclassic period.
Op. 13 was located within an apsidal foundation of megalithic stones to the south of the central platform of Apiary Group (Figures 16a-b). Level 1 contained a great number of ceramics and a chich layer between 17 and 39 cm b.s. that probably represents the original surface of the perishable structure. Beneath level 2 and the stone surface is where large stones and bedrock were encountered between 40 and 50 cm b.s. The two levels produced almost 1,500 diagnostic sherds that are mostly Cehpech ceramics.
bedrock that appeared between 27 and 53 cm b.s., nothing else of significance was found in this unit.

Op. 15 was placed adjacent to pyramid and platform 50 m to the west of the Apiary Group (Figure 18a-b). Although there was only one level to bedrock between 28 and 62 cm b.s., several large stones appeared in the west part of the unit indicating the border of the pyramidal platform. Only Cehpech ceramic types were found (>650 sherds) but the pyramid and its platform show stonework indicating Preclassic construction like almost all pyramids and large platforms at Xcoch.

Op. 16 sampled a foundation brace (Structure 2) in the west part of the central platform of the Apiary Group (Figures 19a-b). Level 1 reached 26 cm b.s. where a partially conserved stucco floor was seen in the southwest corner of the unit. This floor was connected to an alignment of facing stones. Almost 1,000 sherds from level 1 were Cehpech ceramics. The unit was then divided and level 2 continued to sample the west half of the unit. Excavation did not penetrate deeper than 127 cm b.s. and produced few ceramics but did not reach bedrock.
Figures 19a-b. Photos of the Op.16 looking northeast showing Structure 2 of Apiary Group (a) and a stucco floor at 26 cm b.s. and a faced stone wall in the southeast corner of the unit (b).

Ceramic Analysis

The 2006, 2009, 2010, and 2011 field seasons at Xcoch recovered a total of 66,300 ceramic sherds that were analyzed using the type-variety classification system employed by most Maya ceramists in the Yucatan during the last four decades. A total of 12,366 ceramics were collected in 2011. 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.

Excavations in 2011 recovered 8,485 ceramic sherds from 16 stratigraphic test units (Operations 1-16). The ceramics near surface are identified as ceramics of the Cehpech ceramic complex typical of the Late-Terminal Classic period including types such as Yokat striated, Muna slate, Ticul thin, Teabo red, and Holactun. Nevertheless, there are significant quantities of Early Classic sherds (polychrome types such as Chac, Timucuy, and Dos Arroyos) within the middle stratigraphic levels. In almost every unit the lowest levels produced diagnostic sherds of the Preclassic period including Chunhinta black, Sierra red, Muxanal red-on-cream, Tipikal red-on-striated, Kin red-orange, Chancenote striated, Dzudzukil cream-to-buff, and numerous other early types.

The mix of Cehpech ceramics and earlier ceramics in many of the surface units cannot be a random pattern (Table 3). The surface survey of 2011 surface collected 3,881 sherds (17,948 total from 2006-2011) from 380 3x3 m units (1,249 total from 2006-2011). As expected, most surface ceramics are of the Cehpech complex, almost all Yokat striated and Muna slate typed without decoration and a few fine paste wares (20 sherds or <1%). This pattern is very unusual given the fact that the majority of the collections have come from near the central monumental zone of Xcoch. 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 (serving and storage vessels) 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. The Early Classic and Preclassic ceramics at Xcoch are found across a wide area of the surface survey area. These surface patterns suggested a major Preclassic occupation during the 2006 season (Smyth and Ortegón 2008) and have been absolutely confirmed by test excavation and radiocarbon dating in 2009-2011.

These data demonstrate that the center of Xcoch had a significant occupation during Middle Preclassic and that many of the surrounding settlements were constructed at this time such as the Candelero, Apiary, and Southwest Huitz Groups as well several located groups south of the E5100 and E5200 brechas that have not been mapped so far. In fact, these survey and excavation data suggest that a Preclassic occupation reached all areas of the site survey to date and covers more than one square kilometer. The distribution of water jars is very high around large water feature such as aguadas but also high near smaller water features including as reservoirs and chultuns, which is not surprising. However, we are in the process of quantifying these relationships and determining any correlations with patterning of climate change including the known drought cycles that occurred in the Preclassic and Late Classic periods.

**Radiocarbon Dating**

Twenty-eight wood charcoal samples were submitted to the National Ocean Accelerator Mass Spectrometry Facility (NOSAMS) for radiocarbon dating in 2009-2011 (Table 1). These samples were recovered from Xcoch Plaza and Great Acropolis, the South Aguada, the Gondola Aguada, the East Aguada, the Gruta Xcoch, and La Vaca Perdida Cave (11 km east). Four samples are modern and likely the result of contamination, six are Colonial, and seventeen samples were prehispanic. The most notable are eight 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. A late Preclassic date is from the La Gondola Aguada. Five Early Classic dates were associated with the La Gondola Aguada, South Aguada, Chultun 2, and the Vaca Perdida cave, a time when Xcoch was being reoccupied after initial abandonment in the Late Preclassic period. Two 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 1: 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. NOSAMS</th>
<th>Conventional 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>20045</td>
<td>78756</td>
<td>2520+/−30</td>
<td>570 BC</td>
<td>716-792 and 539-695 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>1483-1614 AD</td>
<td>Grp. Residential, Op. 8, Lev. 3 - Piso II</td>
</tr>
<tr>
<td>20078</td>
<td>78762</td>
<td>Modern</td>
<td></td>
<td></td>
<td>Grp. Residential, Op. 8, Lev. 5 - Piso IV</td>
</tr>
<tr>
<td>20193</td>
<td>84309</td>
<td>2520+/−30</td>
<td>570 BC</td>
<td>716-792, 695-539 BC</td>
<td>E. Pyr. Plaza, Op. 35, Lev. 8, Piso V (below)</td>
</tr>
<tr>
<td>20198</td>
<td>84310</td>
<td>2590+/−30</td>
<td>640BC</td>
<td>763-809, 673-680 BC</td>
<td>W. Sacbe, Op. 36, Lev. 8, Piso III (below)</td>
</tr>
<tr>
<td>21001</td>
<td>84311</td>
<td>1250+/−25</td>
<td>700 AD</td>
<td>678-784, 786-827, 839-864 AD</td>
<td>Gruta Xcoch, Sta. CC3 (A Passage)</td>
</tr>
<tr>
<td>21005</td>
<td>84312</td>
<td>175+/−25</td>
<td>1775 AD</td>
<td>1661-1694, 1727-1813, 1839-1842, 1853-1859, 1862-1867 AD</td>
<td>Gruta Xcoch, Sta. A4 (A Passage), 1-20 cm</td>
</tr>
<tr>
<td>21014</td>
<td>84313</td>
<td>645+/−25</td>
<td>1305 AD</td>
<td>1283-1324, 1346-1393 AD</td>
<td>Gruta Xcoch, Fire Pit (10 cm), A38</td>
</tr>
<tr>
<td>21014A</td>
<td>84314</td>
<td>525+/−30</td>
<td>1425 AD</td>
<td>1322-1347, 1392-1441 AD</td>
<td>Gruta Xcoch, Fire Pit (25 cm), A38</td>
</tr>
<tr>
<td>21019</td>
<td>84315</td>
<td>385+/−30</td>
<td>1565 AD</td>
<td>1449-1499, 1502-1512, 1601-1616 AD</td>
<td>Gruta Xcoch, Torch, Sta. El13</td>
</tr>
<tr>
<td>21020</td>
<td>84316</td>
<td>225+/−55</td>
<td>1725 AD</td>
<td>1513-1600, 1617-1706, 1719-1820, 1822-1825, 1832-1884, 1913-1953</td>
<td>Vaca Perdida (30 cm)</td>
</tr>
<tr>
<td>20121</td>
<td>84317</td>
<td>1630+/−30</td>
<td>320 AD</td>
<td>348-369, 378-535 AD</td>
<td>Vaca Perdida, Sala 2</td>
</tr>
<tr>
<td>Ya’al Chaac</td>
<td>104687</td>
<td>1530±25</td>
<td>420 AD</td>
<td>433-494, 505-522, 526-599AD</td>
<td>Aguada 10 km N of Muna</td>
</tr>
<tr>
<td>20251</td>
<td>104688</td>
<td>2250±30</td>
<td>300 BC</td>
<td>392-348,317-207 BC</td>
<td>S Terrace Pozo 1 85 cm b.s.</td>
</tr>
<tr>
<td>20254</td>
<td>104689</td>
<td>1560±25</td>
<td>390 AD</td>
<td>427-557 AD</td>
<td>S Terrace Pozo 1 135 cm b.s.</td>
</tr>
<tr>
<td>21019a</td>
<td>104690</td>
<td>1380±25</td>
<td>570 AD</td>
<td>614-673 AD</td>
<td>Vaca Perdida Pozo 1 25 cm b.s.</td>
</tr>
<tr>
<td>21020a</td>
<td>104691</td>
<td>1590±25</td>
<td>360 AD</td>
<td>418-538 AD</td>
<td>Vaca Perdida Pozo 2 25-30 cm b.s.</td>
</tr>
</tbody>
</table>

2011 Investigations into Xcoch Water Features

Environmental excavations at Xcoch were largely targeted at topographic depressions that were not obvious reservoirs within the site center and residential zones. Criteria used to distinguish natural depressions from those modified to capture and hold water included: (1) the presence or absence of floors that enhanced water retention; (2) features used to divert water into the depression; (3) the presence of berms surrounding the depressions that increased water storage capacity; and (4) two of the depressions excavated were located close to the site center, one on the southernmost and lowest
terrace of the central acropolis complex, and another on the eastern side of the Old Pyramid Group north of the Great Pyramid. A third, larger depression was investigated within the northern settlement zone of the site within an area now overgrown with Zacate grass.

North Zacate Zone Soil Pits

The North Zacate zone is situated about 650 m north of the Xcoch Great Pyramid. This is an area of rolling topography with low rocky hills and irregular-shaped basins with deeper kancab soils. Zacate grass with a few stunted trees covers an extensive area of both hills and basins. Many of the areas of higher ground are capped with residential platforms. One basin was investigated to determine if it had once functioned as a reservoir. A low stone wall partially encircles the basin. Three soils were excavated in the basin: Pozo 1 near the basin center, Pozo 2 near the basin’s southern edge, and Pozo 3 about halfway between the other pits (Figure 20).

Zacate 2011 Pozo 1

Pozo 1 was a 1 x 2 m soil pit that reached a maximum depth of 85 cm. Depth to bedrock was very irregular, ranging from 40 to 85 cm, with deep, clayey C horizon occurring only in deeper solution cavities in the bedrock. Bedrock is generally smooth, case-hardened caprock, though fractured in some places. Soil horizons are the same as those found in Pozo 2 and are described in Table 1. Several large stones within the pit appear to be part of a low limestone wall that ran along part of the southern edge of the basin and has mostly collapsed.

Zacate 2011 Pozo 2

Pozo 2 was a 1 x 2 m soil pit that reached a maximum depth of 130 cm. Depth to bedrock was very irregular, ranging from 30 to 85 cm, with deep, clayey C horizon occurring only in deeper solution cavities in the bedrock. Bedrock is generally smooth, case-hardened caprock, though fractured in some places. Soil horizons are described in Table 2.

<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>0-3</td>
<td>Black (10R2.5/1)</td>
<td>8.8</td>
<td>3</td>
<td>16</td>
<td>81</td>
<td>17</td>
<td>1: O: charcoal-enriched; granular; dried algal mat on surface</td>
</tr>
<tr>
<td>3-15</td>
<td>Very dusky red (10R2.5/2)</td>
<td>4.8</td>
<td>5</td>
<td>20</td>
<td>75</td>
<td>8</td>
<td>2: A1: small hard crumbs</td>
</tr>
<tr>
<td>15-33</td>
<td>Dusky red (10R3/2)</td>
<td>3.9</td>
<td>11</td>
<td>20</td>
<td>69</td>
<td>2</td>
<td>3: A2: large hard crumbs; +/- 15% limestone gravel</td>
</tr>
<tr>
<td>33-55</td>
<td>Dusky red (10R3/3)</td>
<td>2.6</td>
<td>14</td>
<td>19</td>
<td>67</td>
<td>2</td>
<td>4: AC: sub-angular blocky; +/- 25% limestone gravel</td>
</tr>
<tr>
<td>55-128</td>
<td>Dusky red (10R3/4)</td>
<td>1.9</td>
<td>5</td>
<td>12</td>
<td>83</td>
<td>2</td>
<td>5: C: massive; a few cobbles and small boulders</td>
</tr>
</tbody>
</table>
Zacate 2011 Pozo 3

Pozo 3 was a 1 x 2 m soil pit that reached a maximum depth of 65 cm. Depth to bedrock was very irregular, ranging from 20 to 65 cm, with deep, clayey C horizon occurring only in deeper solution cavities in the bedrock. Bedrock is generally smooth, case-hardened caprock, though fractured in some places. Soil horizons are identical to those in Pozo 2 and described in Table 2.

North Zacate Zone: Discussion

The karst depression that lies within the North Zacate Zone was examined as a possible reservoir. The fact that this depression retains small amounts of water during periods of heavy rain and the presence of a fragmented surrounding wall suggested that it may have functioned as a small reservoir for nearby residential groups. However, our 3 excavations into the floor and southern edge of the depression produced no evidence that the depression ever functioned as a reservoir. All units showed typical soil development associated with a localized topographical depression with irregular depths over weathered limestone caprock. No floors of linings were detected. Ceramics were found in the A ands AC horizons, but not in the C horizons. The wall surrounding the depression suggests proprietary tights to this land. Such depressions, retain soil water longer than surrounding rocky lands with shallower soils and were prized for their great agricultural potential. Boundary walls surrounding such depressions, demarcating them as private landholdings, are known from other parts of the Maya Lowlands (Kepecs and Boucher 1996; Dunning et al. 1997) and are documented in early Spanish accounts (Roys 1957).

Old Pyramid Group Depression 1

The Old Pyramid Group lies about 200 m north of the Great Pyramid. Most structures in the group lie on a large platform. Runoff from this platform appears to have been directed into depressions on the west and east sides of the platform. Xcoch 2011 Op. 1 was a 2 x 2 m pit near the center of the eastern depression. The strata revealed in the excavation are outlined in Table 3.

Table 3: Xcoch 2011 – Op 1 South Profile

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Color (Munsell)</th>
<th>P (ppm)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>Very dark gray (7.5YR3/1)</td>
<td>11</td>
<td>A1: clay loam; large crumbs.</td>
</tr>
<tr>
<td>15-28</td>
<td>Very dark gray (5YR3/1)</td>
<td>9</td>
<td>A2: clay loam; small crumbs.</td>
</tr>
<tr>
<td>28-50</td>
<td>Dark reddish brown (5YR3/2)</td>
<td>9</td>
<td>Bw: granular silty clay loam in matrix of limestone gravel and chich (+/- 40% stone); abundant sherds</td>
</tr>
<tr>
<td>50-70</td>
<td>Dark reddish brown (5YR3/2)</td>
<td>2</td>
<td>C1: granular silty loam in matrix of limestone gravel (+/- 10%); thickness varies across pit walls from less than 5 cm to almost 25 cm; no sherds; eolian deposit?</td>
</tr>
<tr>
<td>70-100</td>
<td>Dark reddish brown (5YR3/4)</td>
<td>10</td>
<td>C2: granular clay loam in matrix of limestone gravel and chich (+/- 40% stone); abundant sherds</td>
</tr>
<tr>
<td>100-108</td>
<td>Reddish gray (5YR5/2)</td>
<td>9</td>
<td>C3: granular clay loam in matrix of pea gravel, plaster fragments and dust; probable decomposed floor</td>
</tr>
</tbody>
</table>
The depression appears to have originated as a small karst doline that was likely expanded for quarrying. Sometime during the Middle Preclassic, the depression began to be used as a garbage dump as reflected in material below 150 cm. At 138-150 cm, the midden material was capped by a poorly preserved floor of clay, sascab, and gravel, thus converting the depression into a small reservoir. Another poorly preserved floor is found at 100-108 cm, this one consisting of plaster and gravel, indicating the renewal of the reservoir. At 50-70 cm there is a discontinuous and variably thick deposit of fine silt. This is most likely an eolian (wind-blown) deposit that probably is indicative of a period of regional aridity and/or cycle of drought.

**Acropolis South Terrace Excavation**

A small depression in the southern-most and lowest terrace in the Xcoch acropolis was investigated with a test pit. The strata revealed in the pit are described in Table 3 and illustrated in Figure 1. Two probable floors were identified at 80-90 cm (300 BC) and 130–140 cm (390 AD) but it is not clear why the dates are inverted. Both floors were composed of compacted clay and sascab. These floors suggest that the depression served as a water collection tank situated to collect runoff from the paved surface of the terrace. The lower floor was associated only with Preclassic ceramics whereas the upper floor appears to be associated with Late Classic Chépex wares.

### Table 4: Xcoch 2011 – South Terrace Pozo – West Profile

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Color (Munsell)</th>
<th>P (ppm)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>Very dark gray (7.5YR3/1)</td>
<td>8</td>
<td>A1: Clay loam; large hard crumbs; sherds</td>
</tr>
<tr>
<td>15-30</td>
<td>Very dark gray (7.5YR3/1)</td>
<td>6</td>
<td>A2: Clay loam; small hard crumbs; +/- 20% limestone gravel and chich; sherds</td>
</tr>
<tr>
<td>30-50</td>
<td>Dark brown (7.5YR3/3)</td>
<td>6</td>
<td>AC: Clay loam; sub-angular blocks; +/- 30% limestone gravel; sherds</td>
</tr>
<tr>
<td>50-65</td>
<td>Dark brown (7.5YR3/4)</td>
<td>5</td>
<td>C1: Clay loam; sub-angular blocks; matrix of limestone gravel and chich (+/- 40%); sherds</td>
</tr>
<tr>
<td>65-80</td>
<td>Reddish brown (5YR4/4)</td>
<td>8</td>
<td>C2: Clay loam; sub-angular blocks; matrix of limestone gravel and chich (+/- 40%); sherds</td>
</tr>
<tr>
<td>80-90</td>
<td>Brown (7.5YR4/4)</td>
<td>2</td>
<td>C3: Sascab, clay, and pea gravel; sherds; decomposing floor?</td>
</tr>
<tr>
<td>90-130</td>
<td>Brown (7.5YR4/4)</td>
<td>5</td>
<td>C4: Clay loam; granular; matrix of limestone gravel and chich (+/- 50%); sherds</td>
</tr>
<tr>
<td>130-140</td>
<td>Reddish yellow (5YR6/6)</td>
<td>2</td>
<td>C5: Compact sascab and clay with pea gravel and sherds; probable floor</td>
</tr>
<tr>
<td>140+</td>
<td>R: Sascab</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 21: Profile of western pozo wall, southern terrace of the Xcoch acropolis.

Discussion - Xcoch Small Depression Excavation

Excavations in two smaller depressions at Xcoch in 2011 revealed that both had been utilized to collect and store rainwater. This finding indicates that the ancient Maya residents of Xcoch were collecting rainwater at multiple scales including large reservoirs such as the huge Aguada La Gondola, modest sized “tanks” such as those excavated in 2011, and household chultuns.

Cueva de la Vaca Perdida Investigations

The Cueva de la Vaca Perdida is located 11 km east of Xcoch. It was first investigated in 2010 with further work continuing in 2011. In 2010, three speleothems were collected to be isotopically analyzed to recover paleoclimatic proxy data. In 2011, two soil/sediment pits were excavated in order to collect depositional data and sequenced C isotopes to be compared with those in the speleothems. One pit was excavated in soil above the cave and one in accumulated sediment within the same chamber of the cave as the speleothems.
Vaca Perdida Surface Pozo

Most of the surface area above Cueva de la Vaca Perdida is bare limestone caprock or mantle with soil not much deeper than 15 cm. One solution pocket in the caprock with deeper soil was identified about 15 m south of the cave entrance. A 1 x 2 m pit was opened in this pocket. Most of the pit reached bedrock within 10 to 20 cm, but the northern end of the pit reached a depth of 60 cm. The northern pit profile is described in Table 5. Soil samples were collected at 5 cm intervals in the pit wall for future Carbon isotope analysis. A carbon sample from 25 cm b.s. produced a radiocarbon assay of 570 AD +/-25 (uncalibrated, Table 1)

Table 5: Vaca Perdida – 2011 Surface Pozo – 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>0-5</td>
<td>Very dusky red (2.5YR2.5/2)</td>
<td>8.3</td>
<td>7</td>
<td>13</td>
<td>80</td>
<td>7</td>
<td>1:A1: granular</td>
</tr>
<tr>
<td>5-15</td>
<td>Very dusky red (10R2.5/2)</td>
<td>8.2</td>
<td>6</td>
<td>9</td>
<td>85</td>
<td>3</td>
<td>2:A2: small sub-angular blocks</td>
</tr>
<tr>
<td>15-25</td>
<td>Dusky red (10R3/2)</td>
<td>7.1</td>
<td>9</td>
<td>8</td>
<td>83</td>
<td>2</td>
<td>3:AC: massive; +/- 20% limestone gravel and chich</td>
</tr>
<tr>
<td>25-60</td>
<td>Dusky red (10R3/3)</td>
<td>5.4</td>
<td>11</td>
<td>3</td>
<td>86</td>
<td>3</td>
<td>4: C: massive +/- 25% limestone gravel; isolated to deep solution hollow in bedrock</td>
</tr>
</tbody>
</table>

*Note: samples were also collected at 5 cm intervals for Carbon isotope testing (not yet completed).

Cueva de la Vaca Perdida 2011 Cave Pozo 1

Exploration of the Cueva de la Vaca Perdida led by Eric Weaver revealed that the cave functions as a local hydrologic drain for surface runoff. Portions of the cave contain deep deposits of clayey sediment. A 1 x 0.5 m pit was excavated in a sloping sediment deposit in Chamber 2 of the cave. The strata revealed in the pit are described in Table 6. Sediment samples were collected at 5 cm intervals for future Carbon isotope analysis. A carbon sample from 25-30 cm b.s. produced a radiocarbon assay of 360 AD +/-25 (uncalibrated, Table 1)

Table 6: Vaca Perdida – 2011 Cave Pozo 1 – West 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>0-3</td>
<td>Dark red (10R3/6)</td>
<td>4.0</td>
<td></td>
<td></td>
<td></td>
<td>23</td>
<td>Brittle crust: clay and guano</td>
</tr>
<tr>
<td>3-14</td>
<td>Weak red (104/4)</td>
<td>2.1</td>
<td>2</td>
<td>6</td>
<td>92</td>
<td>19</td>
<td>Micro bands of slightly darker color; platy</td>
</tr>
<tr>
<td>14-17</td>
<td>Dark red (10R3/6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Crumbly</td>
</tr>
<tr>
<td>17-22</td>
<td>Weak red (10R4/4)</td>
<td>1.2</td>
<td>9</td>
<td>5</td>
<td>86</td>
<td>11</td>
<td>Some orange mottling; +/- 15% small travertine fragments; crumbly</td>
</tr>
<tr>
<td>22-25</td>
<td>Dusky red (10R3/4)</td>
<td>1.8</td>
<td>2</td>
<td>8</td>
<td>90</td>
<td>18</td>
<td>Crumbly</td>
</tr>
<tr>
<td>25-50</td>
<td>Red (10R4/6)</td>
<td>1.3</td>
<td>3</td>
<td>6</td>
<td>91</td>
<td>16</td>
<td>Platy to massive</td>
</tr>
<tr>
<td>50-52</td>
<td>Dark red (10R3/6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>52-64</td>
<td>Red (10R4/6)</td>
<td>1.4</td>
<td>1</td>
<td>6</td>
<td>93</td>
<td>14</td>
<td>Massive</td>
</tr>
</tbody>
</table>
Work at Xcoch and Vaca Perdida Caves in 2011

In relationship to work with caves the previous focus of the field seasons has been directed at Xcoch cave. The general survey of the cave was conducted in 2009. A follow-up of leads not examined during the original survey was a primary focus in 2010. This resulted in the discovery of the only speleothems in the cave (unfortunately, unusable for speleothem analysis) and the extension of the E passage which doubled the size of the cave. The 2011 field season began with a final effort to exhaust all remaining leads. In 2010, sound contact was made by workers on the surface with the surveyors in the cave. In 2011, an additional effort was made to find a connection with the surface, unfortunately, there was no success. A final trip to the lowest section of the cave—the low air chamber at the water source—was made to determine if any leads were missed due to challenging conditions that inhibited extensive survey. While additional passage was discovered, the results were not significant enough to report.

In 2010, mapping began at Vaca Perdida where several speleothems were collected. Further exploration was stopped due to time restraints, discovery of an additional pit requiring more rope, and equipment for an anchoring system. In 2011, equipment was brought in to collect water samples at the sites where the speleothems were collected. Unfortunately, of the three sites, only one site was feasible for collecting samples. The other two sites were inaccessible. One was too far from the ceiling causing the drip to spray and the other was located precariously on a steep incline at the edge of a precipitous drop-off.

An anchor system was set up in order to rappel into the second pit of Vaca Perdida. The bottom of the pit progression was managed through a small crawlspace which contained evidence of ceramic and charcoal. This suggests that the ancient Maya had explored the area. The passage initially appeared to end in a rock breakdown; however, access to another passage was achieved with digging and removal of several boulders. Exploration of this passage resulted in the discovery of another drop. It was at this spot that the final evidence of previous human presence was noticed. A speleothem was evidently “chopped” at the edge of the drop-off. Negotiation of the four meter high drop resulted in discovery of a small chamber. A long crawl after the chamber revealed a drop of 7-8 m. A passage continued at the bottom of this drop. Unfortunately, the passage soon became choked by a wall of mud. While there remains the possibility of navigating around the mud choke, the effort appears dangerous. There is no suggestion that further progress will show evidence of any ancient Maya presence or reveal any more speleothems useful for paleoclimate reconstruction.

The final survey of Vaca Perdida reached a depth of 61 m over a 103.3 m horizontal span (Figure 22). The AMSL of the cave’s entrance was 71 m based on commercial grade GPS calibrated at sea level in Cancun. The cave covers a brief surface area of 32.2 m. At an average of inclination of 31.7 degrees, it is evident that Vaca Perdida acts as a major
A drain for the hillside. The large amounts of surficial debris washed into the deeper levels of the cave also support this statement. The debris includes large amounts of charcoal that appear to be washed in from the burnt fields and not that of past visitation, as is the case in Xcoch Cave. While no active pools of water were present in Vaca Perdida, the lowest levels of the cave are heavily saturated—even containing large puddles of water—and very muddy which is significantly different from the dry passages of Xcoch.

Figure 22: Profile of Cueva de la Vaca Perdida

Three additional speleothems were identified as appropriate candidates for extraction to be used for paleoclimate studies. The location of the speleothem was marked, the speleothem extracted, and a water sample was collected from the drip source. Several samples of charcoal were collected; however, it appeared evident that these had been
washed into the cave from above. It was also noted that one piece of charcoal had been calcified over and sealed into one of the speleothems that we extracted. Several pieces of ceramic were collected and where classified mostly as Late Classic types such as Yocat striated and Muna slate

Having exhausted leads in both the Xcoch and Vaca Perdida caves, efforts turned to locating new caves in the vicinity of Xcoch that may contain useable speleothems for paleoclimate reconstruction. We were informed by one of the local workers of a cave that he had visited as a child. He indicated that they utilized the cave for collecting water for the milpas. The location of this cave was in close proximity to the Maya site of San Andreas and bears the same name. The cave entrance begins as a large sink and continues at a steep incline. The passage suddenly drops off into a negotiable pit. At the top of the pit is an altar. The bottom of the drop continues as a passage that leads to a pool of water. Ceramics are present in the cave but in much smaller quantities than at Xcoch. All ceramics seen were Terminal Classic as well as Colonial wares. The quality of the air in the cave is similar to Xcoch. It has become evident that the primary issue with poor air quality is through the displacement of oxygen with CO2. Reports from other caves suggest that the CO2 is an issue throughout the region. An ongoing question as to whether the low air situation existed when the Maya utilized these caves persists. The knowledge of the existence of a low oxygen environment to the ritual areas would be an interesting addition to current understanding nature of the rituals conducted in caves by the ancient Maya. This can most likely be answered by determining what has caused the increased CO2. If the CO2 is a result of the rehabilitation of the cave by a sizable bat colony, then it can be concluded that the condition did not exist when the ancient Maya were present. Increased CO2 may have also been induced by the Maya from constant ritual activities (especially from fires).

A continuation of this effort led to an attempt to locate two additional caves that had been described to us by a local worker. Our guide reported that he had once used the first cave to obtain water; however, it had been over 15 years since he had been to the location. A long search through the jungle resulted in no success. The second reported cave was a sink quickly found by the guide and is located on the outskirts of Nohpat (Chetulix). He reported that the cave was used as a water resource for the nearby milpas. The location has a significant sinkhole and is very reminiscent of Xcoch Cave and Cueva San Andreas. The entrance has unfortunately been filled, most likely from time and erosion than intentional actions, and access was not immediately possible. A day and a half of digging helped progress further into the cave; however, it was not enough to get past the debris choke. Evidence of speleothems at the dig spot makes it a hopeful location for a significant cave with active speleothems necessary for stable isotope analysis.

**Bat Fauna in Xcoch and Vaca Perdida Caves**

Observations in Xcoch revealed the presence of at least two species of bats, although only one was identified. The funnel-eared bat (*Natalus stramineus*) was the most abundant species observed. This species, of the family Natalidae, is found from northern Mexico to Brazil and in the Greater and Lesser Antilles, according to *Walker’s Bats of*
Un Estudio de la Antigua Comunidad de Xcoch, Yucatán México: Investigaciones Arqueológicas del 2011

*the World* (Ronald M. Nowak, 1994). Hector T. Arita in 1990 found this species in a number of caves in Yucatan, Mexico. Estimating the size of a colony can be difficult though there appeared to be thousands of individuals. This would most likely be considered a significant colony.

The bats were seen flying throughout the cave, likely a result of our presence disturbing them. There were a few clusters in a room that branched off of the upper passage with the majority of the bats roosting in the large room that connects the upper and lower parts of the cave. This is the area of the cave where the “bad air” first becomes apparent. It seemed that the decreased oxygen levels also had an effect on the bats, as they appeared to be much slower in flight than the bats observed in the upper passages. These bats could actually be caught in air with ease.

It was in this area of the cave where two individuals were observed in hand, one male and one female. The male was too stressed and had to be released before any measurements could be taken. The female was inspected closely enough to make an accurate species identification. Measurements taken in mm of the forearm, body, tail, and ears, fall within the ranges listed for this species in *Walker’s Bats*. A weight was not obtained, however the specimen was well within the 4-10 gram weight range for this species. Identification of the species was based on overall physical appearance, size, distinct characteristics (funnel-shaped ears, non-prominent eyes, and cranium shape), body measurements, and geographic range data.

*N. stramineus* was the only species that was truly observed. There was significant evidence of another species, either one that is very elusive or one that no longer roosts in the cave in significant numbers. Remains were found near the entrance, but species identification was not obtained. Many skulls of this unknown species were found throughout the cave. These skulls were much larger than those of *N. stramineus*, and the shape was much like those of nectar-feeding bats (elongated muzzle). According to Arita, only one nectar-feeding species is found in the entire Yucatan peninsula, *Glossophaga soricina* (*Journal of Animal Ecology*, 1997). There was also a possible sighting of this other species roosting on a wall in the upper passage. There appeared to be a small cluster (3-5 individuals). The light was low and they could not be seen very well from the distance at which they were located. Before a closer inspection could be made, they flew off. These bats were definitely larger than *N. stramineus* and they may have been in the phyllostomid family as a nose-leaf seemed to be present. Again, these bats were located much too far away and in low light to have been observed properly. Further investigation would be needed to determine if there is another species still using the cave.

Bats were observed, in Vaca Perdida, in the two large rooms that comprise the upper part of the cave. No bats were observed in-hand; however, one phyllostomid species was easily identified, with fairly good confidence, by observing ceiling roosts and considering geographic range data. Measurements and inspection of skulls and other remains collected also assisted in their identification. This species, believed to be the Mexican fruit-eating bat, *Artibeus jamaicensis*, was observed in clusters throughout the two main rooms. Many females were observed clutching young. Bats of this species are fairly large
relative to others in the region, 40-60 grams in mass, and were easily observed from a short distance. Photographic evidence of this species was obtained for reference. There were easily hundreds of individuals, but a precise estimate of the colony size was not obtained.

Another, smaller species appeared to be roosting in the cave, but a closer look could not be achieved. They appeared to be of the phyllostomid family, as a nose leaf could faintly be discerned. This species could have possibly been *G. soricina*.

**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 2009 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. In 2010, new usable speleothems were collected from a nearby cave, la 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. In 2011, the annual laminae rings of the speleothem samples were counted, dated, and related to the chronology established from other speleothem records for the region. It was hoped that this analysis could shed light of 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 23 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 Chichancanab sites which will both serve as records that have helped create a chronology for our speleothem record and its interpretation.
Figure 23. Location of Xcoch and other sites used in paleoclimate comparison.

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 (above) 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.
Dating Techniques

Uranium series dating techniques, specifically $^{234}\text{U-}^{230}\text{Th}$, 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 $^{233}\text{U}$ and $^{229}\text{Th}$ 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 $^{234}\text{U}$ and $^{230}\text{Th}$, 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 7. 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 24). 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 7. 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 24 show the time series for the oxygen isotopes for VP-10-1. The δ¹⁸O values for speleothems in the tropics and this region have been found to record changes in precipitation. The cause of this variability in the δ¹⁸O 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 Figure 24. H² and H³ 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 $\delta^{18}O$ record, Figure 24a) which is north of our field site (Figure 23). Once again, the Chaac $\delta^{18}O$ 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 $\delta^{18}O$ 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 $\delta^{18}O$ values can be attributed to the frequent hiatuses in our speleothem, differing growth rates and data resolutions between each record. The Lake Chichanacanab $\delta^{18}O$ record (Hodell et al. 2001) further solidifies both the accuracy of our chronology and our precipitation reconstruction (Figure 25b).

Figure 24 Speleothem VP-10-1 $\delta^{18}O$ (%) record

**NB:** $H^1$ & $H^3$ denote number of hiatuses in short successions

$\blacktriangleright\blacktriangleright$ U/Th date with dating error
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 period. 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 (Figures 25a-b). More recently, they have suggested that only
moderate disruptions in rainfall patterns could have been detrimental to the Maya (Medina-Elizalde and Rohling 2012).

A subsection of the Chaac speleothem record is highlighted in Figure 26 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 27 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.
Based upon the counting of annual laminae rings in the speleothems (similar in principal to counting annual growth rings in trees) of the VP-10-1 stalagmite, a more precise chronology of precipitation reconstruction is now possible. Figure 28 is the precipitation record using the annual laminae starting at 1422 AD. This new chronology improved the match between our record and the Medina-Elizade (2112) record from Tecoh cave (Figure 29).

One can also see that the change in growth rates occurred around the time of the depopulation of the region (Figure 30). Above rates measured for sections of the stalagmite that had a similar deposition rate. For example, between 797-892 AD laminae widths become much thicker than for the period 972-1014 AD. The obvious conclusion is that deposition rates were generally greater from 300-870 AD compared to the period after that. The difference between these two periods is 14 mm.
Un Estudio de la Antigua Comunidad de Xcoch, Yucatán México: Investigaciones Arqueológicas del 2011

Figure 29 Comparison between VP-10-01 and Chaac Stalagmite precipitation reconstruction from the Northern Yucatan, Mexico (Medina-Elizalde et al. 2012)

Figure 30. Variable deposition rate for VP-10-01 around 900 AD.
Figure 31. Photos of speleothem annual laminae rings showing distinct events within VP-10-01. Left value is distance from top (cm), middle is years BP, and right is years AD.
<table>
<thead>
<tr>
<th>Period AD</th>
<th>Type of event</th>
</tr>
</thead>
<tbody>
<tr>
<td>327-322</td>
<td>Series of floods</td>
</tr>
<tr>
<td>691</td>
<td>Flood</td>
</tr>
<tr>
<td>841-845</td>
<td>Series of floods</td>
</tr>
<tr>
<td>902-932</td>
<td>Floods followed by Vuggy calcite</td>
</tr>
<tr>
<td>1012-1015</td>
<td>Flood</td>
</tr>
<tr>
<td>1027</td>
<td>Flood</td>
</tr>
<tr>
<td>1047</td>
<td>Flood</td>
</tr>
<tr>
<td>1165-1179</td>
<td>Several floods with “thick” layers of sediments within calcite</td>
</tr>
<tr>
<td>1197</td>
<td>Flood</td>
</tr>
<tr>
<td>1251</td>
<td>Flood</td>
</tr>
<tr>
<td>1282-1288</td>
<td>Series of floods</td>
</tr>
<tr>
<td>1372-1382</td>
<td>Several floods with distinct black layers</td>
</tr>
</tbody>
</table>

Figure 32. Description of distinct layers in VP-10-01

Figures 31 and 32 show the distinct layers (floods) found within the stalagmite. Rationale for naming the brown layers “flood events” is because the material within the top most layers was found to be a sandy clay which is found above the cave. This sediment could only have been deposited on the stalagmite by a large amount of surface water flowing into the cave carrying with it suspended sediment, i.e. a flood induced by a large storm.

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. However, the investigation of annual laminae rings in the speleothem has been particularly fruitful. This last mode of study has helped create greater precision for the chronology, a technique long undertaken in dendrochronology and has shown even closer correspondence between VP-10-01 and the Chaac speleothem from Tecoh cave. Clear laminations throughout the speleothem show distinct brown layers that are interpreted as flood events induced by intense rainstorms in the past. Consequently, although there are more obstacles to overcome and 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 have been addressed by interdisciplinary work at Xcoch and vicinity. Multiple data sources have identify patterns of Preclassic chronology and culture process and revealing Middle Preclassic community organization for the Puuc hills region by documenting contextual information on architecture and reconstructing the settlement and artifact landscapes. Xcoch may have been a large Preclassic center for the Puuc hills of special importance because it contained one of the three known water-bearing caves in the region. Indeed, 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 patterns of rainfall, at a site that experienced a long occupation with massive monumental architecture as early as the Middle Preclassic period based upon an agricultural economy with complex social organization into the Late Classic period. Xcoch shows evidence of climate change during the site's long span of occupation including multiple collapses, one in the Late Preclassic and another in the Late Classic, perhaps brought on, in part, by recurring cycles of intense drought. Investigation at the site has revealed a sophisticated hydraulic system of water retention that was built and rebuilt including large depression features (aguadas) and potentially dozens of smaller water tanks (reservoirs), canal systems, and chultuns constructed to store vast amounts of rain water for domestic consumption, irrigation, and perhaps trade likely in response to reoccurring drought cycles.

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. The discovery of multiple water tanks integrated into large platforms in 2011 further extends water management. 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 at Xcoch as well as the caves there and vicinity 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. The interdisciplinary 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 (#1132061). 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 Antropología e Historia. We are also gratefulness 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, Karen Crissy, Greg Korosec, Caitlin Curtis, Laurel Triscari, and Rebecca Miller of the University at Buffalo for their services to the Project. 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, Humberto Bonilla Mian, 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.

Bibliography

Anderson David S.

Andrews, E. Wyllys V.

1990 The Early Ceramic History of the Lowland Maya. In Vision and Revision in Maya Studies,

Arita, Hector

Arita, Hector


Bey, George J., III

Bey, George J., III and Rosanna May Ciau

Brainerd, George W.

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

Dunning, N. P.


Dunning, N., T. Beach, and D. Rue,

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

Dunning Nicholas P., Eric Weaver, Michael P. Smyth, and David Ortegon Zapata

Folan, William J.

Ford, Anabel

Gallareta Negrón, Tomás and William M. Ringle
2004 The Earliest Occupation of the Puuc Region, Yucatan, Mexico: New Perspectives from

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

Kepecs, S., and S. Boucher


Lozano-Garcia Maria del Socorro, Margarita Caballero, Beatriz Ortega, Alejandro Rodriguez, and Susana Sosa
2007 Tracing the Effects of the Little Ice Age in the Tropical Lowlands of eastern Mesoamerica. PNAS 104:16200-16203.

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

Medina-Elizalde Martín and Eelco J. Rohling

Mercer, Henry Chapmen

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


Nowak, Ronald

Pires-Ferreira, Jane W.

Pollock, Harry E. D.

Ringle William M., and E. Wyllys Andrews V

Robles Castrillanos, Fernando

Rovner, Irwin and Suzanne M. Lewenstein 1997 Maya Stone Tools of Dzibilchultun, Yucatan, and Becan and Chicanna, Campeche. Middle American Research Institute Publication 65. Tulane University, New Orleans.


Smyth Michael P., Ezra B.W. Zubrow, David Ortegón Zapata, Nicholas P. Dunning, and Philip van Beynen 2011b 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 Early–Concept Grants for Exploratory Research (EAGER), Arctic Social Sciences Program (www.FARINCO.org).


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.