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Sediment History from K"ak" Naab" Column Sample 2: Human-Environment Interaction at a Classic Period Maya Salt Works Site

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Sediment History from K'ak' Naab' Column Sample 2: Human-Environment Interaction at a Classic Period Maya Salt Works Site

by

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INTRODUCTION

Sediment history can be used to reveal onsite and offsite differences in sediment formation processes and anthropogenic impacts on the environment at a Classic Maya salt works. Site formation processes, including sediment deposition and human occupation of the site, build our understanding of human-environment interaction in a coastal environment. Traditional archaeological methods centered on material culture alone are limited in the extent to which they facilitate an exploration of paleoecological conditions and human-environment interaction. Sediment core analysis, when combined with cultural data, provides a powerful tool for understanding the ancient environment and the interplay between humans and the environment in which they lived.

Two sediment columns taken from site 14 in Paynes Creek National Park, Toledo District, Belize allow for the reconstruction of the ancient landscape inhabited by the Classic Period Maya of Paynes Creek. Analysis of Column Sample 1, taken offsite during the 2008 field season, confirmed the ability of sediment analysis to aid in the reconstruction of site formation processes and the ancient environment with which the Maya interacted (see McKillop et al. 2010, 2011). This thesis focuses on a second sediment column taken from the onsite area of site 14 (K'ak' Naab'), which was retrieved during the 2010 field season and transported to Louisiana State University for laboratory analysis. K'ak' Naab' Column Sample 2 is a 60 cm-long sediment column cut from the seafloor of site 14 in close association with material cultural remains. What evidence is there for onsite-offsite differences in the ancient landscape and occupation at site 14? Analysis of the organic content, sediment composition, and radiocarbon dates provide evidence for human occupation and manipulation of the onsite area, as well as vertical change and continuity in site formation processes. Comparison with K'ak' Naab'

Column Sample 1 develops our understanding of landscape changes and paleoenvironmental conditions during site occupation.

SIGNIFICANCE OF RESEARCH FOR MAYA ARCHAEOLOGY

Environmental change and eustatic sea-level rise are challenges that have been faced by human societies past and present. Reconstructing sediment histories documenting paleoenvironmental changes in coastal archaeological contexts can help us to understand how ancient peoples dealt with sea-level rise. Sea-level rise and changing coastlines are ever-present challenges to the livelihoods of coastal populations. These issues are relevant to modern society as we struggle to understand the impacts of global warming and increasing rates of eustatic sea-level rise.

For ancient civilizations, salt production was an essential industry that provided a biological necessity to large, urban populations. The carbohydrate-based diet of the Classic Period Maya (roughly A.D. 300-900) did not provide adequate amounts of salt, making additional salt a vital dietary supplement (McKillop 2008). In the southern Maya lowlands, inland urban centers traded for salt produced at coastal salt works (McKillop 2008). The K'ak' Naab' salt works site, an inundated Classic Period Maya site in southern Belize, is one production center for the southern Belize salt trade. Salt production at K'ak' Naab' is documented by briquetage, a specialized and uniform assemblage of ceramic vessels and supports created specifically for the production salt by boiling brine over large fires (McKillop 2005). A wooden canoe paddle recovered from K'ak' Naab' provides further evidence for canoe-based trade with inland centers (McKillop 2007). My research follows previous studies mapping

and analyzing the wooden architecture and briquetage at K'ak' Naab.' Studying the ancient environment and environmental change contributes to our understanding of the landscape ancient people lived in and how they modified and adapted to a coastal environment.

BACKGROUND INFORMATION

Sediment coring in the Maya area has been used in a variety of environments ranging from terrestrial sites to lakes to marine sediments. A variety of methods have been employed to obtain sediment cores from these diverse settings. Researchers commonly use vibracores or piston corers to extract lake sediments, which may lie meters below the water's surface (Johnston et al. 2001; Dunning et al. 2002; Wahl et al. 2007). Less orthodox but equally efficient coring methods include sampling the wall of an excavation unit or cutting marine sediment out of the sea floor (Beach et al. 2010; McKillop et al. 2010). Sediment coring techniques are extremely adaptable, and should change according to the varying physical conditions of each site and the research goals of each archaeologist.

Paleoecological data from sediment cores have been used to infer both the cultural and environmental conditions of Maya sites. Sediment coring in the Maya area gained prominence with the Chichancanab core, which brought attention to the growing role of environmental and climatological data in archaeological studies (Hodell et al. 1995). Gill (2007) uses the Chichancanab core contentiously to argue for drought as the ultimate cause of the Classic Maya Collapse; however, most archaeologists are wary of using paleoecological data in isolation. Sediment cores taken from wetland settings such as swamps and aguadas have provided valuable palynological data which reveal ancient landscape changes due to both environmental and anthropogenic causes (Abrams and Rue 1988; McNeil et al. 2010; Pohl et al. 1996). Terrestrial

sediment cores have been used to better understand land use, agricultural, and water management practices of the ancient Maya (Johnston et al. 2001; Lucero 2002).

Marine sediment cores in the southern Maya lowlands contain sediments formed by mangrove peat. The southern Maya lowland landscape is underlain by Pleistocene limestone karst which forms the bedrock on which marine sediments, primarily histosols resulting from *Rhizophora* (red mangrove) and *Avicennia* (black mangrove), formed during the Holocene (Gischler and Hudson 2004). The modern coastline of southern Belize is dominated by mangrove forests which thrive in saline intertidal zones. *Rhizophora* is the predominant species near open waters, while *Avicennia* is better suited to the more saline interiors of mangrove stands, which experience less tidal fluctuation (McKee 1995). Mangrove stands accumulate organic matter in response to gradual sea-level rise, resulting in the vertical accretion of mangrove peat over time (Middleton and McKee 2001). In southern Belize, sea-level rise has caused up to 9 meters of mangrove peat to form on top of the underlying karst (McKillop 2005: 5631).

Eustatic sea-level rise has led to the submergence of coastal sites around the world. Changing sea-levels and coastlines in the Caribbean have inundated terrestrial Maya sites throughout the southern Maya lowlands. Survey and excavation of the Belizean cayes have revealed a wealth of submerged Maya sites which are inaccessible to terrestrial archaeology (McKillop 2005; McKillop et al 2010).

Paynes Creek National Park is dominated by mangrove stands surrounding shallow, open water lagoons. The sea floor of these shallow-water lagoons consists of over 4.3 m of mangrove peat (McKillop 2005: 5631). Sediment cores and column samples taken from salt works sites within Paynes Creek National Park suggest that the rate of sea-level rise in southern Belize slowed from the Early Classic to the Late Classic, presumably allowing the Maya to construct

salt works structures on dry land (McKillop et al. 2010). In this case, at some point in the Postclassic sea-level rise outpaced the ability of the mangroves to accrete sediment, and the sites and forest were inundated by rising water (McKillop et al. 2011).

Sediment coring methodologies for submerged coastal Maya sites are determined by the difficulty of transporting equipment to remote, aquatic sites, as well as by the physical constraints of working in a submerged, shallow-water site. One technique which has proved useful for coring submerged sites in southern Belize is cutting sediment columns from the sea floor (McKillop et al. 2010). Marine sediment in the southern Maya lowlands is composed primarily of organic matter, especially small mangrove roots, rather than inorganic minerals (Middleton and McKee 2001: 825).

During the 2007 field season, a sediment core was taken from an offsite area of the K'ak' Naab' site in Paynes Creek National Park and analyzed for organic content, composition, and radiocarbon dated. This study records over 4,000 years of sea-level rise surrounding a Classic Period Maya occupation of the saltworks site. Since the earliest occupation of K'ak' Naab', sea-level rise as documented by mangrove peat accumulation exceeded 130 cm before inundating the mangrove forest (McKillop et al. 2011). This study examines a second K'ak' Naab sediment column taken onsite for comparison to the 2007 core. Following the procedures established by McKillop, Sills, and Harrison (2010) with assistance from Karen McKee, this study will address questions about the ancient landscape of Paynes Creek arising from the K'ak' Naab' column sample 1 data.

MATERIALS AND METHODS

Sediment core collection

The sediment column sample was collected from site 14, K’ak Naab’, located in the East Lagoon of Paynes Creek National Park, as part of a collaborative project with my advisor. The field team included project members Heather McKillop, Cory Sills, John Young, Mark Robinson, Roberto Rosado, Taylor Aucoin, and Jaclyn Landry.

The exact location of the sediment column was decided by my advisor, based on previous research at the site. The 60 cm K’ak Naab’ sediment column sample was divided into 6 levels of 10 cm each. Levels are labeled 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, and 50-60 cm. Each successive level should be older than the previous level, because mangrove peat is laid down as mangrove roots grow in response to sea-level rise. An 80 cm transect was marked by two red flags, labeled “A” and “B,” which provided a visible, above-water spatial reference for the column sample. These flags were used to determine the straight face of the sediment column. We removed an 80 cm by 80 cm by 60 cm block of sediment from in front of the transect. Clearing this block of sediment created a straight wall for the sediment column and provided a subaqueous working area for cutting the lower levels of sediment.

Sediment was cut using 18” stainless steel kitchen knives. A waterproof metric sewing tape was used to measure each 10 cm increment. Two people, working as a team, were needed to sample each level. One team member remained on the surface, holding the sewing tape to the upper right edge of the straight face, while the other measured a 10 cm level and cut a straight line perpendicular to the measuring tape. Once the level was marked by the initial vertical cut, the sides and back of the sediment column were also cut. The resulting sediment sample was approximately 20 cm by 20 cm by 10 cm (Figure 1). We controlled for the depth of the block

more carefully than the length and width because the sediment column was later cut down to a more manageable size in the field laboratory at Village Farm, the organic cacao farm run by our host family, John Spang and Tanya Russ.

Figure 1. Jessica Harrison is cutting the site 14 sediment column. Photo by Heather McKillop.

As each 10 cm level was removed from the sea floor, the sediment was carefully packaged at the Portable Research Station (PRS). The PRS provided a dry workspace and storage area for cling wrap, sharpie markers, and Ziploc bags. The six levels of the sediment column were individually wrapped in cling wrap marked with up arrows, “front,” and “back” to designate the orientation of the sediment column. “Front” referred to the face from which the sediment column was measured and cut. “Back” referred to the opposite wall of the sediment column. The up arrow indicated the surface of the sediment sample which was closest to the seafloor. These markings ensured that the orientation and stratigraphy of the sediment column were preserved after sampling. The wrapped 10 cm levels were then placed into large plastic Ziploc bags which were labeled with site number, sediment column level, collector’s name, and date. To obviate the problem of losing this contextual information, the label was written at least twice on the bag in permanent marker.

The sediment column was further processed in the field laboratory at Village Farm. The sediment columns were cut down and repackaged for export. MA student Roberto Rosado and I worked together to cut each level down to a block of sediment approximately 10 cm by 3 cm by 3 cm blocks. Working one sediment column sample at a time, we laid out the individual levels in numerical order. The wrapped sediment blocks were removed from the plastic bags and photographed to provide a pictorial record. Using a clean stainless steel knife and metric tape, we then measured the length of the sediment block and cut off excess sediment at the 3 cm mark. The width of the sediment was likewise cut to 3 cm. No sediment was removed from the height, which came to slightly less than 10 cm due to water loss after the water-logged sediment column was removed from its marine source. To prevent cross-contamination, the knife and tape were washed between each cut. Once each 10 cm level was cut to a 3 cm by 3 cm by 10 cm block, it was photographed before being repackaged in a fresh piece of cling film marked with up arrows, “front,” and “back.” The wrapped sediment was then packed in a new, labeled plastic zip-top bag. My sediment column was then placed in a large Rubbermaid bin, along with Roberto Rosado’s seven sediment columns from sites 24 and 35 for my advisor to take the sediment to the Institute of Archaeology in Belmopan, Belize to obtain an export permit.

Sorting Sediment

Analysis of the sediment column was conducted at the Coastal Archaeology of Latin America (CALA) and Coastal Geomorphology laboratories in the Department of Geography and Anthropology at Louisiana State University under supervison of my advisor, along with Cory Sills. I met with them as well as Roberto Rosado to formulate and discuss the hypotheses, methodology, and results of my honors project, which is done with their collaboration, but carried out by me. The sediment sample was analyzed to determine the organic composition of

the sediment and to verify the hypothesis that the Paynes Creek sediment consists of *Rhizophora mangle*, red mangrove, roots accumulated in response to eustatic sea-level rise.

The K'ak' Naab' Column Sample 2 was described to note both quantitative and qualitative differences throughout the vertical extent of the sediment. The levels were re-measured to document any change in length, described according to their visual and tactile characteristics, and photographed to provide visual documentation of the condition of the sediment upon arriving in the CALA lab.

Sorting the sediment allows comparison of the site 14 sediment column 2 to the 2008 column taken between site 14 and site 15. Each 10 cm level of the 60 cm sediment column was sorted into its four components: wood, leaf fragments, coarse roots, and fine roots. For uniformity, each sample of sediment was taken from the upper, back corner of the left cut of each level. A 1 cm^3 sample of sediment was rinsed on a 1mm (#18) mesh sieve to separate soil from the organic matter of the peat. The rinsed sediment was placed in a petri dish with water and sorted under magnification following the procedure established by McKillop, Sills, and Harrison (2010) with guidance from Karen McKee.

Sorted sediment for each level was divided into four labeled vials to separate and store the four components (leaves, wood, fine roots, and coarse roots). Inorganic material, such as grains of quartzite, was also sorted out of the sediment and stored in a separate vial for later analysis. Sorted sediment was refrigerated to deter deterioration.

Loss-on-ignition

Loss-on-ignition (LOI) was conducted in the Coastal Geomorphology lab to determine the organic content of the marine sediment, thus determining whether or not the sediment was peat. We moved some equipment, including the muffle furnace and drying oven, from the CALA

lab to the Coastal Geomorphology lab in order to carry out loss-on-ignition. Peat should have relatively high organic content because peat forms in anoxic conditions which preserve organic material. Small samples of sediment from the middle of each of the six 10 cm levels, as well as a sample from the base of the column sample, were selected for LOI. These samples, ranging from 12.9g to 15.0g, were cut from the center of each level. For levels 1, 2, 3, 4, and 6, the sediment sample was taken from between 4.5 and 6.5 cm. Level 5, which was compacted to an 8.5cm extent, was sampled between 3.5 and 5.5 cm. The base of level 6 was sampled between 9 and 10 cm. The wet sediment samples were placed on clean petri dishes and placed in a 60° C oven for 24 hours to dry. Dry sediment was then ground into a fine powder using a mortar and pestle (Figure 2) before being returned to the 60° C oven to continue drying overnight.

Figure 2. Ground sediment in mortar. Photo by Heather McKillop.

Meanwhile, crucibles and crucible lids were cleaned in a dilute, 10% HCl solution. A fume hood, protective gloves, and protective eyewear were used as a safety precaution. The clean crucibles were then dried overnight in a 60° C oven to remove all water, which would skew the results. Clean, dry crucibles were labeled 1 through 6 using heat resistant acrylic craft paint. Once the paint was dry, the crucibles were weighed on an electric balance (Figure 3) to determine dry crucible weight.

Figure 3. Ground sediment is weighed on an electronic balance. Photo by Jessica Harrison**.**

About 1 to 2g of dry, ground sediment from each of the column sample levels was added to its corresponding crucible. The crucibles were weighed again to determine crucible plus sample weight. The samples were then placed in a 105 C oven for four hours to continue drying. After four hours in the 105 C oven, crucibles were cooled in a desiccator for 10-15 minutes and then weighed again to determine crucible plus dry sediment weight. The crucible weight was subtracted from the combined dry sediment and crucible weight to find the dry sediment weight.

Dry sediment samples were then placed in a 550° C muffle furnace (Figure 4) and combusted for 8 hours to burn off all organic material, resulting in ash. The temperature of the oven was carefully maintained, as fluctuations in temperature greatly affect the LOI results. After 8 hours, the sediment was placed into the 105° C oven for one hour to cool, then transferred to the desiccator to cool for a further 15 to 30 minutes. Once cooled, crucibles were weighed a final time and the crucible plus ash weight was recorded. Percent organic matter (OM) was calculated by dividing dry sediment weight minus the ash weight by dry sediment weight and multiplying by 100 to obtain a percentage value.

Figure 4. Crucibles in muffle furnace. Photo by Jessica Harrison.

AMS Radiocarbon Dating

Two samples for Accelerator Mass Spectrometry (AMS) dating were submitted to Beta Analytic. Beta Analytic provided the radiocarbon dates for the 2008 K'ak' Naab' sediment core, so I used the same facility to ensure that results from the sediment cores can be compared chronologically. To obtain at a minimum sample size of 1g of fine roots, a sample of sediment from 32 cm in level 4 and 60 cm in level 6 was rinsed and sorted under magnification and fine roots were stored in a glass vial.

The samples were chosen to address several research questions. A visible change in the Munsell soil color, from very dark brown to black, of the column sample at 32 cm indicates a change in soil formation processes. This raises the possibility that occupation-related clearance caused the change in pedogenesis. The level 4 AMS sample also explores the 13% increase in OM observed during LOI. Radiocarbon dating the base of level 6 will provide a chronological extent for the column sample and determine the average rate of peat accumulation, and thus sea-level rise, from the level 4 radiocarbon sample to the base of the sediment column.

RESULTS

Description of Sediment

Measuring each level of the sediment column found that some levels of the sediment column were compacted, either during transport or through the loss of water content once K'ak' Naab' column sample 2 was removed from the seafloor. Two levels of the sediment column were compacted. Level 1 was 9.5 cm long, and level 5 was 8.5 cm long. All other levels remained an original length of 10 to 10.5 cm. A small amount of yellow-white mold was noted on the upper portions of levels 1, 2, and 3. The mold was only present on the surface of the sediment samples, and did not penetrate into the interior of the sediment.

Using a Munsell soil color chart, the sediment coloration was described both before and after LOI. Analysis of the marine sediment found that the sediment column was divided vertically into two different soil colors, with a lighter coloration persisting from 0-32 cm and then changing abruptly to a darker coloration for the remaining depth. This shift in color was visible as a line slanting horizontally from 32 cm at the face of the column to 37 cm at the back of the column. The upper 35 cm were classified as 10 YR 2/2 very dark brown, and the lower 25 cm as 10 YR 2/1 black. This change in coloration coincides with a change in the texture of the sediment. The areas of levels 1-4 which were classified as 10 YR 2/2 were more fibrous to the touch, while levels 4-6 described as 10 YR 2/1 were less firm and fibrous to the touch.

After LOI, the ashed sediment was described using a Munsell soil color chart, revealing a shift from dark brown to pale reddish soil color (Table 1). The ash color varied greatly among the sediment column samples from sites 14, 24, and 35. After LOI was performed on site 14 column sample 2, the top centimeter was 2.5 YR 5/3 reddish brown. Level 1 was 5 YR 5/4 reddish brown. Level 2 was 5 YR 6/4 light reddish brown; level 3 was 5 YR 6/6 reddish yellow;

level 4 was 5 YR 5/4 reddish brown; levels 5 and 6 were 5 YR 7/4 pink; and the base was 7.5 YR 8/4 pink.

Table 1. Munsell Soil Color Classification

Sample ID	Sediment before LOI	Ashed Sediment
14-2-Top	10 YR 2/2	2.5 YR 5/3
14-2-1	10 YR 2/2	5 YR 5/4
14-2-2	10 YR 2/2	5 YR 6/4
14-2-3	10 YR 2/2, 10 YR 2/1	5 YR 6/6
14-2-4	10 YR 2/1	5 YR 5/4
14-2-5	10 YR 2/1	5 YR 7/4
14-2-6	10 YR 2/1	5 YR 7/4
14-2-Base	10 YR 2/1	7.5 YR 8/4

Sorting

Sorting the sediment found that the four major organic components of the K'ak' Naab' Column Sample 2 were fine roots, coarse roots, leaf fragments, and wood. By volume, fine roots composed the majority of the sediment. Coarse roots were the second most prevalent component, with leaf fragments and wood being the scarcest of the four major components of red mangrove peat. Matter which could not be classified as fine roots, coarse roots, leaves, or wood was placed in vials labeled 'Other'. Leaves were not identified among the sorted material from this column sample.

Level 1 consisted mostly of large fine roots which were well-preserved. Coarse root pieces were plentiful, whole, and well-preserved. Level 1 had no wood or sand grains. Level 2 contained a similar amount of well-preserved fine roots, and coarse roots were split between

small, degraded pieces and larger, well-preserved fragments. The sample from 10-20 cm contained no wood or sand. Level 3 contained a similar amount of fine roots, though coarse roots were scarce and much more degraded. Level 3 contained no wood or sand. Level 4 contained a moderate amount of somewhat degraded fine roots. Coarse roots were plentiful, and included both large and small, degraded root pieces. No wood or sand was recovered from the level 4 sample. The 40-50 cm sample revealed fewer fine roots than previous samples. Coarse roots and leaves consisted of tiny, degraded fragments. One small piece of wood was recovered from level 5, but the sample contained no sand. Level 6 fine roots were more degraded than previous levels. Coarse roots were abundant and included both large, well-preserved and small, degraded pieces. No sand was recovered from the 50-60 cm sample.

Across the six 10 cm levels of the K'ak' Naab' column, the sediment was primarily composed of fine roots. The quality of preservation of both fine and coarse roots decreased as depth below the seafloor increased, with the best preserved fine roots in level 1 (0-10 cm) and the most degraded fine roots in level 6 (50-60 cm). The preservation of coarse roots also showed a vertical trend, with best preserved coarse roots in the uppermost levels and the most degraded roots in the lower levels.

Loss-on-ignition

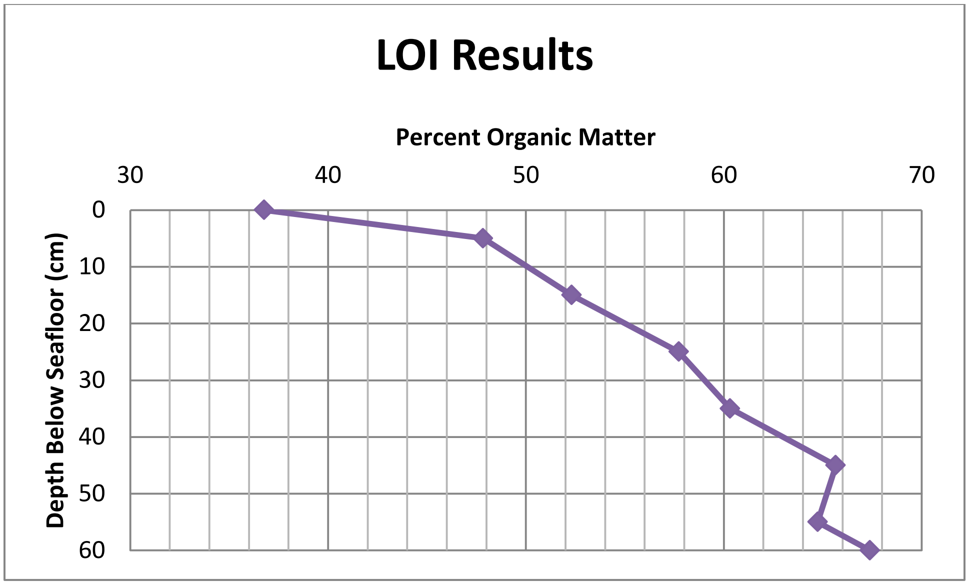
Loss-on-ignition of site 14 column sample 2 revealed an overall trend of an increase in percent organic matter (OM) as depth below the seafloor increases (Tables 2 and 3). OM ranged from 36.78% in the uppermost centimeter of the sediment column to 67.38% at the base of the column, revealing a vertical increase of almost 31% OM across the 60 cm sediment column. With an OM of 36.78%, the uppermost centimeter of the column sample was not a histosol; however, the sediment is within 4% of being classified as a histosol. All other levels of K'ak'

Naab' column sample 2 are above 40% OM, and thus are classified as histosols, or peats. The average percent organic matter for column sample 2 was 56.56%, within the expected range for red mangrove peat (McKee and Faulkner 2000). Notable differences in OM occur in level 1, which shows an 11% increase between 0 and 5 cm, and in the 13% increase in OM between levels 3 and 5. This increase in organic matter between levels 3 and 5 corresponds with the sudden, distinct color change running at 32-37 cm in level 4.

Table 2. K'ak' Naab' Column Sample 2 LOI Results

Sample ID	Depth Below Seafloor (cm)	Percent Organic Matter
14-2-Top	0	36.78
14-2-1	5	47.84
14-2-2	15	52.32
14-2-3	25	57.73
14-2-4	35	60.32
14-2-5	45	65.66
14-2-6	55	64.75
14-2-Base	60	67.38

Table 3. Graph of LOI Results, K'ak' Naab' Column Sample 2



Radiocarbon Dates

Two radiocarbon samples were chosen from K'ak' Naab' Core 2. The first sample, taken from level 4 at a depth of 35 cm, sits at the abrupt change in sediment color noted above. The sample was taken from just above the shift from 10 YR 2/2 very dark brown to 10 YR 2/1 black. The 35 cm sample was dated to A.D. 890-1020, which includes the Terminal Classic and Early Postclassic periods. A second radiocarbon sample, taken at 59 cm depth, derives from the base of the sediment column. This level dated to A.D. 1020-1170, which is in the Early Postclassic period.

DISCUSSION

Qualitative description of column sample 2 revealed several vertical changes in the sediment. Sorting the sediment under magnification demonstrates that the onsite sediment at the K'ak' Naab' site is fairly homogeneous, at least throughout the upper 60 cm of the seafloor. Each level of the sediment column consists primarily of red mangrove peat (roots, leaves, and wood), with few other inclusions. The lack of sand in site 14 column sample 2 suggests that the K'ak' Naab' site is situated in a sheltered area of the lagoon, where wind and wave action did not move sand into the sediment column. Conversely, the site may have been at a higher elevation than the surrounding areas, leading to sand deposition on nearby depressions on the sea floor. The complete lack of sand in the sorted sample is somewhat misleading. A small amount of sand was present on the top of level 1. Traces of sand were found throughout the sediment column, suggesting that sorting 1 cm^3 of sediment from each level may not always provide a truly representative sample of the entire column sample.

The sediment showed a strong vertical trend of increasing decomposition as depth below the seafloor, and thus the age of the sediment, increased. The vertical change in the preservation of organic matter is to be expected even in the relatively anoxic conditions of mangrove peat, as lower levels of sediment undergo environmental processes and weathering for increasingly longer periods of time.

The abrupt change in color that occurs in level 4 is the most visually evident vertical change in the sediment. A line slanting horizontally downwards from 32 cm at the face to 37 cm at the back of the core marks the transition from 10 YR 2/2 to 10 YR 2/1. This change in color is simultaneous with a change in the texture of the sediment. Above the break, the sediment is

lighter and more fibrous than the lower half of the sediment, which is markedly darker, wetter, and less fibrous. The concurrent change in color at texture is significant, because the change implies different sediment formation processes above and below the break.

The sudden change in sediment formation suggests a dramatic environmental change occurred which affected the accumulation of mangrove peat. Previous studies of briquetage and wooden building remains from K'ak' Naab' determined that the site is a Classic Period salt works (McKillop 2005). In order to inhabit the site and construct the salt works building, the Maya would have needed to clear the mangroves, bringing peat accumulation to a standstill for the duration of the site's occupation. Is the change in sediment formation related to human occupation of K'ak' Naab'? The 35 cm radiocarbon sample was taken to address this question. The 35 cm sample dates to A.D. 890-1020, the end of Classic Maya occupation at K'ak' Naab'. The shift in sediment color from 10 YR 2/1 black to 10 YR 2/2 very dark brown at 35 cm represents an environmental change which may be the regrowth of mangroves following human abandonment of the salt works structure at K'ak' Naab'. The site 14 salt works structures were built on dry land which has since been covered by an additional 35 cm of sediment and submerged by 43 cm of ocean water (McKillop et al. 2011). In order to create a habitable space within the mangrove forest, the Maya would have had to clear areas of the mangrove stands. In histosols dominated by red mangrove, forest clearance would greatly impact both the rate of sedimentation and the composition of sediment. The sudden change in color noted in level 4 is most likely attributable to forest clearance, although environmental, rather than anthropogenic, factors may have caused the abrupt change in sedimentation.

While the unashed sediment column showed only one change in Munsell soil color, the ashed sediment was classified differently for seven of the eight LOI samples. Ashed sediment

was consistently paler and redder than the pre-LOI sediment samples; however, there is no correlation between the original sediment color and the ashed sediment color. Perhaps various mineral inclusions which were undetectable during sorting caused the dramatic color differences present in the ashed sediment. After LOI, red mangrove peat generally tends to become paler and redder, but with a wide range of variation in color. Color change in ashed red mangrove sediment is to be expected, and based on analysis of five sediment columns, Munsell color of the ashed sediment will range from reddish or light reddish brown to yellowish red to pink or pinkish gray. The variability in color is an interesting result which could be pursued through further analysis of the mineral inclusions of each level of mangrove peat.

Given the results of LOI, K'ak' Naab' sediment column 2 is composed entirely of histosols, with the exception of the uppermost centimeter of level 1. Although no sand was recovered from the $1cm^3$ sorted sample of level 1, sand was noted in the very top of the sediment column. The higher inorganic content of the uppermost centimeter of the sediment is caused by the movement of sand and other inorganic materials along the surface of the seafloor. Wind, waves, and storm surge from the frequent tropical weather disturbances all carry material along the seafloor from open water into the lagoon system, resulting in a different sediment regime at the seafloor surface.

LOI of the 2008 offsite sediment column found a similar trend, with OM increasing with depth below the seafloor. Column sample 1 had consistently higher organic than column sample 2, with average OM of 65%, which is 9% higher than the 56% average OM found for column sample 2 (McKillop, Sills, and Harrison 2010). Unlike column sample 2, column sample 1 yielded the lowest OM around 50 cm, which coincides with the occupation of site 14 (McKillop, Sills, and Harrison 2010). In column sample 2, occupation of the site is not marked by such a

decline in organic content. Instead, the trend of gradual increase from 37% OM to 67% OM continues throughout the entire 60 cm sediment record.

The methods used for loss-on-ignition vary widely. Exposure times as low as 1 or 2 hours, and temperatures as high as 950-1000° C are reported in the literature (Heiri et al. 2001; Smith 2003). In general, highly organic sediments require longer burning times to ensure that all organic matter is completely ashed. Conversely, sediments lower in organics require a lower burn time. LOI methodology varies according to sediment type. For *Rhizophora mangle* peat, an exposure time of 8 hours at a temperature of 550° C produces consistent results. Our methods for loss-on ignition have been refined through running the procedure on five sediment columns from Paynes Creek. After re-ashing two column samples that yielded lower-than-expected OM results and finding as little as seven one-thousandths of a percent change, we are confident in the methodology for conducting loss-on ignition on tropical histosols. Variability in the results, then, is caused by lower than anticipated organic content of the uppermost levels of sediment rather than a deficiency in the methods.

A sediment core taken in the offsite area between sites 14 and sites 15, K'ak' Naab' sediment column 1, reveals the end of Classic Period occupation to be at 75 cm (McKillop et al. 2011: 4), placing the abandonment of site 14 a full 40 cm further below the sea floor than in the onsite sediment column. The landscape of site 14 at the time of Classic Period occupation must have been very different from the modern landscape, which is a fairly flat seafloor of mangrove peat submerged 43 cm below sea level. Given the 40 cm difference in elevation at the time of occupation, it seems that K'ak' Naab' column sample 1 represents an offsite channel where the terrain was lower than the ground surface of the occupied area. A greater accumulation of mangrove peat occurred in this channel than on the cleared, dry site area, suggesting that the

offsite area was inundated at the time of occupation. Sedimentation in the offsite channel was able to continue throughout the site occupation, resulting in the 40 cm difference in the depth below seafloor at which the occupation level is found.

The 35 cm radiocarbon date reveals the ancient landscape in which the Maya salt makers lived and worked. The site area was cleared, dry, and elevated above a nearby channel running between sites 14 and 15. If the channel was inundated, it could have provided a convenient route for transportation to and between the salt works area. Based on radiocarbon dates from K'ak' Naab' column sample 1, Maya occupation of the site began in the Early Classic (McKillop et al. 2010), and continued until the Terminal Classic/Early Postclassic abandonment of the site documented by column sample 2. These dates provide a chronological basis for a cultural, as well as environmental, understanding of the K'ak' Naab' site, centered around an occupation spanning the Classic period.

Throughout the sediment history documented by K'ak' Naab' Column Sample 2, pedogenesis results from the interaction of mangroves, humans, and eustatic sea-level rise. As such, the sediment column reflects site conditions before, during, and after the Classic Maya occupation of the site 14 salt works. The bottom 25 cm of sediment reflect the continuous accumulation of peat in a presumably undisturbed mangrove forest. At this point, the mangroves are able to keep pace with gradual sea-level changes by building up the land surface simultaneous with sea-level rise. At some point below 35 cm, the Maya cleared the mangroves at site 14 and constructed a salt works which was occupied until A.D. 890-1020. During occupation, the land surface must have been above the tide line, and peat accumulation stagnated as long as the site was maintained by forest clearance.

Following abandonment in the beginning of the Early Postclassic, mangroves reclaimed the site and sediment accumulation resumed. The A.D. 1020-1170 date at 59 cm suggests that relatively high levels of bioturbation occurred after abandonment in the Early Postclassic. Coarse roots from mangroves colonizing the site penetrated at least 25 cm into earlier sediments, then decayed to such an extent as to be unrecognizable when the 14C sample was collected from the base of level 6. Clearly the roots sample from 59 cm belong to the mangroves which reclaimed site 14 following the abandonment of the K'ak' Naab' salt works, and the base of the sediment column actually dates to a much earlier time. Despite providing an unexpectedly late date for 59 cm, the sample still informs us about site processes following abandonment. By A.D. 1020-1170, the mangrove forest had completely reclaimed the Classic Period occupation area, suggesting that the mangrove forest had a high degree of resiliency which allowed the local ecology to rebound following intentional forest clearance and occupation. The two radiocarbon samples describe a significant human impact on the local ecology and the rapid recovery of the environment after anthropogenic activities ceased to be a factor shaping the landscape. The degree of bioturbation demonstrated by the 59 cm sample is within a vertical range of 25 cm from the land surface, and fits within the amount vertical movement of coarse roots which can be expected from *R. mangle*.

The mangroves were able to keep pace with eustatic sea-level rise for a time, but were eventually drowned by sea-level rise which outpaced the ability of the mangroves to vertically accrete peat. This final act in the sediment history is represented by the seafloor, while the 43 cm of water which submerge site 14 are the result of continued sea-level rise since the inundation of K'ak' Naab'. One question which remains to be answered is when this final inundation occurred.

A 14C date of the seafloor surface would place the seafloor in chronological context and allow further analysis of sea-level rise since the submergence of the site.

CONCLUSION

The K'ak' Naab' sediment column provides a history of paleoecological change and the complex interplay between Classic Maya salt makers and the local environment in which they lived and worked. This history, starting at the base of the 60 cm core and moving forwards chronologically towards the sea floor at 0 cm, documents a dynamic interaction of the anthropogenic and environmental factors which shaped the development and change of a coastal mangrove forest.

LOI analysis of organic content throughout the sediment column revealed a high level of continuity in sediment formation processes before and after the occupation of site 14. Though anthropogenic activity must have had a significant impact on the local environment, the effect of forest clearance and occupation on site formation processes seems to be limited to the sudden change in sediment color at 35 cm which marks site abandonment. High levels of bioturbation, as indicated by the Early Postclassic date at 59 cm, may have altered the stratigraphy of the upper levels of sediment. Significant disruption of stratigraphy, however, seems unlikely as the *in situ* sediment showed no visible signs of disturbance at the time of coring.

A comparison of the loss-on-ignition and radiocarbon data from the two K'ak' Naab' sediment columns expands our understanding of the landscape and environment inhabited by the Classic Maya occupants of Paynes Creek. The 40 cm difference in elevation between the onsite and offsite areas suggests that a shallow, possibly tidal, channel ran alongside the occupied area

of site 14. This channel would have been important for the production and transportation of salt, as it could have provided a source of salt water as well as a convenient route for canoe travel to and from the salt works.

The Maya must have engaged in a long-term, small-scale campaign of environmental modification in order to create and maintain a clear, inhabitable space within the ancient mangrove forest. Mangroves grow in dense, inhospitable clumps which would hinder construction unless the forest was cleared and the land surface managed. At the same time, maintaining near-site mangroves would provide an abundant source of wood for a variety of activities.

Though the site is currently covered by 43 cm of ocean water which has effectively drowned the mangrove forest, paleoenvironmental data suggest that very different conditions existed during the Classic period. The 35 cm of sediment accumulated since occupation ended hint at the time which passed between site abandonment and the modern inundation of the site. The upper level of sediment from column sample 1 was dated to A.D. 1150-1270, suggesting that mangroves in the offsite canal were finally overcome by rising sea-levels in the Early Postclassic (McKillop et al. 2010). If the offsite canal was inundated by A.D. 1270, the elevated onsite area may have remained above sea-level for some time afterwards. The sediment history of site 14 can be added onto in the future with radiocarbon analysis of the seafloor.

The regrowth of the mangrove forest during the Early Postclassic speaks to the resiliency of red mangroves to repopulate and stabilize a marginal environment following anthropogenic activities, such as forest clearance, which significantly affect the local ecology. This environmental recovery suggests that even in liminal environments, the Maya practiced

sustainable landscape modification and natural resource use which did not permanently alter or damage the surrounding environment.

Sediment coring in underwater sites is a methodology which can be applied productively to sites within Mesoamerica and beyond. Since the end of the Ice Age, eustatic sea-level rise has inundated countless coastal sites around the world. Many of these sites lie unnoticed in shallow coastal waters, overlooked by terrestrial and underwater archaeologists alike. By bringing both terrestrial and underwater archaeological methods to bear on shallow-water submerged sites, archaeologists are able to explore previously inaccessible sites. Innovative methodologies for obtaining sediment cores in liminal site conditions open the door for studies of human-environment interaction in previously unexplored contexts.

Sediment coring brings a new dimension to understanding the interaction between humans and the ancient environment. Rather than focusing solely on material cultural remains, sediment analysis explores paleoenvironmental conditions as they changed through time. By examining site formation processes, sediment histories provide chronological records of continuity and change in the environment. When paleoenvironmental data are incorporated with cultural data, archaeologists are able to form a more complete, dynamic understanding of the living conditions of ancient humans. Human-environment interaction is not a static process; it is a dynamic, ever-changing network of environmental and cultural processes. Only through investigating sediment histories can archaeologists begin to truly understand the interplay between ancient humans and their environment.

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