A Late Holocene Record of Caribbean Sea-Level Rise: the K'ak' Naab' Underwater Maya Site Sediment Record, Belize

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Recovery and analysis of a sediment column from between two Late Classic (A.D. 600-900) Maya salt works reveal a 4000 year record of sea-level rise in southern Belize. Abundant briquetage—broken pots from boiling brine to produce salt, indicate salt production in wooden buildings, whose posts were preserved in a peat bog below the seafloor. Loss-on ignition, microscopic identification of plants, and radiocarbon dating suggest the sites were on dry land at the time of occupation and later were inundated by sea-level rise. Modern sea level is 132.7 cm (4.4 ft) higher than the time of initial settlement during the Early Classic (A.D. 300-600). The canoe paddle at one of the sites, K'ak' Naab,' has cracking caused by alternating wet and dry environments in antiquity. Abandonment of the salt works is linked to the abandonment of inland cities—consumers of massive quantities of salt—rather than sea-level rise.

Introduction

Low lying areas worldwide are subject to inundation by sea-level rise, posing a significant threat to coastal communities. Post Pleistocene sea-level rise resulting from global warming melted glaciers and raised sea levels at varying rates during the Holocene. Discovery and excavation of inundated coastal sites (Curry 2006; Faught 2004; Hanselmann et al. 2009) expands our knowledge of early Holocene settlements and documents sea-level rise. Ancient Maya sites along the coast of the Yucatan in Mexico and Belize dated to the late Holocene between 300 B.C. and A.D. 1200 were submerged by sea-level rise and are buried under living mangroves, below the water table on land, or underwater and offshore (McKillop 2002; McKillop and Winemiller 2004). Ancient Maya underwater sites add to the growing record of European shipwreck sites investigated off the Yucatan coast and sites in cenotes (sinkholes) within the peninsula (Leshikar-Denton and Luna Erreguerena 2008; Luna Erreguerena et al. 2009).

Sea-level rise inundated ancient Maya salt works along the coast of Belize, removing evidence of a once-thriving salt industry that supplied this basic biological commodity to the inland Maya at Classic period (A.D. 600-900) sites where salt was scarce (McKillop 1995, 2005a, 2007, 2009a, 2009b; Sills 2007; Somers 2007). Now underwater, the salt works include wooden buildings preserved in a peat bog below the seafloor, along with briquetage—broken pottery vessels used to boil brine to make salt (McKillop 2007, 2010). Study of a sediment core from the peat bog between the K'ak' Naab' site and Site 15 (Figure 1) informs on Late Holocene sea-level rise and settlement in the coastal area. Laboratory research included loss-on ignition, microscopic sorting and identification of organic material, and radiocarbon dating. The Paynes Creek sea-level data correspond to the Late Holocene sea-level curves reported elsewhere in the Caribbean (Toscano and Macintyre 2003).

The sediment and archaeological record on the south coast of Belize indicate environmental change did not precipitate major cultural changes at the end of the Classic period. From sediment cores in the northern Maya lowlands of the Yucatan peninsula in Mexico,

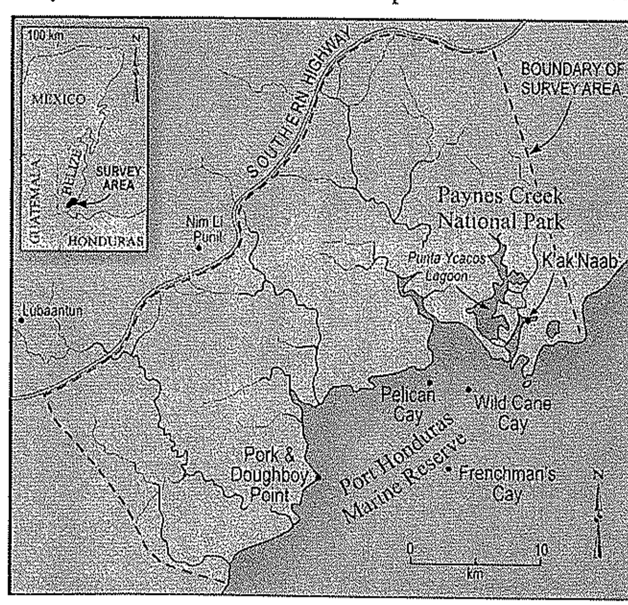

FIGURE 1: MAP OF SOUTH COAST OF BELIZE STUDY AREA SHOWING UNDERWATER SITES IN PAYNES CREEK NATIONAL PARK (MAP BY MARY LEE EGGART, LOUISIANA STATE UNIVERSITY).

geologists have documented significant climatic changes in the form of an enduring drought between A.D. 800 and 1000, coinciding with the Classic Maya collapse (Curtis et al. 1996; Hodell et al. 1995). Some researchers attribute the collapse of the Maya civilization in the southern Maya lowlands of Guatemala and Belize and abandonment of the cities to a drought (Gill 2000). Archaeological research on the coast, cays, and shallow coastal water of southern Belize indicates there was a complex interplay between environmental and cultural factors at the end of the Classic period, cautioning a return to simplistic models of environmental determinism as espoused by Gill (2000) and Meggers (1954). As a case study of the impact of environmental change on ancient Maya communities, the coastal Maya of southern Belize took action to counter flooding caused by sea-level rise at the trading port of Wild Cane Cay, whereas some communities such as Pelican Cay were abandoned (McKillop 2002). Other sites, including the Paynes Creek salt works, were likely abandoned before they were inundated by rising sea levels.

Underwater Archaeology in the Maya Area

Underwater sites are common in the Maya area (Andrews and Coreletta 1995), although most research focuses on cenotes and shipwrecks (Leshikar-Denton and Luna 2008) instead of inundated land sites (McKillop 2002, 2005a; Somers and McKillop 2005). Excavations are commonly abandoned when the water table is reached at coastal sites in Belize and the Yucatan of Mexico (McKillop 2002). Research in the coastal region of southern Belize underscores the benefits of archaeological research in inundated deposits.

Previous archaeological research on the south coast of Belize documented Classic Maya sites on the offshore cays and coastline partially or fully below sea level (McKillop 1995, 2002, 2005b; McKillop et al. 2004; McKillop and Winemiller 2004). At the trading port of Wild Cane Cay, the Classic period midden deposits are below the water table (McKillop 2002, 2005b). A significant part of the Classic period site is offshore and buried below the seafloor, as demonstrated by a program of 172 offshore shovel tests (McKillop 2002: Figures 5.4-5.6). Excavations were carried out in 20 cm levels to a maximum depth of one meter below the seafloor. The excavations indicated the Classic Maya site of Wild Cane Cay was approximately 10 acres in size, which was reduced by sea-level rise and shoreline erosion to its modern size of 3 ½ acres (McKillop 2002: Figure 5.4). Radiocarbon dating indicates sea-level rise of at least one meter since the end of the Classic period in the region (McKillop 2002).

Settlement on Wild Cane Cay increased with the expansion of circum-Yucatan canoe trade after the Classic Maya collapse in the southern Maya lowlands (2005b). Midden accumulation and construction of coral architecture kept pace with rising seas. Although the Early Postclassic midden deposits at Wild Cane Cay were submerged during the rainy season, most of the coral architecture remained above the water table. The clearing of mangroves on Wild Cane Cay associated with historic settlement beginning in the late 19th century further contributed to shoreline erosion. Following the abandonment of the historic settlement, mangroves took hold offshore and protected the shoreline from further erosion. In the absence of continued midden accumulation, sea-level rise will eventually submerge the remaining dry land of Wild Cane Cay, as a natural process of mangrove island formation.

In contrast to the scenario at Wild Cane Cay where anthropogenic factors of midden accumulation and coral architectural construction ameliorated the deleterious effects of rising seas on the island, the nearby community on Pelican Cay was abandoned at the end of the Classic period. With the lack of midden accumulation in the Postclassic, the sea reclaimed the island. Red mangroves (*Rhizophora mangle*) encroached on the site, accumulating mangrove peat among the roots. The Classic period site on Pelican Cay is buried below 40 cm (15.7 in.) of mangrove peat, covered by living mangroves, and underwater. The entire island is slightly below sea level, with no surface evidence of an ancient Maya settlement, which was only discovered by shovel testing (McKillop 2002). The scenario at Pelican Cay underscores the likelihood that Classic Maya settlement lies buried below mangroves elsewhere on the low-lying mangrove coastline and offshore cays in Belize.

Underwater Sites in Paynes Creek National Park

Regional survey on the coast and cays of the Port Honduras Marine Reserve indicated that Late Classic Maya sites were up to 1.5 m (4.9 ft.) below modern sea-level, both on land and in offshore areas of sites, such as at Pork and Doughboy Point, Wild Cane Cay, and Frenchman's Cay (McKillop 2002; McKillop and Winemiller 2004). With this knowledge, survey was extended to shallow water where there was no land, on the assumption that sites would be found if sea level was lower in the Late Classic. Systematic boat survey traversing Punta Ycacos Lagoon in Paynes Creek National Park led to the discovery of three underwater sites: Stingray Lagoon, David Westby, and Orlando's Jewfish sites, which were inundated terrestrial sites (McKillop 1995, 2002). Comprehensive underwater survey in 2004 led to the discovery of underwater sites with wooden posts and the K'ak' Naab' canoe paddle protruding from the seafloor (McKillop 2005a). Survey and mapping from 2005 to 2008 included the discovery and mapping of 4,000 wooden posts at 103 underwater sites (McKillop 2009a, 2009b; Sills 2007; Somers 2007). Site maps revealed the footprint of buildings defined by the pattern of vertical posts extruding from the seafloor. In some cases, the rectangular shapes of buildings of various sizes were clear (McKillop 2010). The seafloor at the underwater sites was littered with briquetage, indicating salt production.

What remained perplexing was the underwater setting of the Late Classic architecture and associated briquetage. The posts that protruded from the seafloor were preserved in a peat bog, but information was lacking on the formation of the peat bog in relation to the sites, the species composition of the peat and its depth, and the location of land at the time of occupation of the sites. In order to begin answering these questions about the sediment history in relation to the sites, archaeologists excavated a column of sediment from beside one of these sites, K'ak' Naab'.

Environmental History from Marine Sediment

In contrast to northern Belize, where the limestone of the barrier reef lagoon is near or at the ground surface (Dunn and Mazzullo 1993), the southern barrier reef lagoon where the Paynes Creek sites are located is much deeper, with a Holocene sediment history yielding as much as 11 m (36 ft.) of mangrove peat on the limestone bedrock (Macintyre et al. 1995; McKee and Faulkner 2000; McKee et al. 2007; McKillop 2002). A test probe was carried out between sites 14 (K'ak' Naab') and 15 in 2004 in Punta Ycacos Lagoon, Paynes Creek National Park (Figure 1). Mangrove peat extended to the 4.3 m (14.1 ft.) maximum depth of the probe (McKillop 2005a).

In 2008, a column of sediment was excavated from the seafloor between Sites 14 and Site 15 (Figure 1). Named the K'ak' Naab' core, the sediment column was cut from the peat in 10 cm (3.9 in.) levels. The maximum depth was 1.5 m (4.9 ft.) below the seafloor. The marine sediment was packed in cling wrap and Ziploc bags by 10 cm (3.9 in.) levels (with arrows indicating orientation) and transported to Louisiana State University for study. Archaeological analysis includes loss-on ignition, sediment analysis, radiocarbon dating, and study of artifact contexts. Other analyses, including analysis of the abundant pollen and wood, are in progress.

Loss-on Ignition of K'ak' Naab' Sediment

Loss-on ignition documented the percent of organic matter in the sediment, and was conducted to determine the organic composition of the sediment. Loss-on ignition was run for every sample collected, for a total of 15 samples. Overall, the organic content of the sediment from the K'ak' Naab' column is high, with an average of 65% (Figure 2). The lowest level for organic material is level 1 (0-10 cm), which is 50% organic material. The organic content is high and consistent with other peat sediment deposits on the cays of Belize (McKee and Faulkner 2000; McKee et al. 2007; McKillop 2002).

Microscopic Identification of Sediment

Organic material was sorted from the sediment under magnification to identify the species composition of the peat. Objectives included determining whether the sediment consists of mangrove peat accumulated in a marine setting under pressure of rising seas. Alternatively, was there evidence of terrigenous soil indicating dry land in the area? One cubic cm (0.39 in.^{3}) of sediment was selected from levels 1, 2, 3, 4, 8, 11, and 12. The samples were rinsed through a 1 mm (.4 in.) sieve and placed in a Petrie dish in water under a microscope. The sediment was examined and then sorted for coarse roots, small roots, leaves, and wood. Analysis of the morphology of the sediment examined under a microscope indicates that the peat is composed primarily of *R. mangle* roots. This finding indicates the landscape in the immediate area of the Paynes Creek salt works was a mangrove swamp dominated by *R. mangle* throughout the entire sequence represented in the sediment core. Furthermore, the environmental setting of the Paynes Creek underwater sites was subject to actual sea-level rise, as evidenced by the solid record of mangrove peat, which is deposited as *R. mangle* keeps pace with rising seas.

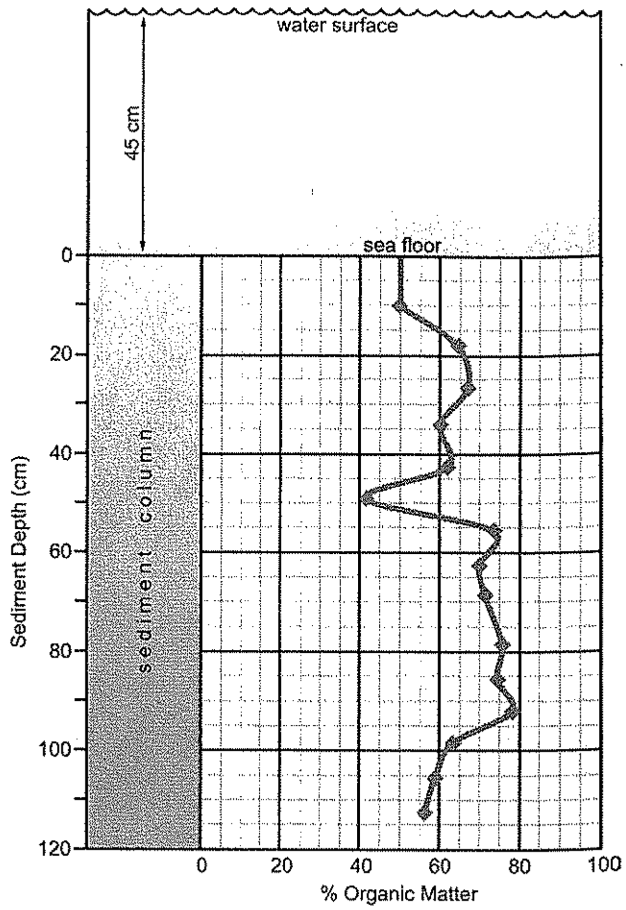

Figure 2: Profile Drawing of K'ak' Naab' Sediment Core Showing Loss-on Ignition (Drawing by Mary Lee Eggart, Louisiana State University).

Radiocarbon Dating

The depths of radiocarbon-dated sediment layers below sea level were used to evaluate the timing and rate of sea-level rise. The Paynes Creek sediment core shows a radiocarbon dated 4000-year record of vegetation changes mirroring the rise and fall of the Paynes Creek salt works (Figure 2). Radiocarbon samples were submitted to date the top and bottom of the sediment as well as several intermediate layers of the sediment. The samples consisted of small *R. mangle* roots sorted under a microscope (Figure 3). Modern studies of mangrove ecology demonstrate that small mangrove roots accumulate at the ground surface and have minimal vertical movement in mangrove peat, in contrast to the large mangrove roots, which can permeate deeper into the sub-surface sediment (McKee and Faulkner 2000). Sediments were sorted under a microscope to select small *Rhizophora mangle* roots for C14 dating. They accumulate in layers instead of the large roots that can permeate greater depth.

Sea-Level Rise and Inundation of the Saltworks

Since *R. mangle* peat accumulation is a measure of actual sea-level rise, the 4.3 m (14.1 ft.) of mangrove peat in the test probe indicates significant actual (eustatic) sea-level rise during the Holocene. The K'ak' Naab' sediment column records actual sea-level rise in the Late Holocene (Figure 2). The Paynes Creek sites likely were subjected to relative (isostatic) sea-level rise as well. Natural and anthropogenic causes of isostatic sea-level rise include subsidence from land clearing by the Classic Maya or by hurricanes, and tectonic activity causing rapid subsidence. The Paynes Creek Maya impacted their landscape ("anthropogenic factors") by land clearing for construction and cutting trees for fuel and perhaps for land-reclamation efforts (if the palmetto palm posts were for land-retaining). Modern studies indicate land clearing of mangroves causes local subsidence (Cahoon et al. 2003; Langley et al. 2008). Ground water withdrawal and natural settling can cause human-induced subsidence (Winterwerp et al. 2005).

Clearly, the rate of sea-level rise must have slowed down, or even reversed, if dry land was available for construction of the Classic Maya buildings. Sea level has risen about 130 cm (4.3 ft.) since the first Paynes Creek wooden structures were built in the Early Classic. If the structures were built on dry land and at least minimally above water, sea-level rise since the Early Classic period was likely greater.

The depth of radiocarbon-dated deposits in the K'ak' Naab' sediment core measures a 4,000-year record of actual sea-level rise. Sea level was rising before the Early Classic Maya settlement, as indicated by the 26.6 cm (10.5 in.) of peat from the base of the core to the beginning of the Early Classic levels. The ground surface at the beginning of the Early Classic settlement was 132.7 cm (4.4 ft.) below modern sea level, as indicated by the depth of radiocarbon-dated material below water surface (1580 ± 40 BP/ Cal AD 410-590). The end of Late Classic settlement is 75.2 cm (2.5 ft.) below modern sea level. During the Classic period settlement, sea level rose a total of 57.7 cm (1.9 ft.). The continued deposition of mangrove peat after the Maya sites were abandoned marks an additional 30.2 cm (0.99 ft.) increase in actual sea level.

Radiocarbon dates from the sediment were compared with a recent sea-level curve based on mangrove peat and coral dates elsewhere in Belize (Toscano and Macintyre 2003). A sample from 75.2 cm (2.5 ft.) below

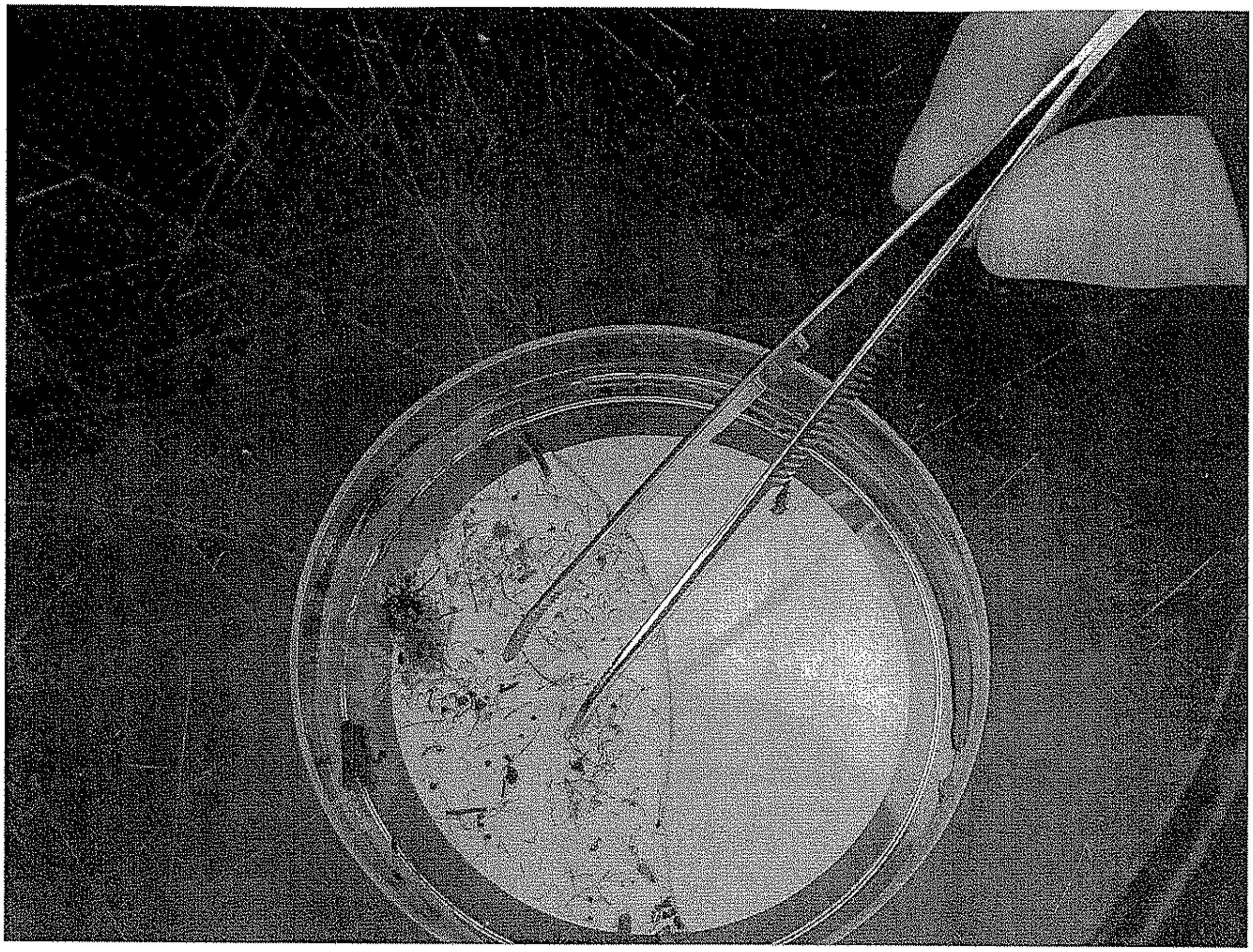

Figure 3: Small mangrove roots of Rhizophora mangle in a Petrie dish to be sampled for Radiocarbon dating (Photo by Heather McKillop).

the water surface dates to 920 ± 40 BP (Cal AD 1020-1200). Three other samples consisted of small *R. mangle* roots sorted from 10 cm (3.9 in.) levels. The deepest level, 149.4 to 159.4 cm (4.9 to 5.2 ft.) below water, dates to 4140 BC ± 40 BP. The uppermost sediment level, 45 to 55 cm (1.5 to 1.8 ft.) below water, dates to 850 ± 40 BP (Cal AD 1060-1080 or 1150-1270). This date overlaps with a date from 55 cm to 63 cm (1.8 to 2.1 ft.) below water at 750 ± 40 BP.

Using mangrove peat to calculate the rate of sea-level rise reveals fluctuations in the rate over time and suggests that subsidence occurred. The rate of sea-level rise from 4,140 BP to 1,580 BP (2,560 years) was 0.010 cm (0.003 in.) per annum, surprisingly low. The rate of actual sea-level rise during the 660 year Maya settlement was 0.087 cm (0.03 in.) per annum. The rate of sea-level rise in the 300 years of the Early Postclassic was .01 cm (0.004 in.) per annum, an increase in the rate compared to the Classic period. The 45 cm (17.7 in.) water depth to the top of the sea floor occurred some time after the Early Postclassic. Owing to the lack of peat deposits after the Early Postclassic, a working hypothesis infers that rapid sea-level rise drowned mangroves in Late Postclassic and left the salt works underwater. Using the 45 cm (17.7 in.) water depth to the seafloor, the rate of sea-level rise from the end of the Early Postclassic to the present (A.D. 2000) is 0.06 cm (0.02 in.) per annum.

Archaeological Evidence that Paynes Creek Sites Were on Land

A variety of lines of archaeological evidence support the interpretation that the Paynes Creek salt works were built on dry land that subsequently was inundated by sea-level rise. Piece plotting of 506 artifacts on the seafloor at the K'ak' Naab' site revealed that briquetage was widespread on the seafloor except inside the structures (McKillop 2007). Evidently salt production was indoors and the work area was kept clean. The widespread presence of charcoal along with briquetage,

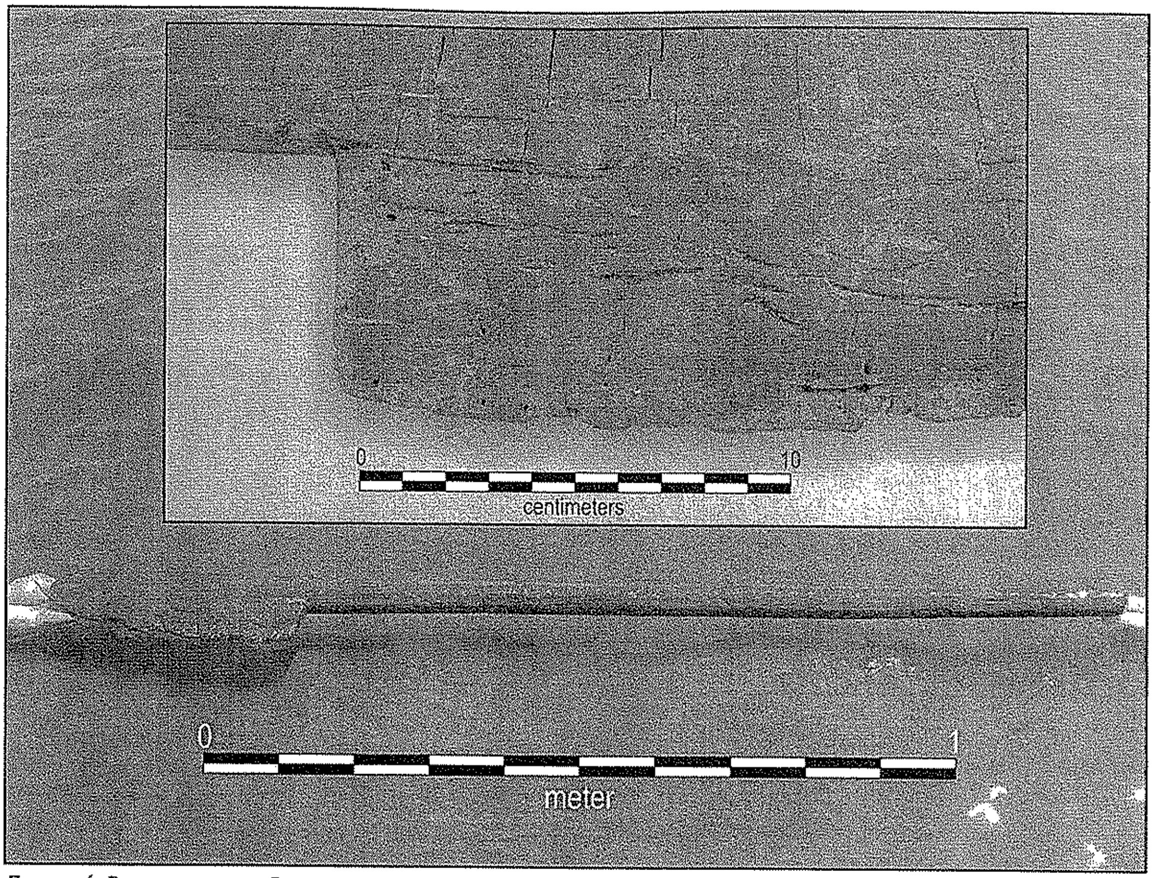

Figure 4: Portion of the Blade of the K'ak' Naab' wooden canoe paddle showing cracks caused by fluctuating wet and dry conditions in antiquity (Photo by Heather McKillop).

including a large hearth at Stingray Lagoon (McKillop 1995), underscores the in situ location of the ancient salt production. The absence of wooden floors, which would have been preserved in the peat bog, adds further evidence that the salt works were not elevated over the water, but instead were constructed on dry land that subsequently became inundated. The placement of lines of palmetto palm posts at the edge of sites may have served to keep out rising seas, in an effort to reclaim land—an effort that ultimately was unsuccessful.

The context and appearance of the K'ak' Naab' canoe paddle suggest the K'ak' Naab' site was on dry land when used and subsequently was inundated. The paddle was recovered from the edge of the site, as determined by distribution of posts and artifacts on the seafloor. How did the paddle become part of the archaeological record? One hypothesis infers that the paddle was lost and sunk in the water near the K'ak' Naab' site. Alternatively, the paddle could have been dropped at the edge of the K'ak' Naab' site on the land. Since the K'ak' Naab' paddle is made from Sapodilla wood that sinks, it could have been lost in the water. Although, once abandoned, the paddle was subjected to an environmental setting of alternating wet and dry conditions, as indicated by cracks on the paddle that were only visible after the paddle was conserved (Figure 4). The cracks are short straight lines visible on the blade and shaft of the paddle. The cracking occured in antiquity and not during the conservation process (Wayne Smith, 2009 personal communication).

Worm marks on the paddle indicate that it was deposited in shallow water or on land, in an area that was subjected to alternately dry and wet conditions and not in deep water. Most of the paddle was protected below the seafloor in mangrove peat. The portion of the blade that protruded from the seafloor was worm-eaten, as indicated by curvilinear incisions in the wood (Figure 4). Cracking and worm marks on the K'ak' Naab' paddle support the interpretation that the K'ak' Naab' site was on dry land and that when the site was abandoned, rising seas submerged and protected the wooden structures and the canoe paddle.

Conclusions

Analysis of a sediment column sample from a peat bog below the sea floor between two archaeological sites in Paynes Creek National Park, Belize revealed a 4000-year record of sea-level rise in the Late Holocene that includes the Classic Maya underwater sites. The sediment was identified as red mangrove peat (*Rhizophora mangle*), which is an indicator of actual sea-level rise: if sea-level rise is gradual, mangroves are able to grow in height and keep pace with sea-level rise, but if it is rapid, mangroves are drowned. The ground surface at the time of initial Maya settlement was 132.7 cm (4.4 ft.) below modern sea level, as indicated by the depth of radiocarbon-dated material below water surface. This ground surface may have been inundated as indicated by the presence of *R. mangle*, since the sediment was recovered between archaeological sites. Sea level rose 57.7 cm (1.9 ft.) during the Classic period. After the salt works were abandoned at the end of the Classic period, sea level rose an additional 30.2 cm (11.9 in.) during the Early Postclassic. Rapid sea-level rise during the Late Postclassic, either isostatic or eustatic, drowned the sites and left them underwater. Despite the long record of actual sea-level rise, the area was dry land for about 600 years when Classic Maya salt works were in operation. The demand for salt by inland urban Maya consumers waned with the abandonment of nearby inland cities at the end of the Classic period, providing a cultural explanation for the abandonment of the Paynes Creek salt works.

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