DECODING THE SECRETS OF ANCIENT ECUADORIAN POTTERY ENGINEERS

Lue Fang, Sareena Kalinani, Saketh Karri, Lukas Liakhovitch, Amy Lin, Kaixiang Loke, Ardiv Mirza, Karthik Vemparala, Sebastian Villa, Dylan Wigdahl

Advisor: Maria Masucci, PhD
Assistant: Victoria Kuenzel

ABSTRACT

The creation of white-on-red pottery has long been attributed to the people of Guangala due to the abundance of these ceramics in the Guangala region; however, there are numerous inconsistencies that challenge this assumption. To address these discrepancies, a deeper examination of the pottery's material composition and manufacturing method is required. This study utilizes experimental archaeology to investigate the white-on-red pottery's forming techniques and tests different organic tempers like corn husks and balsa wood. While this unique pottery has been assumed to have originated from Guangala, Instrumental Neutron Activation Analysis (INAA) and petrographic analysis reveal non-local material compositions, suggesting alternative explanations of its presence, like trade networks with Northwest Peru or other neighboring regions. To support this suggestion, thick-section imaging identifies the pottery as highly micaceous, which is extremely uncommon for clay native to Guangala. By replicating ancient pottery techniques and comparing void size and orientation, this research demonstrates that slabbing and drawing methods, coupled with corn husk temper, achieve the characteristic void orientations and sizes found in white-on-red pottery. The research contributes to understanding the captivating white-on-red pottery and new insights into the Guangala people and their interactions with neighboring regions.

BACKGROUND

The beauty of Guangala white-on-red pottery has captivated archaeologists and historians for decades, yet the secrets behind its unique composition and crafting techniques remain largely unknown. The Guangala culture existed in southern Ecuador from 100 B.C.E. to 800 C.E. (Figure 1) and was named after the village where archaeologists first discovered their distinctive pottery. One particular type of pottery, white-on-red, has been noted from early investigations as unique and unusual (Bushnell, 1951). Also unusual are the virtually identical vessels found at archaeological sites of the Jambelí culture (located in southern Ecuador) and abundant examples at sites of the Pechiche-Garbanzal cultures in the Tumbes Valley, northern coast of Peru (Currie, 1989; Izumi &

Figure 1: Map of white-on-red occurrences

Terrada, 1966). While some have assumed that this pottery was produced by the Guangala, its abundance in neighboring areas and its distinct composition have led researchers to question its origin. Some characteristics of the white-on-red pottery: the mica visible in cross sections and on vessel surfaces; and their unusual paste characteristics, with open pores, may point to a potential origin in or around northern coastal Peru (Bushnell, 1951).

Cultural remains from the Guangala culture have been found along the coast of Guayas Province from the Santa Elena Peninsula to the southern Manabí Province, first discovered by Geoffrey Bushnell (Bushnell, 1951). This time period throughout coastal Ecuador is known as the Regional Developmental Period. The period of Regional Development saw the emergence of distinct regional ceramic styles, customs, as well as complex political and social organizations throughout coastal Ecuador (Masucci, 2008). During Regional Development, there was increased social stratification within Ecuadorian societies, but the Guangala do not exhibit similar inequality (Masucci, 2008, p. 490). The same white-on-red pottery found at the Guangala sites is also found in Jambelí and Tumbes Valley, northern Peru, but limited research has investigated how these settlements interacted with each other and the extent to which they were autonomous.

The southwestern Ecuador region contained hill systems, wetlands, and semi-arid areas. Farmsteads and mud huts were typical of Guangala sites rather than stone architecture, likely due to the arid and hot climate. Along the Pacific coast, Guangala fishing communities thrived and cooperated with the inland Guangala farmers as evidenced by the deep sea marine fish bones found at inland settlements (Reitz & Masucci, 2004). Masucci and Hoopes (2022) concluded that people belonging to pre-Colombian communities were experts in their landscapes and had watercraft capable of long-distance travel and exploring vast territories. These communities invented multiple modes of transportation, one of them being large balsa wood rafts, primarily found on the Pacific coast of Ecuador. In addition, it is believed that the development of these rafts aided the creation of numerous trading routes. Some researchers believe that peoples like the Guangala could travel as far as to Costa Rica (Masucci and Hoopes 2022).

One area in this region, El Azúcar Valley (Green Dot in Figure 1) has been studied extensively due to an abundance of Guangala pottery. Two sites, Site 30 and 47, provide a dense source of Guangala material culture. Arenillas (El Oro Province) is a modern town in southern Ecuador where Jambelí remains have been found (Orange Dot). The Jambelí sherds include white-on-red pottery similar to the pottery in Guangala across the Gulf of Guayaquil. Due to this similarity and the Guangala's ability to travel across large bodies of water, it is possible that the Guangala could have traded with the Jambelí in order to acquire their white-on-red pottery. Moving south, the Tumbes Valley is also known for its archaeological richness, although it is also not well studied. Throughout this valley, two of the most prominent sites are near the towns of Garbanzal and Pechiche (Blue Dot), both containing abundant white-on-red pottery.

Therefore, not only is the white-on-red pottery unique compared to other Guangala pottery, virtually identical vessels are found in southern Ecuador on sites of the Jambelí culture (Currie, 1989) and on the northern coast of Peru in areas inhabited by the Pechiche-Garbanzal culture (Izumi & Terrada, 1966). The white-on-red pottery in southwest Ecuador is best dated to the latter half of the Early Guangala period (c. 100 B.C.E. to 200 C.E.). The Guangala white-on-red pottery was replaced in 200 C.E. with a different style and seemed to have ceased production rapidly. In contrast, the white-on-red pottery in the Tumbes Valley appears earlier in the Late Formative and continues throughout the period (Izumi & Terrada, 1966; Currie, 1989).

Other aspects of the white-on-red ceramics in Guangala suggest its origins being elsewhere. Compositional studies show that the ceramics contain non-local materials (Masucci & Macfarlane, 1997), as well as technological aspects and stylistic motifs common to the pottery of southern neighbors' pottery and uncommon in Guangala pottery. Following the "Law of Abundance," stating that abundant objects at a site are likely locally made, some researchers (Renfrew, 1977) concluded that the white-on-red pottery was produced locally in the Guangala, Jambelí, and Pechiche-Garbanzal regions. However, white-on-red's unique materials, motifs and forming methods, none of which are found in Guangala pottery, cast doubt on this conclusion.

The unique decorative technology of the white-on-red pottery found in Guangala, but also in Jambelí and Pechiche-Garbanzal, consists of a red burnished slip usually applied both in the interior and exterior of small hemispherical bowls and shallow plates with a ring base (Figure 2, Valdez and Veintimilla 1992). The exterior basal areas are left unslipped. Simple line patterns in a very thin white paint is applied to the exterior surfaces of the bowls and interiors of the plates. These designs found on the ceramics are not merely decorative but are considered purposeful arrangements that convey cultural symbols, beliefs, and identities. The fact that the designs are so similar within the three areas further suggests they may be produced in one area only or the ideas were shared. To decode the visual language, a component of cognitive archaeology known as design analysis is used. Through the comparison of the pottery artifacts with related ceramics from other sites and periods, researchers are able to gain insights into the production techniques, cultural influences, and the social and ritual life of Guangala (Masucci, 1992).

In addition to a characteristic decorative style, the white-on-red pottery found in all three regions has a unique paste composition and appearance which could be due to either raw materials, forming methods, or a combination of both. Chaînes Opératoires, or operational sequences, is an approach which is integral to understanding pottery production methods. This analytical framework examines each step in the manufacturing process, from raw material acquisition to the final firing. By reconstructing these sequences, archaeologists can infer technological choices and cultural practices associated with pottery production (Schiffer & Skibo, 1987). This analytical approach provides a comprehensive understanding of the technological and cultural dynamics. The underlying principle of studies employing the approach of Chaînes Opératoires is that manufacturing steps which involve repeated actions and motor skills are the least likely to change, and become characteristic often over long periods of time.

Figure 2: Guangala Figurine and White-on-Red Sherds

Instrumental Neutron Activation Analysis (INAA) is a powerful analytical technique that can be used to uncover the chemical composition of pottery. This method is valuable for provenience studies and allows for comparing the elemental breakdown of a range of pottery in areas with each other and potential clay sources (Glascock & Neff, 2003). Since 2000, Instrumental Neutron Activation Analysis (INAA) has been conducted by the University of Missouri-Columbia Research Reactor on ceramic and geological samples from sites throughout Southwest Ecuador, primarily from Guangala settlements (n=336). Samples of white-on-red vessels discovered in the Jambelí region, near the border of Ecuador and Peru, were also included (n=3). The chemical composition of the vessels was then determined to be different from that of raw material sources throughout southern Ecuador. Optical petrography detected an unusually high presence of mica in white-on-red ceramics, further supporting a source of clay outside the Guangala region, possibly in or around Northwest Peru (Masucci et al., 2019). By helping to understand the geochemical background of the clay, INAA helps to trace the movement of materials and understand the possible trade networks and cultural interactions between different regions during the Guangala period (Glascock & Neff, 2003).

Petrographic Thin Section analysis provides further data on the unique fabric of the white-on-red pottery. In addition to the non-local elemental signatures shown by the INAA, petrographic analysis shows the abundance of micaceous minerals. The petrographic analysis also shows planar void structure and preferred orientation of voids (the specified path or pattern that collective voids follow) not found in any other Guangala pottery samples studied. Scientists do not agree on where the unusual void spaces and orientations come from. Researchers questioned the cause of the microscopic spaces scattered throughout cross-sections of the sherds. Other published experimental archaeological research finds that pottery forming methods or the temper used (functional additions to the clay) could have a role in causing these types of voids and orientations (Thér, 2020; Ross & Fowler, 2021). Cross-cultural analyses show a wide array of tempers were used and available to ancient potters, including wood, animal dung, bone, shell, and plant fibers and seeds. Not all of these types of materials would have been available to potters in ancient South America. Coastal peoples, for example, did not have large domestic animals to collect dung from. Though the Guangala region was semi-arid with few trees, they had access to balsa wood, wild cotton, and corn. Organic tempers leave large voids when they burn within the clay, but there is minimal data on void shapes. Therefore, it is possible that some type of organic material such as a grass, crop or wood could account for how the voids were created, but the shapes may vary.

The voids observed in the white-on-red pottery are all similar sizes and shapes suggesting it may be one common type of temper. More importantly, they all have a preferred orientation. Other experimental researchers suggest that the preferred orientation can be caused by using a drawing type of forming method rather than a rolling or coiling, not just the temper used (Thér, 2020; Ross & Fowler, 2021). The challenge, then, is to discover which organic tempers may have been used and confirm which forming and shaping methods produce preferred orientation. Identifying and defining the Chaînes Opératoires and matching this to a specific geographical location could aid in discovering who made the mysterious Guangala pottery. Thus, the potential forming method and organic tempers have become the primary source of inquiry in determining the origins of the white-on-red pottery.

Previous work has been done on this subject, and results and applicable methodologies have been found. Ross and Fowler (2021) suggested an innovative imaging method to identify ceramic shaping techniques using inclusion and void orientation. This method, which involves scanning radial sections of vessels, offers additional insights inaccessible through traditional imaging techniques. The researchers conducted experiments with 30 bowls crafted using various shaping methods (e.g., coiling, pinching) and clay recipes to test the visibility of these techniques. Their methods effectively identify shaping techniques, providing a basis for void analysis. The study demonstrates that planar cross sections imaged with a desktop scanner effectively visualize compression patterns and wall morphologies, aiding in identifying ceramic shaping techniques. While the method is highly destructive, it offers a flexible approach that complements existing imaging techniques and enhances our understanding of pottery-forming practices.

Thér (2020) discusses different options for reconstructing pottery-forming techniques. Reliable interpretations of forming practices are made using these techniques based on archaeological evidence. Classifications are made of forming techniques, which include distinctions among the potter's behavior and the visibility of effects in the archaeological record. Individual techniques are often combined sequentially (form one part) or segmentally (create different parts). Relevant diagnostic attributes of pottery-forming practices are surface morphology and topography, variation in the wall thickness, remnants of segmental joints, specific fractures, and orientation of the components of the ceramic body. Potential misinterpretation of diagnostic features may correlate features with a particular technique but do not necessarily establish a relationship of causation or correlate features of a particular technique with another technique.

METHODOLOGY

Experimental archaeological methods were used to test techniques that may have been used in the production of white-on-red pottery and result in the characteristic void orientation and shape. The two variables that were tested throughout this experiment were the clay forming method and the type of organic temper included. The two forming methods that were focused on throughout the research were drawing, which is placing light pressure on the clay to shape it, and rolling, which involves rolling the clay into a ball before either coiling or pinching it. To start, kaolinite clay was selected for the experimental ceramics due to its lack of impurities and naturally micaceous properties, and red earthenware clay (levigated and unlevigated), due to its similarity to the clay used in the white-on-red ceramics in regards to color. However, neither clays were suitably micaceous when compared to the white-on-red ceramic pastes. Thus, a portion of mica weighing one percent of the weight of the clay was added. This proportion was determined through the analysis of white-on-red pottery sherd thin sections. The added portion contained 50% white mica and 50% brown mica, which was meant to simulate the natural mica used in the white-on-red ceramics. Sample 10 was a notable exception as a mixture of red earthenware clay and kaolinite clay in a 1:1 proportion were used (Table 1).

Next, an organic temper was added into the mixture to test the effect on void shape and orientation. Three organic tempers were used: corn husk fibers, wild cotton fibers, and balsa wood fragments. These were materials that would have been widely available to South American potters and which could have been used in the tempering of the white-on-red pottery. These tempers were then added into the clay. Care was taken to maintain the assigned forming technique to ensure that the forming technique was not compromised. The amounts of each organic temper added into the clay varied to test if the quantity of temper would have any effect on the pottery. Samples 10 and 11 were two exceptions. Both samples used corn husk as the added organic temper and both samples utilized a folding method when adding the temper. The folding method involves flattening the clay out into a relatively thin sheet, distributing the corn husk temper evenly on the surface, and then folding one half of the clay over the other half in a way that the surface of the clay with the corn folded onto itself. The clay was slightly flattened, and this step was repeated six to eight times. Sample 10 used longer strips of the corn husk as the inclusion, while Sample 11 used smaller pieces of the corn husk as the inclusion.

A variety of methods were used to shape the clay after the clay was prepared. These methods fall broadly into the categories of drawing and rolling. The method that fell in the drawing category was slabbing and the methods that fell in the rolling category were pinching and coiling.

In the case of slabbing, a piece of clay that was roughly even in height and width was drawn. Clay was pulled in a single direction through the application of pressure onto the clay and the directing of that pressure in a certain direction and the clay was steadily drawn until the thickness was relatively even throughout the clay slab.

For the rolling technique, the prepared clay mixture was rolled into a ball and then pressed and shaped, by pinching the sides while rotating it to form a small, round, open container.

For coiling, the clay mixture was thoroughly kneaded and rolled into a cohesive ball. The rolled clay was formed into a coil pot by rolling the clay into long, thin coils and stacking them in a spiral pattern, smoothing and blending the coils together.

The finished pottery was left to dry in a well-ventilated area for 48 hours before being burnished, polishing through rubbing a smooth stone on the clay, to achieve a smooth, glassy, less permeable layer on the surface of the pottery. White-on-red pottery is always burnished.

For the firing process, the pottery was placed in a kiln, starting at 150 degrees Celsius. The temperature was then increased by 150 degrees Celsius every 15 minutes until it reached 600 degrees Celsius, where it was maintained for a sufficient period to ensure proper firing and hardening of the clay. This method aimed to replicate the traditional materials and techniques used in Guangala pottery and ensure historical accuracy in the finished pottery. There is no evidence that the Guangala fired any pottery above 700 degrees celsius as there is no record of the Guangala creating pottery that was vitrified, or heated in such a way that the pottery becomes glasslike.

After the clay was finished firing and sufficiently cooled, a gem saw was used to cut the pots/slabs and create a thick section that provided a clear view of the composition and orientation of the fabric, specifically the inclusions and voids. The thick sections were then placed under a compound microscope which allowed magnifications of between 10.5x to 45x and photography with an iPhone was used to capture a clear image of the thick section.

TECHNIQUES AND EQUIPMENT

Neutron Activation Analysis: Neutron activation analysis was previously performed on samples of white-on-red pottery and the other samples of pottery found in Guangala and throughout Southwest coastal Ecuador. The chemical analysis showed that the chemical composition of the white-on-red ceramic samples did not match with the chemical makeup of other types of ceramics collected from Guangala settlements (Masucci & Macfarlane, 1997).

Gem Saw: A gem saw was used to cut the team's ceramic samples into thick sections. The gem saw creates a smooth face on the ceramic sherd for void measurements.

Thick Section Samples: The thick section samples were produced by sawing the ceramic samples we produced into two sections with a gem saw. This resulted in one face of the sherd showing the internal makeup of the sherd. The thick section samples were made in order to determine if there was preferred orientation or planar voids in any of the forming methods or organic tempers being tested. These aspects of thick sections were observed through the use of a binocular microscope.

Binocular Compound Dissecting Microscope with reflected light: The binocular microscope was used at 10.5x magnification providing a 2 cm magnified field of view on the thick section samples of the sherds we produced. The compositions of the thick section samples were observed by using the binocular microscope to view the face of the thick section sample that had been cut by the gem saw. Pictures were taken through the binocular microscope in order to perform analysis of the void orientation and the shape of voids in the ceramics we had produced and the sherds gathered from Guangala.

Table 1: Replicated Ceramics Sample Measurements

Sample Provenience	Clay Type	Mass of Clay (g)	Mass of Mica (g)	Mass of Organic (g)	Type of Organic Temper	Clay Working Technique	Forming Method
#1	Kaolinite	55.3	0.553	0.17	Corn	Drawing	Slabbing
#2	Kaolinite	57	0.57	0.18	Corn	Rolling	Coiling
#3	Kaolinite	46.5	0.465	0.07	Corn	Drawing	Slabbing
#4	Kaolinite	81.2	0.88	0.31	Wood	Rolling	Pinching
#5	Kaolinite	14.27	0.14	0.0		Drawing	Slabbing
#6	Kaolinite	55.3	0.55	0.34	Corn	Drawing	Slabbing
#7	Kaolinite	49.03	0.5	0.67	Wood	Drawing	Slabbing
#8	Kaolinite	49.03	0.5	1.01	Cotton	Drawing	Slabbing
#9	1:1 Ratio Kaolinite and Red Earthenware	54.5	0.0	0.2325		Drawing	Coiling
#10*	1:1 Ratio Kaolinite and Red Earthenware	54.5	0.0	0.2325	Corn (manual orientation)	Drawing and Rolling	Coiling
#11	Kaolinite	54.3	0.701	0.191	Corn	Drawing	Slabbing
#12	Kaolinite (thin added outer layer of Red Earthenware)	Kaolinite: 30.76 Red Earthenware: 11.94	0.399	0.109	Corn	Drawing	Slabbing
#13**	Red Earthenware		0.0		Corn		
#14**	Red Earthenware		0.0		Corn		
#15**	Red Earthenware		0.0		Corn		

* Sample 10 produced the most successful results in reproducing the planar void shapes and the preferred orientation of the voids.
** Samples 13, 14, and 15 were created only to experiment with the impressions that corn leaves on the surface of clay. The temper was only placed on the surface of the clay.

Thin Section Samples: Thin section samples were made from many of the ceramic samples collected from Guangala and other sites where white-one-red pottery was discovered. Thin section samples are 30 µm thick samples of ceramic sherds affixed to a microscope slide and coverslip (Quinn, 2013). These thin section samples were made to be observed through the use of a petrographic microscope with polarized light.

Petrographic Microscope: The petrographic microscope was used with 40x magnification and had a 5.0 mm magnified field of view. Ceramic petrography uses the techniques of thin section petrography and optical mineralogy to determine the mineral makeup of a ceramic sample and identify the types of voids in the sample (Quinn, 2013). Through ceramic petrography the composition of a sample, the shape of inclusions in a sample, and the size of inclusions within a sample can be determined (Quinn, 2013). An Iphone was used to capture images through the petrographic microscope of the thin section samples from Guangala and Jambelí sherds in order to measure the presence of certain minerals and the shape and orientation of voids in the ceramics.

Kiln: A benchtop furnace was used to fire the experimental ceramics.

Visual Image Analysis: Fusion 360 is a powerful, industry-level CAD (Computer Aided Design) Program. Void lengths and shapes were compared and analyzed between samples from different regions. Two photos of each sample were taken with an iPhone, one with plane polarized light and the other with cross polarized light on a petrographic microscope. These photos were labeled and loaded into the XY plane of Fusion 360 as a 2D image. A circle of 5 millimeters, corresponding to the field of view of the microscope was made on a sketch, and the image was sized to match the scale. Continuing in the sketch, each void was outlined. The process of tracing voids took two to three hours per photo. The measuring tool was then used to highlight the space outside of the void and within the circle. Subtracting this value from the area of the circle would give the total area of voids. Finally images of the void outlines, void outlines projected on the image, and the 3D extrusion of the circle with the voids inset were created. A sample of images of thick sections of experimental samples taken through a binocular microscope were also analyzed and are displayed in Figure 3.

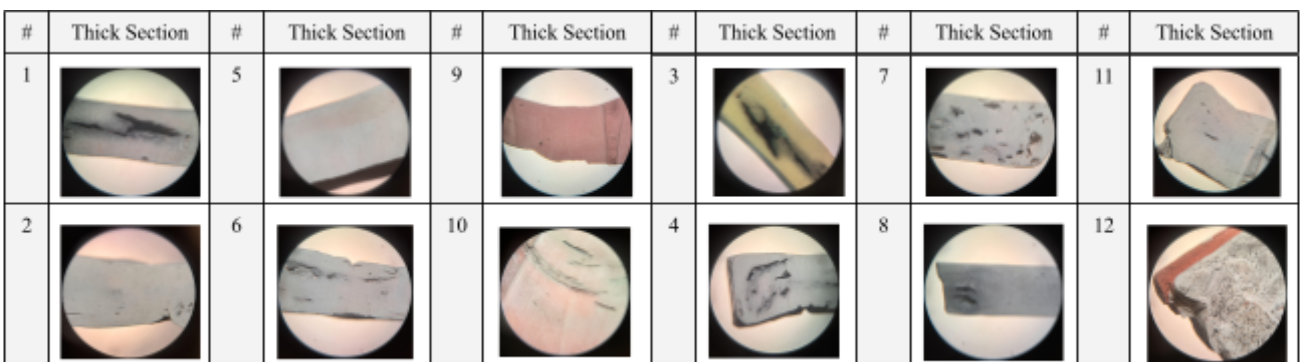


Figure 3: Thick Sections for Experimental Samples 1-12

SAMPLE ANALYSIS

After Sample 10 was removed from the kiln, it was cut with the gem saw. Transverse and sagittal sections were taken, with visible voids in the shape that was sought as well as a preferred orientation. This sample was observed further under the binocular microscope, and the void shapes were very similar to the voids observed in the white-on-red Guangala pottery: both had planar voids with a seemingly tapered end (Quinn, 2013). The only difference between the voids in Sample 10 and the voids observed in the sherds from the archaeological sites in Arenillas was that Sample 10 had relatively large voids visible to the human eye whereas the sherds had voids visible under a microscope. The piece was photographed and analyzed in more detail. However, there was one seemingly minor phenomenon observed on the underside of the outer layer of the sample. There was a small piece of the outer layer flaked off and missing, which revealed

Figure 4: Potential Corn Husk Impressions In Clay

underneath a ridge-like pattern (shown in Figure 4). This ridge-like design appears to be an impression left in the fired clay by the ridges on the corn husk (also shown in Figure 4). This was a surprising finding, and spurred an inquiry to look for similar impressions on sherds found on archaeological sites linked to Guangala or white-on-red. When looking at some of these sherds under a binocular microscope, similar minute impressions were discovered that seemed to resemble the ridges of a corn husk. For example, a sherd from Arenillas of the Jambelí (Sample 251), has a similar impression (shown in Figure 4).

As seen in Figure 4, similarities can be seen in the two samples. For one, the lines are very similar and some seem to move parallel to each other, while other lines converge. Although these similarities are visible, there are many differences. Sherd 251 from Arenillas has much less pronounced lines, whereas the ones in Sample 10 are very clear. However, time, burial and erosion can likely account for these differences. A piece of clay pottery being buried beneath many layers of sediment can cause a lot of wear and tear on the piece itself, especially on something as fragile as these lines. These findings are a step forward in determining the organic temper that the creators of the white-on-red pottery likely used in their ware to create the shaped voids and achieve preferred orientation. But, these findings only lead to this potential conclusion, rather than confirm it (Figures 4 and 5).

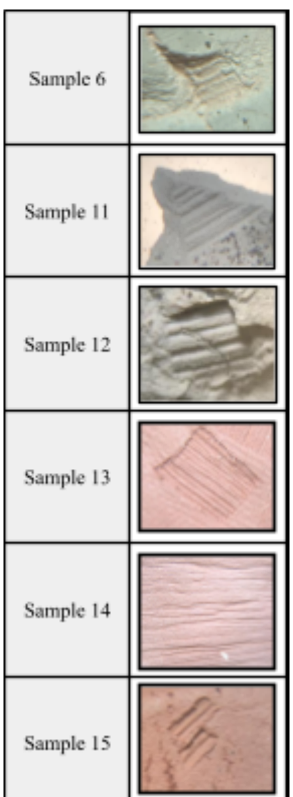


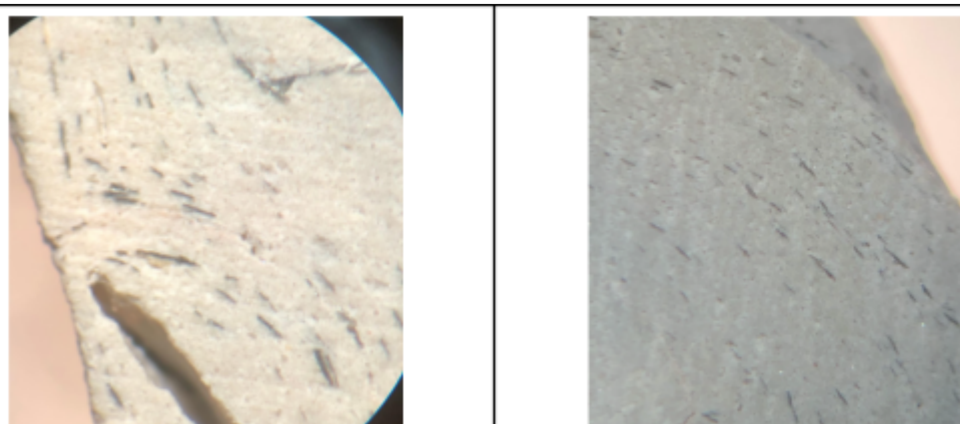
Figure 5: Corn Impressions

Both the voids in Sample 10 and the unintentional phenomenon of the corn husk impression allowed for two further trials involving the forming and working technique of the clay and another regarding the impressions of the corn husk in clay. Samples 13, 14, and 15 were produced without regard to the forming technique of the clay and instead focused on the impressions left in the clay by the corn husk. In Figure 5, these three samples are shown, as well as Samples 6, 11, and 12, in which corn husk impressions were found that resemble the possible corn husk impression observed on sherd 251 from a site in Arenillas.

With all these variants of corn husk impressions being left in the clay after being fired in the kiln, it strengthens the possibility that the white-on-red pots were created using corn as an organic temper inclusion. Not only that, but Sample 10 allowed for further inquiry on determining the forming and working methods of the clay, as mentioned earlier. Sample 10 used a mix of manually orienting the corn and then using a drawing technique, followed by a coiling technique in order to roll up a long strand of the clay, and then coil it into the desired shape.

Sample 7 was created for the purpose of visualizing the voids made by organic temper, and had double the amount of organic temper to ensure clear voids. The results of Sample 7 show a variety of void shapes that resemble many of the shapes identified by Quinn (2013). Vesicles, vughs, and the rectangular voids are all found together in Sample 7. In addition, upon cutting Sample 7 under a Gem Saw, the voids showed black coloration, similar to the black residue often found by organic tempers throughout the white-on-red. The length of the corn husk fragments likely contributed to the shape of the voids.

This analysis of void formation and residue support the idea of organic tempers being used in the production of the white-on-red ceramics. However, Sample 7 and the inclusion of wood is likely not the solution or the method used by the white-on-red potters due to the lack of a preferred orientation. Multiple trials and different forming methods with the wood all resulted in large, diverse voids with no pattern. That being said, we cannot discount the wood as a support for the idea of organic tempers.



Sample #2 (Corn Temper, Coiling) | Sample #11 (Corn Temper, Slabbing)

Figure 6: Rolling vs. Drawing

Through careful analysis of pottery temper and void size, the forming and working methods used by the creators of the white-on-red pottery were most likely drawing and slabbing, utilizing a folding method when working the temper into the clay. A comparison of the thick section images of the samples revealed that when corn husk was used as the organic temper in coil-formed pots (Sample 2), the correct void size was achieved, but preferred orientation was not (see Figure 6 above). However, when the slabbing method was employed (Sample 12), along with drawing and adding corn as the organic temper, both the preferred orientation and the void size closely matched those of authentic white-on-red pots (see Figure 6 above). This comparison between the coiled pots with corn husk, which lacked the preferred orientation and the slabbed pottery with corn husk, which exhibited the correct void size and orientation, demonstrates that the forming method significantly affects these characteristics. Through further analysis of the thick section images of the pottery, it becomes clear that the voids in the slabbed corn pots were more consistent with those found in the white-on-red artifacts. Consequently, it can be inferred that the potter most likely used corn husk as the temper and employed drawing and slabbing as their primary forming techniques. This conclusion is further supported by the distinct differences in the microstructural properties observed between the two forming methods, highlighting the importance of the addition of corn husk temper and slabbing in achieving the characteristic features of Guangala white-on-red pottery.

ANALYSIS OF TEMPERS, INCLUSIONS, AND FORMING METHODS

An observation that was made when comparing white-on-red pottery with the samples created throughout the experiment was the fact that similar types of fibers were found in both types. For example, Sample 6's cross section showed an inside filled with corn husk impressions and corn fibers coming out of the outer walls of the piece. Similarly, Sherd 47-VI-28, found in a Guangala archaeological site in buried contexts where white-on-red was also found, had exposed fibers along its edge that had similarities with that observed in Sample 6.

Figure 7: Fiber Comparison

This finding potentially further demonstrates that the corn temper was used in the fabrication of white-on-red. For instance, it is noticeable that in Sample 6 (Figure 7) there are corn husk fibers throughout the walls of the piece. On the other hand, Sherd 48 (Figure 7) also has fibers embedded within its walls; however, without further analysis such as with a Scanning Electron Microscope, it is impossible to verify the composition of these fibers. However, other types of Guangala pottery (not white-on-red) did not possess any fibers along their cross-section even though these types of pottery were present during the same period and buried at the same depth. For example, Sherd 47-V1-28 (a Guangala pot, Figure 7) does not have any type of visible fibers, while Sherd 48 (white-on-red) does. This further suggests that the white-on-red pottery found in the Guangala sites may have been produced with corn husk or another type of organic fibrous temper and not made by the Guangala.

Comparing the different types of tempers and methods used throughout the experiments, it was clear that the corn and the balsa wood were the more promising organic tempers.

The cotton samples did produce some voids, however, the voids seen were small circles with no preferred orientation which did not resemble the voids seen in white-on-red sherds. In addition, cotton did not produce any preferred orientation, and was hard to work with during the pottery making process. The cotton had to be separated many times and proved to be difficult to incorporate into the clay.

The wood samples also produced voids within the pottery. Some of the voids found in the pottery samples fired with balsa wood were vesicle voids, and others were vughs. These voids do not resemble those of the white-on-red pottery in terms of shape. In terms of size, the size of the voids in the balsa wood fired white-on-red pottery varied greatly, unlike white-on-red. There was a great variety of size and shape of voids within the balsa wood fired pottery. There was also no preferred orientation of voids within the balsa wood fragments.

Corn husk provided the most promising results of all the tempers. The voids from the corn were similar in shape to the voids from the white-on-red pottery, with both being long and fibrous. In addition, there was preferred orientation of the voids in all pottery sherds formed through drawing. There was no preferred orientation of the voids in pottery sherds formed from rolling however, indicating that forming methods likely had an impact on void orientation.

RESULTS

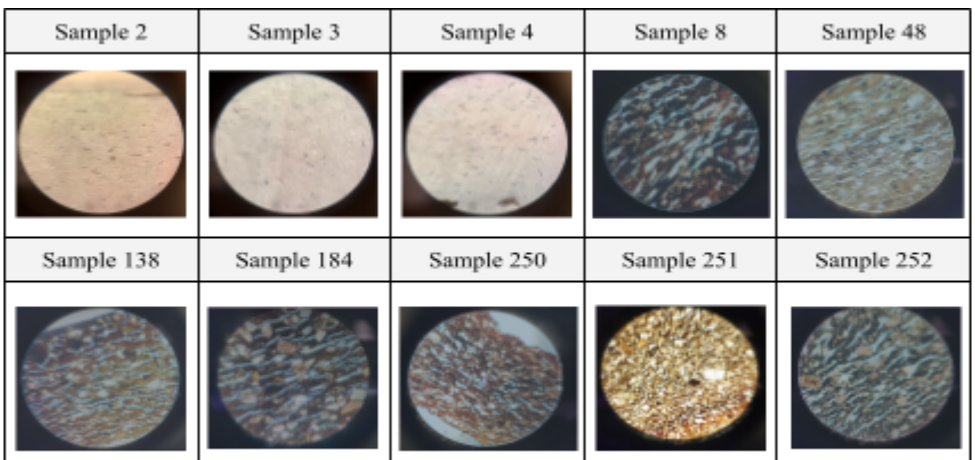


Figure 8: Archaeological Samples Analyzed

Visual analysis was conducted on the void spaces in the pottery. Specifically, thin sections of pottery from the Guangala and Jambelí region were used, and thick sections of the experimental pots.

Figure 8 displays the samples that were analyzed. Samples 2, 3, and 4 were experimental samples. Samples 8, 48, 138, and 184 were found in the Guangala region. Samples 250, 251, and 252 were found in the Jambelí region.

Table 2 displays Range and Average void size. Table 3 (see Appendix) displays the percentage void calculations on each sample which could be useful in the future if additional white-on-red ceramic samples and thin sections are obtained.

ANALYSIS

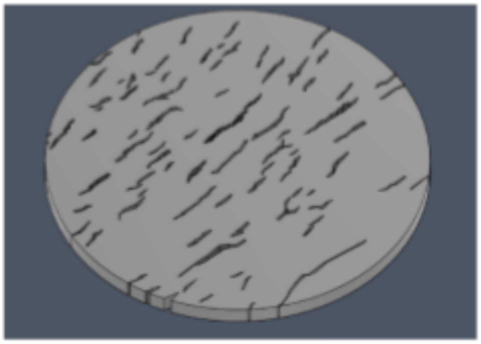
There were two key parts to analyze with the sections done with the Fusion Software: size of voids and the shape.

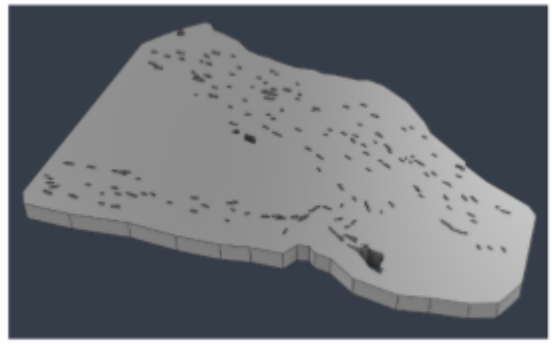
Table 2: Average Void Size and Range of Void Size of Each Analyzed Sample		
Sample Number	**Range of Void Size (mm)**	**Average Void Size (mm)**
Archaeological	0.350 - 0.769	0.495
Experimental	0.303 - 0.401	0.353

As shown in Table 2, the average void size from the archaeological samples was roughly 0.495 mm, and the average void size for the replicated samples was 0.353 mm. This analysis does show differences in experimental and archaeological samples, but it does not disprove the presence of organic tempers. Size of the voids is attributed to the preparation methods and sourcing of the raw materials, and the procedure used in the experiment may not have been identical to an Ecuadorian procedure. In the preparation of the tempers for the experimental samples, equipment like scissors and a fine sieve were used, which can influence the average size of the voids created. Additionally, the different raw materials could have contributed to the difference in size of voids created.

Shape is where the most significance and analysis can be made between the archaeological and experimental samples. The main shape observed in the archaeological samples was the 'planar' void shape, which is a long rectangular void with a small width. Shape analysis shows that the archaeological samples have planar voids with rough edges and uneven lengths, while the experimental samples had straighter edges. While this may seem like a large difference, there are many factors that could have contributed to this, one being the decay that the archaeological samples have been thorough. In addition, as mentioned before, preparation methods of the tempers varied greatly, which could contribute to the difference in exact shape.

As seen in Figure 9, void sizes are not great indicators of the similarities between Archaeological and Experimental samples, due to the difference in thin and thick sections. But the presence of planar voids is evident between the samples. This supports the idea of an organic temper being used in the production of these white-on-red ceramics, as Sample 11 was created with corn.





Archeological Sample 48	Experimental Sample 11

Figure 9: Comparing 3D Images of Archaeological and Experimental Samples

The preferred orientation of the samples is also seen within Figure 9, as the voids follow the same parallel orientation. The preferred orientation has less to do with the actual type of temper tested, but more with the method used during the forming process, which could shed light on the engineering of these ceramics. The sherds that showed the best preferred orientation with void paths were slabbing and drawing ceramics, as the rolling samples involved dispersing the tempers through a mixing process.

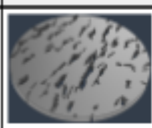
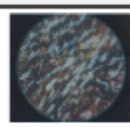
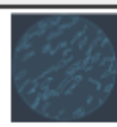
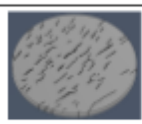
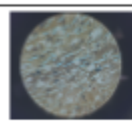
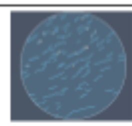
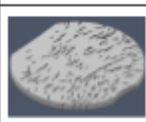
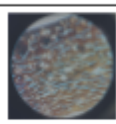
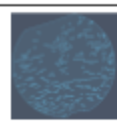
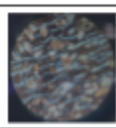
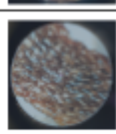
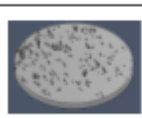
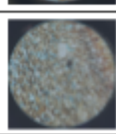
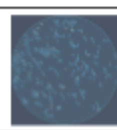
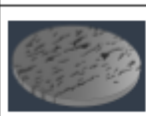
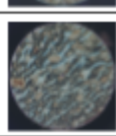
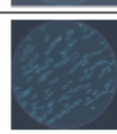
Origin	3D	Hilite	Holo
Guangala 8			
Guangala 48			
Guangala 138			
Guangala 184			
Jambeli 250			
Jambeli 251			
Jambeli 252			

Figure 10: Fusion 360 Image Analyses of Archeological Samples

Figure 10, to the left, displays the 3D images, Hilite images, and Holo image renditions for 7 different Guangala and Jambelí archaeological samples. These samples show the preferred orientations of the voids, and some of the experimental samples that were successful resemble these voids closely, as seen in Figure 10.

DISCUSSION

The experimental pottery with drawing and slabbing, and coiling led to the presence of preferred orientation that most resembled the white-on-red pottery. As mentioned earlier, a key aspect of white-on-red pottery is the preferred orientation of voids found within it. During the creation of the experimental pottery, the clay working techniques that were used were drawing and rolling. Rolling created a void orientation that can best be described as circular which does not match the white-on-red pottery sherds' void orientations at all. However, drawing led to a planar orientation that resembled the white-on-red sherds. These orientations suggest that the creators of the white-on-red pottery used a drawing technique as that was the only technique used that replicated the void orientation seen in white-on-red.

The experimental pottery that was created through drawing and tempering with corn also had similar void shapes to the white-on-red pottery. According to the digital analysis, the experimental pottery had both preferred orientation and similar void shape to the white-on-red pottery. The Archaeological and Experimental ceramics had long, planar voids. Though the size of the voids were different from one another, this was due to differences in the preparations of organic tempers when creating Experimental Samples. In addition, the Archaeological analysis was done on thin sections, while the Experimental Samples were done on thick sections. It implies that the organic temper used in white-on-red pottery was more similar to the corn husk that we used compared to the balsa wood and the cotton strands.

IMPLICATIONS

The conducted research has implications for understanding the engineering of white-on-red pottery, and sheds light on the methods used for creating this pottery. The experimental pottery sherds created during this experiment has led to several potential paths for future research and has produced conclusions.

One implication is the presence of corn husk impressions in the pottery. This provides possibilities for future analysis of white-on-red pottery as well as other pottery sherds with unknown tempers. Through further research and experimentation, it is possible to determine the precise tempers that were used in white-on-red pottery.

Another implication is the impact that drawing had on the preferred orientation of voids. Experimental sherds that were formed using the drawing method had voids with preferred orientation while experimental sherds that were formed through rolling did not. This suggests that drawing was the primary method used by potters during the formation of the white-on-red pottery. This also resolves the outstanding debate on the impact of forming methods upon void orientation.

In addition, the fact that void shapes were similar in both experimental and white-on-red pottery sherds implies that the techniques used in the process for the creation of pottery sherds were similar to those used by the creators of white-on-red. This reinforces the idea that white-on-red potters used similar techniques and tempers to the ones used during the creation of the experimental sherds.

With analyses conducted regarding fibers found in the pottery, potential corn husk impressions left in the pottery, void spaces and preferred orientation in the pottery, as well as the microscopic foundation of the pottery itself, the mystery of the white-on-red pottery is brought closer to a solution.

LIMITATIONS

There were many potential sources of error in this project. Due to the lack of access to raw materials from Southern Ecuador and Northern Peru and ceramic samples from Northern Peru many assumptions had to be made regarding the creation of the pots.

The first attempt to imitate white-on-red pottery was done with commercially sourced red earthenware clay. This attempt followed the process laid out under methodology except for the amount of mica added to the clay. Several pots and slabs were created using the various techniques and various tempers explored under methodology. However, after gem-sawing was completed, various issues with the completed experimental samples were discovered. Sand particles in the clay were too large and as a result they masked evidence of the experimental tempers. In addition, the clay found in white-on-red pottery has a completely different particulate composition. The particles in white-on-red pottery are significantly smaller than the particles found in the red earthenware pottery sherds. This may have impacted any findings from the red earthenware pottery sherds. In order to rectify this issue, kaolinite clay was selected. Kaolinite clay is finer and is naturally micaceous, making it more similar to the clay found in white-on-red pottery.

Another major source of limitation was the chemistry of the clay used in the experiment. We only know that the white-on-red ceramic pastes are unlike the raw materials in the Guangala region but we have not yet identified the origin of the raw materials. As a result, the clay for the experiment had to be created from commercial materials based on estimations of inclusions observed in thin sections of white-on-red ceramics. For example, the amount of mica added into the clay was based off of an estimate regarding the volume of the mica contained within samples of white-on-red pottery. This estimate was formed by counting mica grains within a thin section of white-on-red pottery. However, a thin section only samples a very small area of a vessel and may not be fully representative of the rest of the pottery. It is possible that the mica content and chemical composition of the raw material used for white-on-red had a role to play in the void structure and preferred orientation.

Another limitation was the calculations of the amounts of mica and organic temper to be added. The calculations that were used to find the amounts of mica and organic temper that was to be added to the clay was derived from the weight of the clay. This method was used because it would have been difficult to determine the densities of the organic temper and calculate the proper amounts of mica and temper to be added by the volume, which would have been more accurate to the data collected from the thin sample of the white-on-red pottery. If the densities of the mica and the clay were very different, then a disproportionate amount of mica could have been added to the clay. However, the results of our experiment can show the presence and type of void that could have been formed with the white-on-red technology. While a perfect replica of the white-on-red was not attainable, proving that the voids shapes within our samples using organic tempers do match those in the white-on-red pottery can support the idea that these methods were used in the making of the ancient ceramics.

The image analysis of photomicrographs of thin sections also could introduce errors. The manual identification of voids and tracing of their shapes is tedious and time consuming and it is difficult to consistently and accurately measure the shapes and sizes of the voids. This could be addressed by large sample sizes of thin sections being analyzed and multiple analysts to check for interanalyst reliability and consistency.

FUTURE INQUIRIES

This study serves as an expansion of past research in trying to understand the material composition and origin of ancient South American white-on-red pottery. It is important to note that future research is necessary in order to better explore this topic and test the results presented here.

A comparative analysis of pottery from different neighboring regions in Northwest Peru and other parts of Ecuador would be crucial in finally gaining an understanding of the origin and significance of white-on-red pottery. The evidence is strong that the pottery is not made in or by Guangala potters but their origin is still unknown. The study only had three samples of white-on-red sherds from the Jambelí region and none from Northern Peru. By examining ceramics and raw materials from the neighboring areas, researchers may be able to further uncover similarities and differences in materials, temper types, and forming methods. For example, if similar clay and pottery with similar properties to white-on-red pottery were found in different areas of South America, it would suggest a relationship between this area and the Guangala as well as the Jambelí. It is likely that if a community utilizes organic temper and the drawing method in creating a portion of their pottery (e.g., white-on-red) that this Chaînes Opératoire would be present in other types of their pottery. By studying Guangala pottery in the context of a regional framework, it could become possible to trace societal interactions, trade, and the spread of ceramic technologies to better understand the culture of ancient South American societies.

One major limitation of this research was the lack of clay originating from Southern Ecuador and Northern Peru, the other regions where white-on-red pottery is found. There are many possible impacts that using clay from the areas surrounding Guangala could have upon future research. For example, local decaying plant material present in the clay may impact void size and orientation. If materials from regions around Guangala, especially Ecuador and Northern Peru, were available, it would be possible to create control sherds that mimic pottery from surrounding areas to compare to the white-on-red pottery and determine the origin. Furthermore, since chemical analyses (INAA) have been conducted on Guangala white-on-red pottery and raw materials from the Guangala region, conducting the same chemical analyses on materials and pottery from the neighboring regions could help point to a more definitive answer to the pottery's origin.

The number of tempers explored was also very limited in this research. Only three possible tempers were tested in this case, representing several possible organic tempers that were widely available to potters throughout the Americas. With further research, it could be possible to narrow down the potential organic tempers used by the potters of the white-on-red pottery further. Although this study found that corn husk fragments is a likely candidate for the organic temper used in white-on-red pottery, there are still a variety of other organic tempers that could have been used but were not represented such as leaves, squash, and grass.

Finally, further research into the impressions left by organic materials in the white-on-red pottery is essential for a comprehensive understanding of the ceramic production techniques. Organic tempers such as corn husks not only influenced the physical properties of the pottery but also left impressions that can provide clues about their composition. Further analysis of these impressions, using advanced imaging technologies like Scanning Electron Microscopy (SEM), can reveal the exact organic temper used (Froh, 2004). Additionally, studying these impressions can help identify patterns of temper selected by the regional potters and reveal choices made by the potters. By comparing these impressions with those found in pottery from other regions and periods, researchers can trace the evolution of ceramic practices and the influence of environmental and cultural factors that may have led to this unique style of white-on-red pottery.

Ultimately, further investigation into organic material impressions and comparative chemical and petrographic analysis of ceramics and clays will shed light on ancient pottery-making techniques, interregional interactions and finally help determine the origin of the white-on-red ceramic. One question, however, will then remain, what was so special about these white-on-red vessels that they were traded or transported between regions and societies?

First, it is possible that one of the cultures with white-on-red pottery had power and influence over other regions, and promoted a certain style of pottery over their conquered regions. However, this is unlikely, due to the difference in mineralogical and chemical composition of the Black Guangalan Vessels and the white-on-red found in the Guangalan sites (Masucci & MacFarlane, 1977). If this explanation were to be feasible, the style would have to have been shared through the different regions, but with local potters copying the style with their own materials. Things such as the micaciousness of the clay, difference in chemical composition, and difference in thin section analysis all confirm that the raw materials in the white-on-red do not match the non-white-on-red Guangalan pottery which has been shown to be locally manufactured, so this explanation can not work.

Another explanation could be that the clay moved from another region to Guangalan potters. This explanation also does not make sense, given the weight of clay raw materials and the length (ca. 400 years) of white-on-red pottery manufacture. In addition, ethnographic studies have shown that heavy raw materials are not transported over long distances (Arnold 1988). Balsa Rafts were available and likely used by the Guangala to trade between these societies. but there is no evidence that raw materials such as clays would have been transported (Masucci and Hooped 2022, Dewan & Hosler, 2008).

In addition, the potters could have moved from region to region, creating the white-on-red ceramics everywhere they would have gone. However, it falls into the same dead end as the previous explanation, as potters likely traveled but could not have carried heavy raw materials such as clays over long distances, but instead were sharing their methods.

Finally, the most likely explanation is that these ceramics were transported through the region as measures of exchange and offerings between regions and communities. Especially since the white-on-red vessels are specialized in that only two forms are present and they represent only 1-3% of the pottery assemblage at any point in the Guangala sequence (Masucci 1992). It would be useful to examine what percentage they are in the assemblages of the neighboring regions. There is evidence of ceramics used in rituals of the villages of South America, so these vessels could have held religious and cultural significance to the Guangala people, which would explain the desirability and presence of this style of non-local ceramic in the Guangala region (Ikehara et al., 2013).

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APPENDIX

Table 3: Void Percentage of Each Analyzed Sample	
Sample Number	**Percentage Void**
184	8.334%
8	13.725%
48	4.000%
138	6.174%
250	3.451%
251	5.714%
252	10.028%

Table 3 displays the percentage of void space recorded in each archaeological sample. These data were not used in the current study but could be useful for future research if comparative archaeological samples are obtained from neighboring regions.