29 THE IMPORTANCE OF USING SEDIMENT CHEMISTRY TO INTERPRET ANCIENT MAYA SALT MAKING ACTIVITIES AT THE PAYNES CREEK SALT WORKS

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Chemical analysis of soils and sediments are useful for finding activities and defining space not readily apparent in the artifact assemblage due to varied preservation. In the Maya cultural area, chemical analysis of anthropogenic and naturogenic terrestrial soils and marine sediments have been used to find activities that occurred at ancient Maya sites both inside and outside of buildings. The Underwater Maya project has adapted soil chemistry, usually conducted at terrestrial sites, to the submerged Paynes Creek Salt Works. The acidic red mangrove peat has remarkably preserved wooden posts that form the outline of buildings and botanical remains but does not preserve bone or shell. The differential preservation at the salt works could obscure the full plethora of activities taking place, under shadowing the complexity of production of salt for the Late Classic Maya. In this paper, we discuss the importance of soil and sediment chemistry analysis in the Maya are, methods for sampling sediment at the Paynes Creek Salt Works, and the chemical signatures of human activity that are most likely to occur at the salt works.

Introduction

Soil and sediment chemistry has been used to find and evaluate ancient Maya activities and features not readily identified through architecture and artifact assemblages. At the Paynes Creek Salt Works, Belize chemistry of marine sediment has proved successful in defining activities associated with salt production inside and outside of wooden buildings at Chan b'i (Figure 1; Sills et al. 2016). The success of adapting chemical analysis from terrestrial contexts to marine sediments at Chan b'i underscores its utility for discovering additional activities that were occurring in conjunction with salt production elsewhere at the Paynes Creek Salt Works. The Underwater Maya Project has collected marine sediment from the inside and outside of wooden buildings at two of the largest salt works, Ta'ab Nuk Na and Ek Way Nal, as part of a National Science Foundation Grant to the authors titled *Labor Relations in a Traditional Complex Society* (Figure 2). The purpose of chemical marine sediment analysis is to discover residues associated with human settlement and activity not preserved in the acidic peat matrix that has preserved wooden posts and botanicals.

Ta'ab Nuk Na and Ek Way Nal each has ten buildings that provide an opportunity to compare the range of activities that were taking place in addition to salt production. The results of floatation surveys indicates that at least one of these buildings at each site was used as a residence, challenging an assumption that salt production was a tertiary part of the ancient Maya

Figure 1. Map of the Maya area showing the location of The Paynes Creek Salt Works and site mentioned in the text. Map by E. Cory Sills.

Classic period economy (McKillop 2019; McKillop and Sills 2001, 2002). Considering this new information, the application of sediment chemical analysis to these underwater sites is used to explore the possibility of activities and features that have been identified through the artifact assemblage and ethnographic analogy. The finding of residences at the salt works requires a re-evaluation of the size and organization of space within buildings and in yards than what has previously been associated with salt kitchens.

Activities previously identified at the Paynes Creek Salt Works includes salt production, brine enrichment, salt drying or drying fish, wood working, food preparation, and ritual behaviors (McKillop 1995, 2002, 2019; McKillop and Aoyama 2018; McKillop and Sills 2021; Sills and McKillop 2018). Salt was produced indoors in salt kitchens using the boiling method where salty water is placed in pots over fires and boiled until all that remains is salt (McKillop 1995, 2002, 2019). This method of salt production leaves behind briquetage which is the broken pottery from the process and consists of pottery vessels, cylinder supports, and spacers, sockets, and bases that attached to the vessels and evenly distributed them across the fire (see Reina and Monaghan 1991; McKillop 1995: Figure 10, 2002). The pottery vessels were broken to remove the salt inside. After finishing the salt production, the briquetage was swept to the corners and walls with some retained in the fire for heating (McKillop 2002; Sills and McKillop 2018). The briquetage was produced locally but evidence that the pottery was fired at the salt works is missing (McKillop 2019). Other materials required for boiling brine is firewood that was possibly stored in the salt kitchen or nearby.

Brine enrichment is typical of salt production using the boiling method (Andrews 1983; MacKinnon 1989; Reina and Monaghan 1981; McKillop 2002, 2019). Salt-laden soil is elevated on a platform with holes at the base and a collecting vessel below. Brine is poured on the salt-laden soil and collected underneath. This process is repeated continuously until the brine is salty enough for boiling. At Sacapulas, balls of corn are used to test the salinity prior to boiling (Reina and Monaghan 1981). If they float, then the brine is ready for boiling. Evidence of brine enrichment was recovered from the Eleanor Betty Salt Works where a funnel was found underneath a canoe (McKillop 2019; McKillop et al. 2014).

Use-wear analysis of stone tools from the Paynes Creek Salt Works has revealed evidence of salt-drying fish and woodworking as well as a

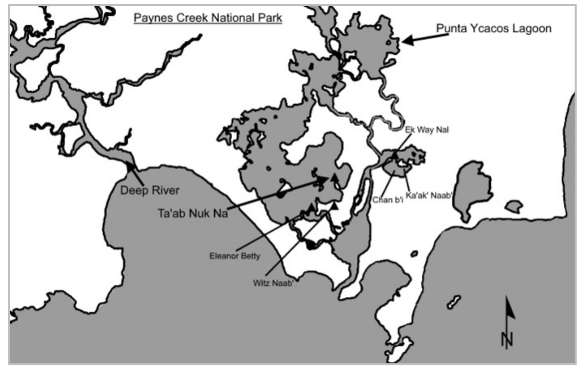

Figure 2. Map of Paynes Creek National Park showing locations of Chan b'i, Ta'ab Nuk Na, and Ek Way Nal salt works. Map created by E. Cory Sills.

fishing weight (McKillop and Aoyama 2018; McKillop 2019). Additional artifactual evidence of salt-drying fish such as fish bones is missing. Food preparation likely occurred inside or close to a residence or around hearths. Evidence of food preparation found at the Paynes Creek Salt Works includes manos and metates and preserved native palm fruits (McKillop 2019). The remains of bones from meals are absent. The Maya commonly buried their dead in the floors of their homes, which may have occurred at the residences found at Ta'ab Nuk Na and Ek Way Nal. Evidence of rituals performed at the salt works includes ocarinas (figurine whistles) and Belize Red serving bowl sherds (McKillop 2002, 2019). Sediment chemistry may reveal evidence of saltdrying of fish, burials, and further define the spatial division inside of salt kitchens, residences, and yards.

Chemical Analysis of Soils and Sediments in the Maya Area

Except for a study conducted at the ancient Maya salt work of Chan b'i (Sills et al. 2016), soil chemistry in the Maya area has been conducted on terrestrial soils These studies have largely focused on architecturally defined ancient cities with defined plazas and buildings (Anderson et al. 2012; Cap 2015; Cook et al. 2006; Coronel et al. 2015; Dahlin et al. 2007; Fulton et al. 2017; Hutson and Terry 2006; Lamoureux-St-Hilaire et al. 2018; LeCount et al. 2016; Parnell et al. 2002a, 2002b; Terry et al. 2004; Wells et al. 2000; Wells 2004). Ethnoarchaeological studies of modern Maya house floors have been conducted to evaluate the results of chemical soil analysis results from archaeological sites (Fernández et al. 2002; Middleton and Price 1996). Numerous activities associated with human activities and features that leave behind residues on earthen floors, plaster floors, and the landscape include food preparation, consumption, and disposal, storage of food, hearth placement, burials, middens, craft production, rituals, feasting, marketplace activities, and salt making (Anderson et al. 2012; Barba 2007; Cap 2015; Cook et al. 2006; Coronel et al. 2015; Dahlin et al. 2007; Fulton et al. 2017; Hutson and Terry 2006; Lamoureux-St-Hilaire et al. 2018; LeCount et al. 2016; Parnell et al. 2002a, 2002b; Sills et al. 2016; Terry et al. 2004; Wells et al. 2000; Wells 2004).

Chemical analysis of plazas in ancient Maya cities show that many activities occurred in these spaces. High values of phosphorus from the main plaza at El Coyote, Honduras indicate areas with food preparation and consumption (Wells 2004). The combination of barium, magnesium, manganese, and zinc found in the plaza at Palmarejo, Honduras was interpreted as an area for the burning of incense and food consumption associated with rituals (Fulton et al. 2007). Disposal areas were found at Xtobo, Mexico was associated with craft production due to the combination of copper, iron, manganese, and lead (Anderson et al. 2012). Marketplaces occurring in plazas have been identified by the presence of phosphorus and zinc indicative of food preparation and consumption activities at the sites of *Chunchucmil* and Cobá, both in Mexico, and at Buenavista del Cayo (Cap 2015; Colonel et al. 2015; Dahlin et al. 2007; Terry et al. 2015). Iron, associated with butchering coupled with phosphorus and zinc were found in a proposed marketplace at the site of Telchaquillo, Mexico (Terry et al. 2015).

Inside of buildings, in more restricted areas than plazas, phosphorus is also associated with food preparation, consumption, and food storage such as maize (Eberl et al. 2012; Fernández et al. 2002). Phosphorus has also been found in food disposal areas such as middens Wells et al. 2000). Potassium and magnesium have higher amounts in areas near hearths (Fernández et al. 2002). Also, phosphorus and magnesium have been associated with hearths especially if food is prepared or consumed in the area (LeCount et al. 2016). Phosphorus is associated with the doorways and the edges of buildings likely due to frequent sweeping inside towards the edges (Anderson et al. 2012; Hutson and Terry 2006; Parnell et al. 2002b; Terry et al. 2004). Iron concentrations are associated with pyrite at elite residences at Aguateca, Guatemala (Terry et al. 2004). Lead has also been associated with craft production and/or combined with other elements such as mercury, iron, and zinc (Cook et al. 2006; Parnell et al. 2002a, 2002b). Many of these elements overlap in areas where cooking and food preparation occur suggesting that craft production occurred in the same places as food production and consumption (Dore and López Varela et al. 2010; Lamoureux-St-Hilaire et al. 2018; LeCount et al. 2016)

Heavy metals such as those mentioned above were found at Piedras Negras suggesting that houses were painted by the combination of but not limited to copper, iron, manganese, lead, and zinc (Wells et al. 2000). At Cerén, El Salvador, hematite was found within every excavated household denoting its common use (Sheets 2000). Mercury and cinnabar were found at *Chunchucmil* associated with a burial (Hutson and Terry 2006) and at Cancuén, Guatemala (Cook et al. 2006). Mercury and iron were found in floors at Actuncan, Belize possibly associated with the use of cinnabar and ochre (LeCount et al. 2016).

Areas where trace elements are diminished does not mean that activities were not occurring (Wells 2004). Instead, areas with low phosphorus can be interpreted as walkways (Parnell et al. 2002b; Terry et al. 2004) or areas under the eaves of buildings (Parnell et al. 2002a). Areas that do not have regular use or are isolated exhibit low phosphorus (Fernández et al. 2002). Also, flint knapping can occur in areas with low phosphorus but with an increase in iron (Cap 2015).

Analysis of marine sediment from Chan b'i using chemical analysis was successful in defining salt making activities (Sills et al. 2016). The Chan b'i site is underwater in the East Lagoon of Punta Ycacos Lagoon. The site consists of at least one building with room division and two out flaring lines of palmetto palm posts. Phosphorus, magnesium, and potassium occur in the central area of the building next to wooden posts. Additionally, aluminum, iron, and sodium occur in these areas confirming that the floors were swept and the ash from fires and salt production were pushed to the walls. The results of chemical analysis were supported by two transect excavations through the building that yielded abundant briquetage inside and directly surrounding the building. The elements that were present inside the building were minimal between the two lines of palmetto palm posts suggesting salt production was not occurring there. The area is also bereft of salt making pottery and lower in elevation than the wooden building. The sea floor has thick silt—20 cm and greater in depth—that overlays the red mangrove peat. However, the area is demarcated by palmetto palm posts which implies some function associated with the building. Correspondingly, sodium is lower in this area than all the other tested marine sediment samples from Chan b'i. A hypothesis is that the area was used to extract salty peat for enriching the salinity of salty water before it was evaporated in pots over fires (Sills et al. 2016).

Figure 3. Photograph of a laying out a transect at Ek Way Nal to sample marine sediment. Photograph by Cher Foster.

Figure 4. Photograph of an example of collecting marine sediment in a sterile whirl-pak at Ek Way Nal. Photograph by Cher Foster.

Sedimentscape and Preservation at The Paynes Creek Salt Works

The Paynes Creek Salt Works are in Paynes Creek National Park, southern Belize. All but two of the salt works, Witz Naab and Killer Bee, are located underwater in Punta Ycacos Lagoon (McKillop 2002; Watson and McKillop 2019). The lagoon is subject to tidal variations as most of the water is supplied by the Caribbean Sea with some fresh water from nearby Fresh Water Creek that drains from the nearby pine savannah. The salinity of the Punta Ycacos Lagoon fluctuates depending on rain fall—more salinity in the dry season and less in the rainy season. The vegetation around the lagoon is a mangrove ecosystem dominated by red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), and white mangrove (*Laguncularia racemosa*).

The salt works were once on dry land but close to the lagoon as a source of brine for evaporating in pots over fires. After the salt works were abandoned at the end of the Late Classic period, rising seas inundated the salt works with some of the sites keeping pace with sea level rise due to mangrove accretion. The sea floor consists of firm peat overlain with a layer of silt. The peat is formed by organic red mangrove tissues (McKillop et al. 2010a and 2010b). Loss-on ignition indicates high organic matter accounting for approximately 60% of the sediment (McKillop et al. 2010a and 2010b). The peat has remarkably preserved wooden posts and other botanical remains including cohune endocarps (*Attalea cohune*) (McKillop 2005; McKillop and Sills 2021) but is not conducive to the preservation of bone and shell (Sills et al. 2016). The wooden posts were made from a variety of hardwoods including black mangrove and other species (Robinson and McKillop 2013). Most sites have lines of palmetto palm posts (*Acoelorrhaphe wrightii*) used as land retaining walls (McKillop and Sills 2017; McKillop 2019).

Sediment Collection at the Paynes Creek Salt Works

Marine sediment samples have been collected from Chan b'i (Sills et al. 2016), Ta'ab Nuk Na, and Ek Way Nal. Transects were established at each site to sample the inside and outside of buildings, marked by the presence of a wooden posts, and to include open areas defined

Table 1. Potential Marine Sediment Chemical Signatures of Ancient Activities at The Paynes Creek Salt Works. Information below is inferred from the available literature on chemical analysis of soils and sediments.

Activity	Chemical Signatures
brine boiling	phosphorus, magnesium, potassium
storage of food	phosphorus, magnesium, calcium
storage other	low phosphorus
briquetage production	aluminum, magnesium, manganese, potassium, zinc
salt enrichment	low sodium
salt drying fish	sodium, iron, calcium, strontium
fish processing	iron, calcium, strontium
wood working	low phosphorus, iron
food preparation, disposal, and consumption	phosphorus, zinc, aluminum, magnesium, barium, manganese
ritual	barium, magnesium, manganese, zinc
burial	phosphorus, strontium, calcium, mercury, iron, lead, copper, manganese
other craft production	copper, iron, manganese, lead

as yards (Figure 3). The samples were collected to correspond with planned or potential excavations (Sills et al. 2016). A 1 x 1 m grid frame was placed along transects, with marine sediment collected at 50 cm and/or 1 m intervals. Samples were collected using a stainless-steel spoon to collect a 2 to 3 cm section of the sea floor for analysis. The marine sediment was placed in a sterile labeled whirl-pak bag (Figure 4). Notes about the location of each sediment sample and the condition of the sea floor were made in a water-resistant book. Photographs were taken of the sediment and the procedure. The marine sediment was excavated under permit by the Institute of Archaeology of Belize to Heather McKillop. The sediment is currently stored at the Louisiana State University Archaeology Laboratory.

The sediment from Chan b'i was analyzed by Christian Wells at the Laboratory for Anthropogenic Soils Research at the University of Southern Florida using the digestive technique of inductively coupled plasma-mass spectroscopy (ICP-MS) (Sills et al. 2016). The marine sediment from Ta'ab Nuk Na has undergone chemical analysis at the Louisiana State University AgCenter and is awaiting analysis by the authors. Selecting marine sediment samples from Ek Way Nal is ongoing. Sediment from Ta'ab Nuk Na and eventually Ek Way Nal will be analyzed by using a digestive process called inductively coupled plasma-atomic emission spectrometry (ICP-AES). Both ICP-MS and ICP-AES detect trace elements that have bonded to the soils and sediments. The instruments used for these studies report the results in ppm of numerous elements that are indicative of human settlement including calcium, iron, magnesium, manganese, phosphorus, potassium, zinc, aluminum, and lead to name a few.

Modeling Chemical Signatures of Activities at The Paynes Creek Salt Works

Many activities can be detected by chemical analysis of marine sediment at the Paynes Creek Salt Works including brine boiling, food storage, other storage, pottery production, brine enrichment, salt drying of fish, fish processing, wood working, food preparation, disposal, and consumption, rituals, burials, and other craft production (Table 1). Brine boiling was occurring indoors in salt kitchens at the Paynes Creek Salt Works. Chemical signatures of this activity would resemble those identified at Chan b'i with phosphorus, potassium, and magnesium occurring together (Sills et al. 2016). Potassium and magnesium are often associated with fires and wood ash and could also represent hearths or areas of burning for rituals (Fulton et al. 2017; LeCount et al. 2016; Wells 2004).

Food storage associated with a residence and/or salt production would have phosphorus, magnesium, and/or calcium. At Sacapulas, if balls of corn float in the brine, then it is ready for boiling (Reina and Monaghan 1981). Other storage associated with salt production would include storage of firewood and pottery. These likely would have lower phosphorus than brine boiling. Pottery storage would also have aluminum and manganese present (Sills et al. 2016). Briquetage production would include materials that are present in the clay and temper of locally produced pottery such as aluminum, magnesium, manganese (Sills et al. 2016) and potassium associated with fires. Brine enrichment would have areas of low phosphorus as those areas that are not engaged in food storage, consumption, or disposal (Parnell et al. 2002b; Terry et al. 2004). Also, sodium values would be lower than the inside of salt kitchens (Sills et al. 2016).

Other activities tangential to salt production such as salt drying of fish and fish processing would have phosphorus present as well as calcium and strontium found in bone and shell. Wood working areas would likely have less phosphorus, but iron would be present due to the stone tools required to work with the wood (Cap 2015). Consuming, preparing, and disposal of food would have phosphorus but also zinc, aluminum, magnesium, barium, and/or manganese (Fernández et al. 2002; Parnell et al. 2002a). Many of the buildings and salt kitchens could also show evidence of ritual as well as burials as is noted at Cerén where hematite was common in most residences (Sheets 2000). Hematite along with other pigments could be present and would include the presence of iron, manganese, copper, lead, and/or mercury (LeCount et al. 2016; Terry et al. 2004).

Conclusions

Chemical analysis to detect elements associated with human activities in soils and sediments is an important method for discovering additional activities missing from the artifact assemblage due to differences in preservation. Chemical sediment analysis such as ICP-MS and ICP-AES has been successful in finding additional activities as well as defining salt kitchens at the Paynes Creek Salt Works. The environmental factors at of an acidic anaerobic sediment and sea-level rise after the sites were abandoned preserved wooden buildings and botanicals but not bones or shell. Combining various methods including excavation, artifact analysis, use-wear analysis, and ethnographic sources with sediment chemistry aids in defining the organization of production at the Paynes Creek Salt Works. The Paynes Creek salt makers were engaged primarily in salt production inside of salt kitchens for surplus production living next to their salt works. The pottery used in salt production was produced near-by and brine enrichment occurred close to the salt kitchens. However, the adoption of chemical analysis of sediment will illuminate other possible activities and features such as salt drying fish, fish processing, ritual, burials, brine enrichment, residences, and craft production.

Acknowledgements We appreciate the institutions and people who have supported our sediment chemistry research. The collecting and export of sediment was carried out under permit to Heather McKillop by the government of Belize Institute of Archaeology. The National Science Foundation funded the fieldwork through grant 1826653 to Heather McKillop and E. Cory Sills. Louisiana State University and The University of Texas at Tyler provided institutional support. We thank Christian Wells and Zachary D. Atlas of University of South Florida for the geochemical analysis of sediment from Chan b'i. We are thankful for the help of the 2022 field team that includes Rianna Bowen, Conner Flint, Cher Foster, Hollie Lincoln, Kaitlyn Samples, Dr. Rachel Watson, and John Young.

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