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Elemental Analysis of Mangrove Unslipped Pottery from The Paynes Creek Salt Works Using a Portable XRF Machine

Undergraduate Honors Thesis

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Introduction

In this thesis, I study the elemental composition of Classic Maya pottery to learn about the temper materials and clay used to produce them. From there, I determine the origins of the pottery and its relationship to Classic Maya trade. Specifically, I examine Mangrove Unslipped storage jars that were used as brine storage vessels in salt production at the Paynes Creek Salt Works in Belize. I examine the elemental composition of the pottery by using a Portable X-ray Fluorescence machine. By determining the elemental components of the pottery sherds and comparing them, interpretations can be made about the types of clay and temper materials that were used to make the pottery. From there, conclusions can be drawn about where the pottery was made, by looking at geology. These conclusions can give insight into from where the people at the Paynes Creek Salt Works were getting their pottery.

Paynes Creek Salt Works
The Paynes Creek Salt Works are located in a 10 km² area in Punta Ycacos Lagoon, Belize (Figure 1). Radiocarbon analysis of a sediment column of red mangrove peat from the K’ak’ Naab site shows that the area has been submerged in salt water, due to sea level rise (McKillop et al. 2010:250). The lagoon is surrounded by mangrove forests, which are also submerged. The mangrove peat has preserved wood. Dr. Heather McKillop and her team focus their research on this area. She believes that the Paynes Creek Salt Works were used by the Maya for mass salt production (McKillop and Aoyama 2018; McKillop and Sills 2021). She has found
many artifacts there to support her claims, including many wooden posts (McKillop 2019), as well as abundant pottery (McKillop 2002). The posts have been studied to determine the previous existence and locations of salt production and storage buildings, which allowed for year-round salt production. The pottery has provided evidence of the salt production process. The pottery was used in a brine boiling method, in which salt water was boiled in large pots to make salt (McKillop 2021).

The Paynes Creek Salt Works are composed of 110 salt works, or salt production locations, which date from the Late to Terminal Classic Maya period (A.D. 600-900). The area is divided into different sites. Each site is “defined by a cluster of artifacts and wooden posts visible on the sea floor and at least 10 m distant from another site” (McKillop 2021:3). Thousands of posts have been found, and 4,042 posts have been mapped. These posts outline buildings at 70 different sites (McKillop 2019). At one specific site, Ek Way Nal, at least 10 different buildings have been identified from the locations of the wooden posts (McKillop and Sills 2021). Both salt kitchens and a residence have been identified, based on the locations of different artifacts. By individually mapping each building and noting the types of artifacts that were found there, one can determine the use of each building. Buildings that contain lots of briquetage artifacts (including ceramic pots, bowls, jars, and vessel supports) were interpreted as locales for salt production (McKillop and Sills 2021).

In this project, I look at 13 ceramic pottery sherds from four different sites of Paynes Creek Salt Works, including site 7 (Ta’ab Nuk Na), site 70, site 72, and site 83. The samples include six artifacts from site 7, two artifacts from site 70, three artifacts from site 72, and two artifacts from site 83.

Salt Production
Salt production was important to the Classic Maya diet (McKillop 2019). Salt was also useful for preserving meat and fish and was used in some salt-production rituals. These rituals occurred at the beginning of the salt-production season and included music, food, and dancing (McKillop 2002: 95). Salt was valued by all, but could only be produced in certain areas, mainly on the coasts, which had access to saltwater. As inland populations increased, so did the demand for salt. Because of this increased demand, salt became valuable in trade. In the Maya area, most salt was produced on the coasts and traded inland. Increase in demand for salt allowed the coastal Maya to benefit, since they may have controlled the production and distribution of salt (McKillop and Sills 2017).

The Maya produced salt at multiple different sites, including the Paynes Creek Salt Works. In fact, the salt works center around mass salt production (McKillop and Sills 2021). The salt works are located in a coastal lagoon and had seasonal access to saline water. Maya used this salty water to produce large amounts of salt (McKillop and Aoyama 2018). After the Paynes Creek Salt Works were abandoned, they were submerged, due to sea-level rise. Many of the organic artifacts from the site were preserved and recovered, because they were encased in anaerobic mangrove peat.

To make the salt at the Paynes Creek Salt Works, the Maya used evaporation. They had large, ceramic pots that they filled with saline water, or brine. These pots were identified by Dr. Heather McKillop as the Mangrove Unslipped pottery type, and they were used to store brine before boiling. To make these pots, clay was mixed with a temper material and was then formed and fired. The temper material provided the pots with extra strength and durability. Next, the brine was poured into Punta Ycacos Unslipped pots, for boiling (McKillop 2002: 73). The Maya placed these pots on ceramic or stone support stands and boiled the water in them over fire. Once
the water had evaporated, the salt was left behind in the pots. It was then collected and either used or traded. This technique was used worldwide in ancient times, including at the Paynes Creek Salt Works (McKillop 2019).

After the salt was produced, the jars, jar supports, kilns, and other salt-production pottery eventually broke and were discarded. The remnants of this pottery are referred to as briquetage. Abundant briquetage, as well as mapped wooden buildings, was found at the Paynes Creek Salt Works, serving as evidence for mass salt production (McKillop 2010). Briquetage made up over 95 percent of the artifacts found there (McKillop 2019:30).

**Trade at the Paynes Creek Salt Works**

As stated above, salt was a valuable trade resource, which means that the people at the Paynes Creek Salt Works were likely trading their salt for other goods, such as obsidian, pottery, or ritual-related artifacts. Researchers can study other artifacts found at the Paynes Creek Salt Works and determine their origin locations to learn about trade activity at the salt works.

Archaeologists have studied trade patterns at the Paynes Creek Salt Works by using portable X-ray fluorescence (pXRF) technology. This technology allows researchers to study the chemical compositions of artifacts and determine their origin. By determining the origin locations of artifacts at a given site, archaeologists can discover where the people at the site were trading. Portable XRF technology was used to determine the trace elements of obsidian, including rubidium, zirconium, and strontium, in obsidian artifacts, found at the salt works, to identify the artifacts’ origins. (McKillop 2019: 170-171, Table 7.4) There were two main obsidian sources used at the Paynes Creek Salt Works: Ixtepeque and El Chayal. This pattern matches the Classic period obsidian pattern at Wild Cane Cay (McKillop 2005a: Figure 5.3): At the salt works, 38%
of the obsidian was from El Chayal, similar to 42% at the nearby port Wild Cane Cay (McKillop 2019: Table 7.5).

Similarly, archaeologists did research on a jadeite gouge that was found at the Ek Way Nal site. Many analyses were conducted on the artifact at the American Museum of Natural History, including, “backscattered- electron (BSE) images, SEM (Zeiss EVO 60 with Bruker energy-dispersive X-ray spectroscopy) and X-ray microdiffraction (Rigaku DMAX/Rapid)” (McKillop et al. 2019:509). The results revealed that the elemental composition of the jadeite artifact is similar to jadeite samples from the Motagua River valley in Guatemala. This result means that the gouge did not originate at the salt works, it was likely obtained through marketplace trade or through travel and trade with the Montagua River valley (McKillop et al. 2019).

Rachel Watson (Watson and McKillop 2019) describes typical Maya trade habits during this time. She details how minor elites rose to power as populations increased during the Classic period. These elite rulers maintained urban centers, and often had kinship or marriage connections to other urban centers. Lubaantun, Uxbenka, and Nim Li Punit were large urban centers during the Classic Maya period. They would have had lots of connections and participated in trade with many areas, including the Paynes Creek Salt Works (Watson & McKillop 2019). Dr. Heather McKillop believes that the salt makers at Paynes Creek were trading with these inland, urban centers to meet the inland population’s demand for salt (McKillop 2010). She explains how the inland Maya may have allowed the coastal Maya to enter into their political hierarchy by providing them with access to status paraphernalia and trappings of power in exchange for trade (McKillop 2010:370). Evidence of this suggestion is seen in intricate artifacts found at the Paynes Creek Salt Works, including ocarinas and serving vessels.
(McKillop 2010). In addition, McKillop also discovered a wooden canoe paddle from the saltworks. This discovery supports the idea that the salt makers were using river transport to trade their salt inland (McKillop 2005b).

**Pottery at the Paynes Creek Salt Works**

Multiple types of salt production equipment were used at the Paynes Creek Salt works, most of which was ceramic. In her research at the salt works, Dr. McKillop identified four main ceramic types, including two slipped types and two unslipped types (McKillop 2002:54).

The first slipped type is called Warrie Red. It includes jars, bowls, and dishes with a red slip that has often weathered to a black or grey color. Warrie Red also has a fine paste that is often not visible on the surface. This type may have been used for pouring and storing brine (McKillop 2002:86). The second slipped type is Belize Red. This type includes bowls and dishes with tripod supports. The artifacts contain an easily-erodible, red slip and fine, yellow paste. Belize Red artifacts were serving dishes and may have been used in salt production rituals (McKillop 2002: 90).

The first unslipped type is referred to as “Punta Ycacos Unslipped”, which includes an unslipped surface with a coarse paste showing throughout. Artifacts include jars with out-curved necks and open bowls in a variety of shapes. The artifacts were used in the boiling process as vessels and supports (McKillop 2002: 56). The second unslipped type is Mangrove Unslipped. This type also includes an unslipped surface, but has a medium paste and pore holes visible on the surface. Some artifacts include jars with out-curved or straight necks that were used to store brine (McKillop 2002: 72).

**Mangrove Unslipped Storage Jars**
In this thesis, I study the elements present in samples of Mangrove Unslipped pottery to determine the types of clay and temper materials used to produce them. Mangrove Unslipped refers to a specific type of pottery found at the Paynes Creek Salt Works. The pottery has an unslipped surface that is smooth. It is made from a “medium paste with calcite temper” (McKillop 2002:72) and contains small, visible holes, or pitting on the surface. Some of the Mangrove Unslipped ceramics had white specks on their surfaces, resembling calcium carbonate temper (McKillop 2002:73). The Mangrove Unslipped samples used in this project are all small, broken pieces of pottery. However, this type of pottery originally formed a large jar that was used for storing brine, before it was boiled in the salt production process. The jars had in-curved sides and out-curved necks (McKillop 2002:73). The pottery samples were found on the sea floor at different sites at the Paynes Creek Salt Works, and they date to the Late Classic period (McKillop 2002:76).

All of the pottery sherds that are studied in this project were found in mangrove peat. The presence of mangroves at the sites created peat that encased the artifacts once they became submerged, due to sea-level rise. As the sea rose, the roots of red mangroves trapped leaves and sediment, creating an anaerobic peat. This peat helped preserve the wood and other organic artifacts found at Paynes Creek Salt Works, including many wooden posts (McKillop 2019; McKillop and Sills 2017). However, the acidic nature of the mangrove peat ate away at the pottery, causing the decomposition of certain elements and pitting on the surface (McKillop 2005b).

Temper Material
Temper material is often mixed with clay to add structure and support to pottery. The temper makes the pottery stronger and prevents it from cracking during firing. Temper can be many different types of material, including bone, sand, or crushed stone. Frequently, ancient potters would use their locally available stone as temper material (Hammond 1975). Because geology varied among ancient sites, the origin location of ceramic artifacts can be determined by their temper material.

As stated above, Mangrove Unslipped pottery includes a calcite temper, sometimes showing evidence of calcium carbonate. However, the acidic mangrove peat that the pottery was encased in likely dissolved much of the temper material, leaving behind pitting. Calcium carbonate is found naturally in chalk, limestone, and marble. Therefore, the Mangrove Unslipped pottery was likely produced in an area with one of those rocks.

Norman Hammond (1975) studied pottery at the inland site of Lubaantun. He found that quite often, crushed limestone was used as a temper material in the pottery there. He identified a “Remate Group” of pottery, which had medium to fine grained temper, similar to the Mangrove Unslipped type (Hammond 1975). Similarly, Jillian Jordan studied pottery found at Uxbenka. She found that much of the pottery there contained a calcareous sandstone temper, rather than limestone. This sandstone was available at Uxbenka, indicating that the pottery was locally made (Jordan & Prufer 2020). Since the Paynes Creek Salt Works had trade connections with inland sites like Lubaantun and Uxbenka, and since the Mangrove Unslipped pottery contained calcium calcite temper, it is possible that the Mangrove Unslipped pottery found at the Paynes Creek Salt Works was produced in or near the Lubaantun and Uxbenka sites or elsewhere in a limestone rich area.

X-Ray Fluorescence Methods
X-Ray Fluorescence (XRF) is a non-destructive analytical technique that determines the elemental composition of different materials. The machine sends an X-ray through the sample material, which causes the sample to emit secondary X-rays. Each element that is present in the sample material will emit its own unique X-ray. An XRF machine measures these X-rays to identify which elements are present (Aimers et al. 2011). In this project, I use a Bruker Portable X-Ray Fluorescence (pXRF) machine to analyze the elemental composition of ceramic pottery sherds.

One of the biggest advantages of using XRF technology is that it is non-destructive (Aimers, 2021). The X-ray beam used in XRF does not cause any damage to the artifacts. Another advantage of XRF technology is that it produces results quickly, within minutes. Filters can also be used to focus data on specific trace elements (Tykot 2013). One potential disadvantage of XRF is that it will read the elemental composition of the surface of an artifact. For example, if an archaeologist was interested in studying the composition of the clay used in a piece of glazed pottery, the glaze would impact the reading. However, this problem can be solved by using unglazed, broken edges of pottery sherds. Another problem is that the secondary X-rays of many elements absorb in the air (Aimers 2021). Because of this fact, the farther an artifact is from the XRF machine, the less accurate the readings will be. Therefore, placing artifacts as close as possible to the XRF machine is important, as well as using a flat surface of the artifact, when possible (Tykot 2013:242).

Other XRF Research

XRF technology is used in archaeology to identify the elemental composition of artifacts. Archaeologists are able to group their artifacts by their compositions and make inferences and
conclusions about them. Usually, archaeologists aim to make conclusions about the artifacts’ provenance or production process. Artemios Oikonomou (2006) used this technology to study ancient Greek pottery. He used X-ray fluorescence to determine the elemental composition of 64 potsherds, which were found in Oraon, a Hellenistic settlement in northwestern Greece. From the data in his analyses, he was able to group his pottery into four different groups. He concluded that each group corresponded to a different local production practice. He determined that pots used for cooking included quartz. Pots used for storage and transport included calcite and were fired at low temperatures. Tableware was also tempered with calcite and was well-fired. However, since most of the pottery sherds had uniform chemical profiles, he believes that the different types of pottery were all locally produced (Papachristodoulou 2006).

Ellery Frahm (2018) used portable X-ray fluorescence (pXRF) technology to investigate the elemental composition of pottery sherds found at Tell Mozan in northeastern Syria. Her samples included pottery that was believed to be locally produced, as well as pottery that was believed to be imported, based on visual identifications. She wanted to see if the pottery’s chemical compositions supported the claims by using pXRF. She used chaff and calcite tempered sherds that she knew were locally made. By assaying the sherds with pXRF, she was able to have a “basis for the local elemental signature” (Frahm 2018:35). She compared this information with the pXRF of other sherds. Any sherds with elemental information that matched the chaff and calcite tempered sherds were determined to be locally made. She discovered that sherds that they had initially thought were locally made imitations of imported pottery, were actually not locally made. She mentions the importance of pXRF technology and how it can reveal elemental differences that are not visually apparent to archaeologists.
Goals, Objectives, and Hypotheses

The goal of this research was to identify chemical elements in pieces of Mangrove Unslipped storage jars. By identifying and comparing present elements, inferences can be made about the type of clay and/or temper material that was mixed with clay to make the Mangrove Unslipped storage jars. In this project, I studied 13 artifacts from four different sites. They were each assayed, using PXRF technology.

Based on the findings, interpretations can be made about Maya trade relationships. By determining the location of the pottery’s production, through similarities between the artifacts’ elemental profiles and geology, we can determine trade relationships between Paynes Creek Salt Works and other areas. If the Maya did not produce the pottery at the Paynes Creek Salt Works, then they must have imported the pottery or temper material from somewhere else. By identifying the origin of the pottery, we can determine from where the Maya of Paynes Creek Salt Works were importing their salt-making pottery, and therefore with who they were trading.

I predict that the elemental compositions of the pottery sherds will be similar. Even though the pottery comes from four different sites, the jars are all the same style. They are all Mangrove Unslipped storage jars, which were used for storing brine. I think that the people at Paynes Creek Salt Works would have sourced all of their storage jars from one place, both because of convenience, and since the pottery is all the same style. Therefore, I think the elemental compositions will be the same.

Materials and Methods

In this project, 13 samples of Mangrove Unslipped pottery sherds from Paynes Creek Salt Works are used. All of the samples have been exported from the Belize Government Institute of
Archaeology, and they are under permit to be studied at LSU by my advisor, Dr. Heather McKillop. The methods were conducted in the LSU DIVA Lab, in the pXRF room.

I used a Bruker portable XRF machine to identify the elemental composition of the pottery sherds. This process was monitored by a qualified professional in the pXRF room of the LSU DIVA Lab, in order to ensure safety at all times. A pXRF machine works by shining an X-ray beam on each pottery sherd. The atoms that are hit by the X-ray then emit their own X-rays. The energies of the emitted X-rays are measured by the machine and are used to determine which elements are present. This allows me to identify the elements that are present in the clay and temper material. (Source: Bruker Website)

First, I photographed and organized the artifacts. I grouped them by the sites in which they were found. Next, I created a sketchbook containing labeled drawings of the artifacts. I drew sketches of each artifact, sketching both the front and back. I included any important markings, cracks, or missing pieces. I labeled each drawing with the artifact’s catalogue number. I marked places that I thought would be ideal for conducting the pXRF analysis. I chose points that were clear of marker or glue, in order to get an accurate reading of the elements. I chose points that were relatively flat, in order to have the artifact lie as closely to the pXRF machine as possible and further improve the accuracy of the readings. I have included my photographs of all of the artifacts (Figures 1-2) as well as a selection of sketches (of one artifact from each site) (Figures 3-6) as references.
From top, left to right:
A. 83 T (32/180-48-1/1-T)
B. 7 FFFFFF2
C. 7 RRRR3
D. 83 W (12/180-48-1/1-W)
E. 7 000002
F. 7 TTTT2

From top, left to right:
A. 7 T (32/180-21-1/1-T)
B. 70 L (32/180-38-1/1-L)
C. 72 Kb (32/180-9-5/-1-12)
D. 7 F (32/180-21-1/1-F)
E. 72 Kc (32/180-9-4/1-56)
F. 70 H (32/180-38-1/1-H)
G. 72 Ka (32/180-40-1/1-8)

Figure 3: sketch of artifact 7 F (32/180-21-1/1-F), interior and exterior. (X indicates the planned pXRF analysis location.)
Figure 4: sketch of artifact 70 H (32/180-38-1/1-H), interior and exterior.

Figure 5: sketch of artifact 72 Ka (32/180-40-1/1-8), interior and exterior.
Then, I started my pXRF analysis. I turned on the machine and opened the software. I made sure that all of the settings were correct, according to the machine’s directions. I created a file and named it, corresponding to the artifact’s catalogue number. I put the artifact on the pXRF platform and positioned the artifact to where I thought it would get the most accurate reading. Then, I started the assaying process. I chose to set up an automatic, multiple assay for each artifact. I hoped that including two identical, successive assays for each artifact would eliminate any potential machine error. Each assay took 120 seconds (or 240 seconds total for each artifact). I repeated this process for each artifact. When possible, I used the machine’s cover to contain the radiation. However, most of the artifacts were too large to use the cover.

Once all of the assays were complete, I looked for patterns among artifacts and among sites. I took screenshots of each spectra and labeled them with their artifact number. I used the labels -001 and -002 to differentiate between the first and second assays of each artifact. I also recorded the ROI (region of interest) information table for each artifact spectra in an excel spreadsheet. I expanded both assays for each artifact to look for any differences between element
peaks. Both assays of each artifact were almost identical, so I decided to use the first spectra of each artifact to compare and contrast with other artifacts. Next, I grouped the spectra according to their sites. I first compared the artifacts from within each site to see if there was any variation within a given site. Then, I compared sites to each other to see if there was any variation among sites.

Results

I found the most variation in Ta’ab Nuk Na (site 7). I found that artifacts 7 F and 7 FFFFF2 (Figures 12 and 13) have smaller silicon (Si), argon (Ar), potassium (K), calcium (Ca), titanium (Ti), uranium (U), copper (Cu), zinc (Zn), and arsenic (As) peaks compared to artifacts 7 RRRR3, 7 T, 7 TTTT2, and 7 000002. Artifacts 7 F and 7 FFFFF2 (Figures 8-11) were similar to each other. In contrast, artifacts 7 RRRR3, 7 T, 7 TTTT2, and 7 000002 were similar to each other. I included two groups of spectra (Group 1.1 and Group 1.2) to illustrate the differences in element peaks among the artifacts from site 7.

For site 70, artifact 70 L had slightly higher peaks than artifact 70 H for most elements (Ar, Ka, Ca, Ti, Co, Cu, Zn, and As). However, the differences in peaks between the two artifacts was small (Figures 14 and 15).

For site 72, artifact 72 Kc had a lower calcium (Ca) peak than artifacts 72 Ka and 72 Kb. Artifact 72 Ka had higher (S) and (K) peaks than artifacts 72 Kb and 72 Kc. Artifact 72 Kb had a lower (As) peak than artifacts 72 Ka and 72 Kc. However, these differences between peaks were small (Figures 16-18).

For site 83, I found that artifact 83 W had slightly higher peaks than artifact 83 T for some elements (Ar, Ca, Ti, Co, Zn) (Figures 19 and 20).
When comparing sites, I found that all of the artifacts had similar elemental profiles, except for artifacts 7 T, 7 RRRR3, 7 TTTT2, and 7 000002. These four artifacts had higher (Si), argon (Ar), potassium (K), calcium (Ca), titanium (Ti), uranium (U), copper (Cu), zinc (Zn), and arsenic (As) peaks than did the other nine artifacts. I have included pictures to illustrate the differences in peaks (Figures 8-11).

Group 1.1: spectra of artifacts from site 7 (Ta’ab Nuk Na): 7 RRRR3, 7 T, 7 TTTT2, and 7 000002

![Figure 8: spectra of artifact 7 RRRR3](image-url)
Figure 9: spectra of artifact 7 T

Figure 10: spectra of artifact 7 TTTT2
Figure 11: spectra of artifact 7 000002

Group 1.2: spectra of site 7 artifacts: 7 F and 7 FFFFF2
Figure 12: spectra of artifact 7 F

Figure 13: spectra of artifact 7 FFFFFF2
Group 2: spectra of artifacts from sites 70, 72, and 83

Figure 14: spectra of artifact 70 H

Figure 15: spectra of artifact 70 L
Figure 16: spectra of artifact 72 Ka

Figure 17: spectra of artifact 72 Kb
Figure 18: spectra of artifact 72 Kc

Figure 19: spectra of artifact 83 T
Discussion

The pXRF assays on 13 artifacts from four different sites showed that most of the artifacts have similar elemental profiles. However, four artifacts, 7 T, 7 RRRR3, 7 TTTT2, and 7 000002 differed from the others. They have higher levels of argon (Ar), calcium (Ca), titanium (Ti), copper (Cu), zinc (Zn), and arsenic (As) than the other nine artifacts. Therefore, there are two separate groups, including group 1 with artifacts 7 T, 7 RRRR3, 7 TTTT2, and 7 000002 and group 2 with the other nine artifacts (7 F, 7 FFFFF2, 70 L, 70 H, 72 Ka, 72 Kb, 72 Kc, 83 T, and 83 W).

Since the two groups have different elemental profiles, they could have been made of different types of clay or temper material. The higher levels of calcium (Ca) in group one are particularly interesting, because the difference in levels suggest that the four artifacts could have been made of a different temper material than the pottery in group two, possibly limestone,
which is made of calcium carbonate. Keeping in mind that these artifacts were encased in acidic mangrove peat, it is likely that the pottery originally contained more calcium than is present today.

If the two groups were made of different temper materials, then the groups were likely made in different places. If the artifacts were made in different places, then that fact means that at least one of the groups was not made at the Paynes Creek Salt Works. Therefore, the people living at the Paynes Creek Salt Works must have received pottery from somewhere else. This fact means that they had contact with people from other areas and might have traded with them for pottery.

Based on previous research, the salt makers at the Paynes Creek Salt Works were trading for obsidian with coastal sites, such as Wild Cane Cay and were trading Warrie Red and other pottery from inland sites, such as Lubaantun and Uxbenka (McKillop 2002, 2019).

The Lubaantun site is located in southern Belize, in an area that is rich in limestone (Figure 21). Uxbenka is located in an area that contains calcareous sandstone. As previously stated, these sites used their locally available rocks as temper material for their pottery. This area also contains the Toledo Beds geological region, which has soil containing mudstones, siltstones, and limestones. The soil from this area is typically brow and red clay, which is “well supplied with calcium” (Baillie 1993:6). Limestone is primarily composed of calcium carbonate (CaCO3), as are sandstones. As stated above, the group one artifacts from site seven (7 T, 7 RRRR3, 7 TTTT2, and 7 000002) have higher levels of calcium than the other artifacts, which would have originally been higher, before the artifacts were encased in the acidic mangrove peat. Knowing this geological information, in addition to information about obsidian and other pottery trade among Paynes Creek Salt Works, Lubaantun, Uxbenka, Nim li punit, and Wild Cane Cay,
perhaps the people of Paynes Creek Salt Works were also sourcing clay or temper material from these sites.

![Geological Map of Belize](image)

**Figure 21**: Geological Map of Belize (modified from Maps of San Pedro and Ambergris Cave, prepared by Jan Meerman, Cornec, 2008)

**Conclusion**

In conclusion, in this thesis, I studied Mangrove Unslipped pottery sherds from the Paynes Creek Salt Works to determine the elements present in the clay or temper fabric. I did this by using a pXRF machine to analyze the elemental profiles of each ceramic artifact. After assaying each artifact, comparisons were made between each artifact within a site and then
among sites. From there, I was able to make two groups, based on differences between argon (Ar), calcium (Ca), titanium (Ti), copper (Cu), zinc (Zn), and arsenic (As) spectra levels. The elemental differences between the two groups suggests that the pottery was made of different materials, perhaps in two different places. Specifically, the higher calcium levels of group one suggest that artifacts 7 T, 7 RRRR3, 7 TTTT2, and 7 000002 contained a calcium-rich temper material, like limestone. Therefore, at least one group of pottery was not made at Paynes Creek Salt Works, which means that the people there received pottery from somewhere else, possibly through trade with inland people at sites that contained limestone, like Lubaantun.
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