A PXRF, FTIR and SEM/EDS Analysis of the White Pigment on White Cross-Lined Ware

Rachel Pinkman

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A PXRF, FTIR AND SEM/EDS ANALYSIS OF THE WHITE PIGMENT ON WHITE CROSS-LINED WARE

By

Rachel Pinkman

A Thesis
Submitted in Partial Fulfillment of the Requirements for the Degree of Masters of Art

Art History with a Concentration in Egyptian Art and Archaeology
The University of Memphis

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Abstract

The current study will examine the composition of the pigment used for decorating a type of Predynastic Egyptian ceramic vessels known as “white cross-lined ware” or “C-ware.” Two collections of white cross-lined ware have been analyzed by visual analysis, portable x-ray fluorescence (pXRF), Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy with an electron dispersive x-ray spectroscopy (SEM/EDS). The composition of this pigment may help scholars understand and recognize trade networks within and/or outside of Egypt, the types of materials Egyptian potters used and if different pigment recipes were employed for C-ware at different Predynastic sites. Furthermore, the identification of the materials used for the white pigment may allow scholars to document its use on other Egyptian objects in order to trace if the pigment was utilized continually into the Dynastic era and to document when this pigment started being used in Egypt.
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Chapter One: Background Research and Literature Review

The archaeological record of Predynastic Egypt is dominated by large pottery assemblages with a diverse range of ceramic vessel forms. The Predynastic period coincides with Egypt’s Neolithic era, dating from approximately 5300 BCE to 3000 BCE.¹ The present study will investigate the composition of the pigment employed in the decoration of a specific group of Predynastic ceramic vessels, which are described in the scholarly literature as “white cross-lined ware” or “C-ware”, in order to know what materials were used for it. For this investigation, two collections of white cross-lined ware have been analyzed, which are housed presently in the Museum of Fine Arts Boston (MFA) and the University of Pennsylvania Museum of Archaeology and Anthropology. The analytic techniques employed include visual analysis, portable x-ray fluorescence (pXRF), Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy with an electron dispersive x-ray spectroscopy (SEM/EDS).

White cross-lined ware has been excavated from a multitude of Predynastic Egyptian sites for over a hundred years but the white pigment employed in its decoration has so far attracted relatively little scholarly attention. The composition of this pigment holds the potential to shed light on trade networks within and/or outside of Egypt, what types of materials Egyptian potters employed and if different pigment recipes were used at different Predynastic sites. In addition, the identification of the components of the white pigment might enable us to document its use on other products, such as figurines, rock art, etc., in order to trace its possible, continued use into the Dynastic era and to create an origin point for the use of the pigment.

Overview of the Predynastic Period

Scholars divide the history of ancient Egypt broadly into two major phases. The first of these is the Predynastic period, which dates between 5300 BCE and 3000 BCE, prior to political and cultural unification under a single, royal family. The Dynastic era, also known as the Pharaonic era, dates between 3000 BCE and 30 CE and is characterized by nearly three millennia of rule under successive royal dynasties ending with the death of Cleopatra VII. The Predynastic sites consist of dozens of settlements and cemeteries located along or near the Nile River as seen in Figure 1. The most northern Predynastic site is at Buto in the Nile Delta and the southernmost at Sarras West near the Third Cataract. Scholars characterize these sites on the basis of their geographic locations and distinctive material cultures as either “Lower Egyptian”, meaning the delta sites in the north and “Upper Egyptian”, which are the southern sites in the Nile valley. The Predynastic settlements interacted with each other through trade and potentially, warfare. Over time, more egalitarian settlements became an increasingly stratified society, culminating ultimately in the unification of the state under Egypt’s first kings around 3000 BCE. However, this process was probably not a simple, linear trajectory. Rather the Egyptian state most likely coalesced as a result of overlapping and interweaving developments in politics, ideology, economy and military within and among different villages. The Predynastic period ends

2 Kemp, Ancient Egypt, 14.
3 Kemp, Ancient Egypt, 14.
4 Emily Teeter, “Map of Principal Sites and Areas,” in Before the Pyramids, ed. by Emily Teeter (Chicago: The University of Chicago, 2011), 14.
6 Kemp, Ancient Egypt, 75–78.
formally with the political and cultural unification of Upper and Lower Egypt under a single king named Narmer whom scholars recognize as the first king of Egypt’s First Dynasty.

The timeline of the Predynastic period has been revised frequently since it was created. The system was originally devised by Sir Flinders Petrie, who based it on the sequence dating of material culture, especially pottery (Figure 2). He used seriation and notecards listing the type of pottery found in graves to arrange the pottery in a relative chronological sequence. He assigned the pottery numbers 30–80 because it allowed room for up to 29 more new pottery forms to be added in front of the existing chronology (Figure 3). Petrie then assigned the sequenced pottery to one of the three cultural phase groups he created. The first phase was the “Amratian”, whose sequence numbers are 31–37, then the “Gerzean” with sequence numbers 38–62 and finally, the Semanian, sequence numbers 62–79. These periods were named after the cemetery sites at which their characteristic pottery forms were first encountered, namely, el Amra, Gerza and es Semania.

Petrie’s system has been revised several times by scholars. In 1928, Guy Brunton and Gertude Caton-Thompson added a “Badarian” period, which dates prior to Petrie’s “Amratian” period. In 1957, Werner Kaiser refined Petrie’s three periods and renamed them Nagada I, II and II with subdivisions of a-c for each period. This revised method has remained in use to the present with some additional modifications. Fekri Hassan created a new division system in 1988.

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based on radiocarbon dates from Predynastic sites but it is not widely used by scholars. In 1989, Stan Hendrickx updated Kaiser’s system by adjusting the time frames and adding more subdivisions to some of the three periods and in 1996, he added Nagada IIId as the last phase of the Predynastic era. His current system is Nagada Ia-c, Nagada IIa-d and Nagada IIIa-d and is the most commonly used system by modern scholars. All of the scholars listed above based their timelines on one or more of the following: material culture, spatial distribution and radiocarbon dates.

The material culture preserved from the different phases of the Predynastic era includes basketry, rope, fiber and stone objects consisting of beads, bowls, palettes and drills. Cooper was utilized to make fishhooks, drills, knives and axes while gold was used to cover objects. In addition, they had bone tools, ivory objects like knife handles; shells and pottery. Some of the most well-known objects are the Narmer Palette in the Egyptian Museum Cairo and the Wab Bowl (bowl with human feet) in the Metropolitan Museum of Art.

**Predynastic Pottery**

The pottery of the Predynastic period is grouped by physical shape. Variations within the groups are assigned to a relative, chronological sequence, which archaeologists refer to as seriation. As mentioned above, Petrie’s sequence starts with pottery form 30 and ends with 80, in order to allow room for the addition of newly, discovered forms. The basic Predynastic vessels, which Petrie described include (listed in rough chronological order) are: black-topped ware,
polished red ware, fancy ware, white cross-lined ware, incised black ware, wavy handle ware, rough faced ware (rough ware), decorated ware and late ware. In addition, each type has a nickname, which is usually an abbreviated version of its name with “ware” added to the end, for example, white cross-lined ware is also known as C-ware and decorated can be called D-ware. Critically, not all of the pottery types of the Predynastic period appear throughout all of Egypt. Some are only found in Lower Egyptian contexts as seen with the Ghassulian-inspired pottery, while others exist solely in Upper Egypt such as black-topped ware and white cross-lined ware.¹⁵ As Nagada culture spread from the south to the north, coinciding with the gradual cultural unification of Predynastic Egypt, more Upper Egyptian pottery forms began more to appear in Lower Egyptian archaeological contexts.

White cross-lined ware occurs between the Nagada I and II phases of the Predynastic era. These sequences correspond roughly to the period between 3900 BCE and 3200 BCE.¹⁶ Petrie assigned the ware sequence date numbers 31–34, which he placed in row four under fancy ware.¹⁷ It is the earliest known painted pottery in Egypt, consisting white designs painted over a red wash.¹⁸ The red ochre wash covers most of the vessel’s body, which has been burnished to achieve a shiny appearance.¹⁹ The white, painted designs can cover up to half of the vessel’s body. The depth of the white paint varies from being painted on some vessels thin enough to

¹⁵ Yann Tristant and Béautrix Midant-Reynes, “The Predynastic Cultures of the Nile Delta,” in Before the Pyramids, ed. by Emily Teeter (Chicago: The University of Chicago, 2011), 50.


¹⁷ Petrie, Diospolis Parva, 14.

¹⁸ Alice Stevenson, “Material Culture of the Predynastic Period,” in Before the Pyramids, ed. by Emily Teeter (Chicago: The University of Chicago, 2011), 66.

appear translucent while others have a thick layer that protrudes off of the vessel. Common, decorative motifs include the native wildlife such as hippos, crocodiles, cattle and elephants. Other motifs include geometric shapes (triangles and dots), landscape features (water and mountains), human figures, basketry, hunting and weaving.

Predynastic potters formed white cross-lined ware from one of the two possible fabrics that were available. The word fabric is referred to as a fired paste that contains natural inclusions and temper (inclusions added by humans). A paste is an unfired clay or mixture of two or more clays that contain natural inclusions and temper. Fabrics are classified according to the Vienna system, which was devised in 1980 as a system for describing Egyptian and some foreign pottery. Prior to the Vienna System, each excavation had its own list of fabrics, which documented according to what the archaeologists deemed important and these field specific classifications were not effective for cross-site comparisons. The Vienna System attempted to solve this problem with enough flexibility that archaeologist may still adapt it to fit their sites. The fabrics employed for white-cross lined ware are designated Nile silt A and B1 according to this system. Nile silt A contains fine silt, fine sand, small amounts of coarse sand and mica while Nile B1 is composed of by silt, fine sand, patches of medium to coarse sand, micaeous particles and fine strands of straw. The straw was most likely added as a temper to the paste.

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The main differences between the two clays are that the Nile A clay is finer and usually does not contain straw.

**Pigment Analyses**

Pigment analyses have been conducted on Predynastic and Dynastic objects including pottery, statues and wall paintings. It was common for researchers in the past to conduct visual analyses to determine the material used for pigment. However, the results of a visual analysis can be skewed since color is subjective to the viewer and if the pigment color being observed has changed due to deterioration over time. Nevertheless, it is still important to conduct visual analyses as they show the current condition of the object being examined.

Now, more researchers have changed to chemical analyses to determine the types of materials used as they are more reliable when determining the composition of the pigment because they examine the elements that make up the material used and their properties. For example, pigments used approximately 8,000 years ago to decorate the “New Cave” in Gilf Kébir and Water Mountain near the Dakhla Oasis have been analyzed through FTIR, micro-Raman spectroscopy, SEM and EDS instead of a visual analysis.\(^\text{27}\) The earliest known example of the pigment called Egyptian blue was located on a Predynastic alabaster bowl with the name of King Scorpion from Hierakonpolis through visual analysis, optical microscopy, EDS and visual light-photon induced spectroscopy.\(^\text{28}\) Pigments from wall paintings inside the Tomb of Nakht (TT161) and Tomb of Tetiky (TT115), which both date to the eighteenth dynasty, were examined by XRF and X-ray diffraction (XRD) while the color Amarna blue has been studied on

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pottery, which is also from the eighteenth dynasty, with pXRF, XRD and particle induced X-ray emission (PIXE) analyses. As more research is conducted on Egyptian pigments, a larger corpus will be created that can be used for cross-comparisons and pigment origin points.

Despite the amount of pigment analyses conducted on Egyptian artifacts, very little research has been conducted on the pigments employed in the decoration of white cross-lined ware. The only prior chemical analysis that can be found was a brief study by P. D. Ritchie in the 1930s. The rest of the hypotheses listed in the next two sections for what the pigment is composed of is based on visual observations. Ritchie examined three C-ware fragments out of 11 fragments from various Predynastic vessel types. All of the fragments were from Armant and were excavated by the Robert Mond Expedition. He pulled off the white pigment on two of the C-ware fragments (No. 142/1500 and No. 293/1457) and dissolved them in a solution of hydrochloric acid (HCL). He noted that on the third fragment (No. 31/II M 8), the white pigment was extremely thin and he was not able to pull it off without taking some of the red ochre wash along with it, therefore, he used spectrography instead of dissolving it in HCL to examine the pigment. He also used spectrography on the other fragments.

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Ritchie’s HCL test showed two different results between the first two C-ware fragments. The pigment from fragment No. 142/1500 was composed of a pale iron oxide from yellow ochre with silica while the pigment from fragment No. 293/1457 may have been a calciferous clay.\textsuperscript{35} Neither of the paint samples from the two fragments fully dissolved in the HCL solution.\textsuperscript{36} He further subjected the second fragment to a spectrographic analysis. The spectrographic analysis from the second fragment (No. 293/1457) and the third fragment (No. 31/II M 8) both demonstrated that the pigment mainly contained sodium, calcium, silicon and magnesium.\textsuperscript{37} However, the second fragment also contained iron.\textsuperscript{38} There were also minor amounts of other elements in second and third fragments but he did not label them in his report. He reinstated his original conclusion that the pigment from No. 293/1457 was a calciferous clay and stated that No. 31/II M8 was a light-colored clay but did not report if it was also calciferous like No. 293/1457.\textsuperscript{39} However, an analysis of three fragments from a single site is too small of a sample to draw firm conclusions about the composition of the white pigment on all C-ware vessels across different Predynastic sites in Egypt.

Ritchie’s analysis suggests that more than one paint recipe may have been employed for C-ware. Alexander Scharff noted that the white paint on C-ware vessels from El Mahasna, Kau el-Kebir and El Khozam was applied thickly and has an off-white yellowish hue.\textsuperscript{40} In


\textsuperscript{38} Ritchie, “Some Predynastic Pottery,” 185.


comparison, Scharff also mentioned that the paint from Nagada and Diospolis C-ware vessels was thinly applied and has a true white color. In 1981, Janine Bourriau also noted this change in thickness and color, in addition to observing variation in tone from white to pink. She also hypothesized that the pigment was either a slip, which is a mixture of clay, water and pigment and pigment or a wash, which is only water and pigment. Also from the 1980s, Elizabeth Finkenstaedt further expanded on this work with three articles on C-ware. Finkenstaedt concluded that there were at least two different paint recipes in Upper Egypt, based on how the paint flakes off of the vessels. The paint on C-ware vessels from Abydos and nearby sites flakes in a way that the design cannot be reconstructed because the paint is crumbly and turns into a “granular powder” whereas the paint on vessels from Nagada and other sites usually leave behind a negative of the original design, which can be reconstructed. Finkenstaedt suggests that this negative image may be a silica skeleton. This implies that Nagada area villages and Abydos area villages could have had local pottery shops or households making paint recipes unique to their region.

**Most Likely Pigment Candidates**

There are three candidates of what the white pigment may be based on Ritchie’s analysis:

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43 Bourriau, *Umm El-Ga’ab*, 31.


45 Finkenstaedt, “Painting Style and Place Association,” 37–38.

46 Finkenstaedt, “Painting Style and Place Association,” 37–38.

and other scholar’s visual analyses. These are marl clay, calcium carbonate and gypsum. The latter is from observations by Bourriau. However, there are a few minor candidates (lime, yellow ochre, kaolin clay and huntite) that will be mentioned below. In order to determine which of the three most likely candidates is the pigment, the study will employ visual, pXRF and FTIR analyses as discussed in detail in Chapter 2. In addition, a SEM/EDS analysis will be used to compare against the FTIR analysis. The results of the comparative collection will be mentioned below while the C-ware samples from the MFA Boston and the University of Pennsylvania Museum will be described in Chapter 2. After the review of the potential materials used, a hypothesis will be given on which pigment candidate is the most likely from the seven candidates and what the implications of this pigment means for Predynastic Egypt and Predynastic Egyptian potters.

The first potential candidate is marl clay, which is also known as tafla. Even though Ritchie does not mention marl clay specifically in his analysis, he does identify a calciferous clay on one fragment and a light-colored clay on the other. Zaki Iskander assumed it may be a white or yellow colored clay, which was applied before firing. Barbara Adams also states a calcareous clay was used to create the pigment but does not say that it was a marl clay. Henri Frankfort states it was a ferruginous clay but he does not specify between marl or kaolin clay as both clays contain varying amounts of iron. Bourriau believes the pigment may be a light-


49 Zaki Iskander, Science and Technology of Ancient Egypt (Cairo: The American University in Cairo, 2000), 45.


colored clay used as a slip. All of these conclusions may be indications that marl clay was used because it is a calcareous clay and light colored. Marl clay from Egypt mainly consists of limestone, fine to coarse grain sand and other inclusions such as micaceous particles. It is found in shale and limestone deposits along the Nile river and secondary deposits carried by the river to wadis. The deposits stretch between Cairo and Esna and would have been accessible to the Nagada I potters. However, the clay was not utilized for pottery in Upper Egypt until Nagada II (3,500 BCE to 3,200 BCE), approximately 400 years after C-ware production had started. The marl clay was used to make decorated ware, which is a matte, buff colored ware with red decorations during Nagada II and III. However, two different types of marl clay were being used at least 900 years or more earlier than C-ware during the Omari period (4,700 BCE to 4,400 BCE) for vessels in lower Egypt. Although, neither period used it as a slip to paint designs on the vessels.

If the marl clay was used, it would have been levigated since no dark, micaceous particles are visibly present in the white paint on white cross-lined ware. Levigation is a process by which the clay is mixed with water in a pool and left to settle. The heavier particles fall to the bottom while the lighter particles remain suspended longer and slowly descend on top of the heavier particles. The argument against marl clay is that it does not always fire to a white color and there

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52 Bourriau, *Umm El-Ga’ab*, 31.


would be greater variability in the color of the paint. Marl clays typically fire to red, pale pink, pale gray, grayish-green, pale green, olive green and white. Some other material would have been added to create a white color and keep the color mostly uniform as the paint on C-ware ranges between white and light yellow. The marl clay would then have been used in a colored slip and could have been applied before or after firing.

Ritchie’s HCL test showed the presence of magnesium, which marl clay does not usually contain. Marl clays also have a strong effervescence when mixed with HCL due to the calcium carbonate within it. However, Ritchie did not note in either of his articles if the pigment had a fizzy reaction during his test. Nevertheless, some other material would have needed to been added to the marl clay in order to create a white color, it is the most likely possibility out of the top three potential candidates for the white pigment because the clay has been used to manufacture pottery since Nagada II and is a calcareous clay.

The second potential candidate is calcium carbonate. It is also called whitening chalk. Ann Heywood conducted an analysis on white pigments in the Metropolitan Museum of Art using polarizing light microscopy, energy dispersive X-ray spectroscopy and X-ray diffraction. The white paint from the two Predynastic objects she analyzed was composed of calcium carbonate. Although, she did not say what the two Predynastic objects were. It is composed of

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calcium and carbon (CaCO$_3$). It has many forms and is part of some of the chemical composition of the other candidates such as marl clay, gypsum, lime and huntite. The forms normally used to grind into a pigment are from calcitic stones and minerals such as calcite, limestone, marble and mollusk shells.\textsuperscript{64} All of these stones and minerals are found within Egypt.

Calcite was used to create stone vessels since the Predynastic period and as a pigment for painting ceramics during the Dynastic period. It was also used as a fluxing agent in painted ceramics during firing and was a natural inclusion in the paste like the lime mentioned above.\textsuperscript{65} It is one of the main mineral forms of calcium carbonate (CaCO$_3$) but was rarely used in its pure form as a pigment.\textsuperscript{66} Rather, the other different minerals such as limestone and marble that are produced from calcite were used.\textsuperscript{67} It may have been used earlier than the Dynastic period as a pigment but its chemical composition is not similar to Ritchie’s HCL test results as it lacks silicon unless it was mixed with clay.

Limestone is more likely than calcite to have been used as the white pigment. It is mainly composed of calcium carbonate and is a form of calcite. It has impure forms such as dolomitic or nummulitic limestone.\textsuperscript{68} Limestone is located throughout Egypt in the Nile valley, western desert and eastern desert.\textsuperscript{69} Limestone was accessible to the Predynastic Egyptian potters because it was already in use widely at that time in weapons, tools and statues as well as to a limited extent.


\textsuperscript{65} Arnold and Bourriau, \textit{An Introduction}, 100 and 154.

\textsuperscript{66} Gettens, Fitzhugh and Feller, “Calcium Carbonate,” 157 and 167.

\textsuperscript{67} Gettens, Fitzhugh and Feller, “Calcium Carbonate,” 157 and 167.

\textsuperscript{68} Aston, Harrell and Shaw, “Stone,” 40.

\textsuperscript{69} Aston, Harrell and Shaw, “Stone,” 40.
architectural elements.\textsuperscript{70} However, Ritchie did not note if the pigment effervesced in the HCL, which is a trait of calcium carbonate as mentioned above.\textsuperscript{71} The long-term use and documentation of calcium carbonate in its different forms being used for Predynastic objects and as a pigment makes it a potential ingredient in the white paint on C-ware. It may have been applied as a slip or wash.

The third potential candidate is gypsum. It is also called selenite in its clear, crystal form, satin spar in its fibrous form and alabaster in its fine-grained aggregated form.\textsuperscript{72} Gypsum is sometimes mislabeled as Egyptian alabaster even though the latter is a form of travertine. It is composed of hydrated calcium sulphate (CaSO$_4$2H$_2$O).\textsuperscript{73} Dorothea Arnold and Janine Bourriau mention that white gypsum paint was used to decorate C-ware.\textsuperscript{74} J. E. Quibell also assumed that the pigment is a gypsum and states that it was applied thickly to the vessels.\textsuperscript{75} Kenneth J. Bohač wrote that it was gypsum that was applied after firing in the catalogue description of a C-ware vessel (1920.2008) in the Cleveland Museum of Art but their current online catalogue no longer lists gypsum under the materials section.\textsuperscript{76} These assumptions are most likely based on the fact that during the Dynastic period, gypsum was used to paint other types of pottery.\textsuperscript{77} If it was used

\textsuperscript{70} Aston, Harrell and Shaw, “Stone,” 42; Guy Brunton, \textit{British Museum Expedition to Middle Egypt: First and Second Years 1928 1929: Mostagedda and the Tasiin Culture} (London, 1937), 17 and 21.

\textsuperscript{71} Arnold and Bourriau, \textit{An Introduction}, 160; Ritchie, “An Examination,” 234–236.

\textsuperscript{72} Lee and Quirke, “Painting Materials,” 21–22.

\textsuperscript{73} Lee and Quirke, “Painting Materials,” 21.

\textsuperscript{74} Arnold and Bourriau, \textit{An Introduction}, 96.

\textsuperscript{75} W. M. Flinders Petrie and J. E. Quibell, \textit{Naqada and Ballas} (London: Bernard Quaritch, 1896), 13.


\textsuperscript{77} Arnold and Bourriau, \textit{An Introduction}, 102.
on C-ware, this would show a continued use of the material from the Predynastic period to the Dynastic period.

Gypsum was also utilized outside of ceramics. In the form of alabaster, it was used during the Predynastic period as the base material to make stone bowls, as plaster to be used inside buildings and as an adhesive to fix broken pottery. Gypsum was also used to bond other pigments to surfaces such as blue, yellow and green. Only one quarry, Umm el-Sawwan, is known so far from ancient Egypt and is situated in the northeast section of the Fayum. It dates between the first and fourth dynasties. Despite that, only one quarry has so far been located, gypsum is found in the western desert, along the Red Sea and in the Mediterranean. The wide use of gypsum from the Predynastic period into the Dynastic period makes it possible that it was utilized during the Predynastic period to decorate C-ware. It could have been applied as a slip or wash.

**Least Likely Pigment Candidates**

There are a few additional candidates that the pigment used to paint C-ware may be composed from. However, these are less likely than the possibilities mentioned above because the materials were mainly used later in time or would not be the right color. Lime is a candidate because it was found on Predynastic figurines by Peter Ucko and H. Hodges while carrying out

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78 Lee and Quirke, “Painting Materials,” 22.

79 Arnold and Bourriau, An Introduction, 102.

80 Lee and Quirke, “Painting Materials,” 22.

81 Lee and Quirke, “Painting Materials,” 22.

82 Lee and Quirke, “Painting Materials,” 22.
an chemical analysis on the paint. The paint is composed of calcium and carbon but lime takes on different forms when heated, hydrated or re-carbonated (CaO, CaCO\textsubscript{3} and Ca(OH)\textsubscript{2}). The authors noted that the paint was applied more like a plaster than a fired, ceramic pigment. They also noted that some of the lime may have come from weathered or impure lime source since it was mixed with gypsum. Even though they suggest that quick lime (CaO) may have been utilized to paint the figures, so far there is no evidence other than potentially the figurines that lime burning occurred in Egypt before the Ptolemaic period in order to make quick lime. A silt-lime plaster was used to paint inside the mastaba of Nefermaat and Atet but this technique was only used in a couple tombs. Lime is primarily used for making faience, glass and in its limestone form as a natural inclusion or temper in ceramics. It is not used as a pigment for painting ceramics, prior to firing as it would burn away during the firing process but it could have been applied afterwards. It would have been applied as a plaster or as a pigment with a binder.

Pale yellow iron oxide mixed with silica is another candidate. P. D. Ritchie concluded

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85 Ucko and Hodges, “Some Pre-Dynastic Egyptian Figurines,” 212–213.

86 Ucko and Hodges, “Some Pre-Dynastic Egyptian Figurines,” 211–213.


that it was found on one of the C-ware fragments from his HCL analysis mentioned above.\textsuperscript{91} The yellow iron oxide would have been from yellow ochre (FeOOH). Typically, it is composed of different types of hydrated iron oxide such as goethite or limonite and clay.\textsuperscript{92} Although, this result is most likely from the sample being contaminated from the red ochre wash on the vessels, whose chemical formula (Fe$_2$O$_3$) is similar to yellow ochre. Furthermore, the yellow ochre would always have a yellow tone but the white pigment is not yellow or consistently yellowish-white.

Kaolin clay is also a candidate. Petrie suggested that it may have been used to decorate C-ware while observing the pottery from Nagada and Deir el Ballas.\textsuperscript{93} Frankfort states that the pigment is derived from a ferruginous clay but he did not name if it was a marl or kaolin clay.\textsuperscript{94} However, kaolin clay is not known to have been used for ceramics until the early Roman period in Egypt (100 BCE to 400 CE).\textsuperscript{95} It also is not known to have been used as a white pigment for painted ceramics until the Christian period.\textsuperscript{96} Therefore, it is unlikely that kaolin clay was utilized for painting because its usage is not documented until thousands of years have passed since the production of C-ware.

Huntite is the last candidate because it was used to paint artifacts from the Old Kingdom and may have been utilized earlier than the Dynastic period. It is composed of magnesium calcium carbonate (Mg$_3$Ca(CO$_3$)$_4$), which is found in salt lakes and magnesium deposits from

\textsuperscript{91} Ritchie, “Some Predynastic Pottery,” 164–165.

\textsuperscript{92} Lee and Quirke, “Painting Materials,” 105 and 115.

\textsuperscript{93} Petrie and Quibell, Nagada and Ballas, 37.

\textsuperscript{94} Frankfort, Studies in Early Pottery, 94.


\textsuperscript{96} Arnold and Bourriau, An Introduction, 102.
Tunisia and the Persian Gulf.\textsuperscript{97} It adheres well to objects due to it being a very fine-grained material, which makes it possible that it could have been applied as a wash or slip to the pottery.\textsuperscript{98} During Heywood’s huntite analysis, mentioned above, she did not find any huntite on the two Predynastic artifacts she examined.\textsuperscript{99} It may be unlikely that huntite was used before the Dynastic period since currently, there is no documented uses of it prior.

Out of all the candidates suggested by previous researchers, marl clay is the most likely material used to create the pigment. The other two top candidates (calcium carbonate and gypsum) are also possible. This is due to the literature review, their chemical compositions, similar elemental make up as the elements seen in Ritchie’s analysis and uses related to pottery in Egypt. In order to confirm which of the candidates was utilized, a combination of visual, pXRF, FTIR and SEM/EDS analyses were carried out.

\textsuperscript{97} Lee and Quirke, “Painting Materials,” 114.

\textsuperscript{98} Lee and Quirke, “Painting Materials,” 114.

Chapter Two: Methods

Four complementary analyses — visual analysis, XRF, FTIR and SEM/EDS — were applied to the C-ware corpus from the MFA Boston. A comparative C-ware corpus at the University of Pennsylvania Museum was analyzed through visual analysis and pXRF, as discussed further below. The comparative collection was examined using visual analysis and pXRF. Overall, four types of analyses (visual, XRF, FTIR and SEM/EDS) were used between all three sets of samples.

Visual Analysis

The visual analysis included measurements of vessel dimensions of its width, length, height and rim diameter. Additional measurements were taken if the shape of the object was irregular such as a protruding corner. The color of the white paint, red slip and fabric were assigned values on the basis of a Munsell color chart. The type of lightening system used in the work space was also documented to account for variability in the colors observed. The painted designs on the samples were described according to what they represented, for example, “zig-zags” or “giraffes”. Imperfections such as stains or cracks and restoration work were also noted. Color photographs were taken of each sample, including top, bottom and side images.

PXRF Analysis

PXRF is a non-destructive technique that utilizes a portable emitter to direct X-rays of a known energy value toward a sample, which causes it to reflect X-rays back to the machine with new values that are diagnostic for the specific chemical composition of the sample. The radiation waves are not harmful to the materials. X-rays are a short-wave form of electromagnetic radiation with high energy frequency, whose wavelength lies between the ultraviolet and gamma
radiation spectra.\textsuperscript{1} X-rays strike the sample atoms and excite them, which results in the loss of
an inner shell electron from the K line.\textsuperscript{2} The loss of the electron makes the atom unstable and the
inner shell electron is replaced by an outer shell electron from the L line, which is the next line of
electrons after the K line.\textsuperscript{3} The switching of the two electrons releases energy called
“fluorescence radiation” on the K and L lines.\textsuperscript{4} The radiation emitted from the excited electrons
has a unique signature that permits identification of each element in the sample.\textsuperscript{5} The pXRF
device utilizes counts per seconds (cps) as its measurement, which permits analysis of heavy elements in approximately ten seconds.\textsuperscript{6} However, the longer the pXRF is permitted to analyze
the materials, the more accurate the results will be. Each sample analyzed for the present study
was radiated for 30 seconds.

There are many advantages to using a pXRF over other elemental analyses. It is non-
destructive and allows samples to be reanalyzed in the future, unlike for example, Neutron
Activation Analysis (NAA).\textsuperscript{7} In addition, because the pXRF device is portable, it can be taken
into the field or transported to different collections. X-Ray Florescence does not require
elaborate preparation, and samples with less than half a centimeter of material can still yield
accurate results.\textsuperscript{8} PXRF was selected for identifying the pigment due to it being a non-

\begin{enumerate}
\item Shackley, “An Introduction to X-Ray Fluorescence (XRF),” 16-17.
\item Shackley, “An Introduction to X-Ray Fluorescence (XRF),” 16-17.
\item Shackley, “An Introduction to X-Ray Fluorescence (XRF),” 16-17.
\item Shackley, “An Introduction to X-Ray Fluorescence (XRF),” 16.
\item Shackley, “An Introduction to X-Ray Fluorescence (XRF),” 31.
\item Shackley, “An Introduction to X-Ray Fluorescence (XRF),” 8.
\item Shackley, “An Introduction to X-Ray Fluorescence (XRF),” 9.
\end{enumerate}
destructive technique, portability and ability to give quick and accurate results.

Furthermore, the pXRF technique has been employed by numerous scholars for pottery analysis and rock art from ancient Egypt and other ancient cultures. For example, Mohamed A. Hamdan, et al., utilized a combination of pXRF and Raman spectroscopy to analyze pigment sources for rock paintings in the Wadi Sura, in southwest Egypt, dating between 7,000 BCE and 4,000 BCE. At Amarna, M. Uda, et al., analyzed blue paint on a corpus of Eighteenth Dynasty ceramics, utilizing pXRF, XRD, and PIXE analyses. Many pXRF pottery and pigment analyses have also been conducted outside of Egypt. One example is from Tell el-Dor, Israel, where Shlomo Shoval and Ayelet Gilboa utilized pXRF on red and black pigments found on bi-chrome pottery dating between 1,100 BCE and 400 BCE. As the use of pXRF becomes more widespread at sites within and outside of Egypt, it will become possible to create databases of pigment compositions for efficient comparisons between artefact types, regions and time periods.

The main drawback of pXRF for the analysis of pottery materials lies in the objects’ curvatures and in the temper employed in their fabrics, which can affect the results. In the case of objects with significant curvature (≥ XX units of YY measure), the results can become less accurate because the radiation from the electrons of the lighter elements will not always bounce back to the pXRF receiver due to the curvature of the ceramic vessel or fragment. While

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temper can affect the results by misrepresenting the overall composition of the ceramic due to its heterogeneity, if it is not well-mixed or if the inclusions from the temper are sufficiently large to cause deflection from the focal point of the pXRF receiver. Fortunately, it is possible to counter both of these issues with selective sampling. For analysis of the comparative collection, the MFA Boston and the University of Pennsylvania Museum samples, the flattest part of the vessels or fragments without large inclusions were chosen in order to achieve the most accurate results.

**FTIR and SEM/EDS Analyses**

FTIR employs radiation to analyze chemical composition of a sample, similar to pXRF. Unlike the latter technique, however, FTIR identifies unknown materials by their molecular absorption and transmission of infrared radiation. The radiation is emitted from the FTIR machine to the sample, which absorbs some of the infrared radiation energy, while the rest is transmitted through the item. The radiation excites the atoms that make up the sample and they produce diagnostic wavelengths along the infrared spectrum. As with the pXRF, FTIR is also a non-destructive technique, which allows the sample to be reused for further testing.

FTIR has been utilized in Egypt to identify pigments on wall paintings and wooden objects such as coffins for the identification of pigments. It is also used on pottery for analyzing pigments and ceramic fabrics. Shoval examined two types of Canaanite wares (metallic ware and hole-mouth cooking pots) with FTIR and LA-ICP-MS (laser ablation inductively coupled plasma

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mass spectrometry) to identify their fabrics.¹⁷ In 2014, Hussein H. Mahmoud conducted a FTIR-ATR analysis along with ESEM on pigments from inside the Quasr-el Ghuieta temple in Kharga Oasis.¹⁸ In addition, FTIR has been used to identify pigments on objects and structures across Egypt. FTIR analysis has a large database that permits researchers to compare results from old analyses to new ones.

A FTIR analysis was conducted on the white cross-lined ware from the MFA Boston, to compare against the pXRF data and to ascertain what material form the elements create for the source material of the pigment. A FTIR analysis was not required for the samples from the University of Pennsylvania Museum because the forms in which the elements occur were already known (e.g., huntite, calcite). However, that known data will also be cross-reference with the results of the FTIR analysis of samples conducted at the MFA Boston.

A SEM/EDS analysis was also carried out on the white cross-lined ware from the MFA Boston. It was not employed on the C-ware samples from the University of Pennsylvania Museum. It was also not conducted on the comparative collection as it was unnecessary. The analysis is used to compare against the pXRF and FTIR analyses.

This analysis uses the combination of a scanning electron microscope and energy dispersive x-ray spectroscopy to examine the sample. Electron radiation is sent to the sample to cause its electrons to jump out of their shells.¹⁹ Then an outside electron comes in to replace the missing electron in the shell. This change can be read in the form of x-rays and used to determine

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which elements are present in the sample. Unlike the first two technique, a small sample is sometimes removed but the sample can be re-used for future testing.

SEM/EDS analyses have been employed on Egyptian pottery and other Egyptian artifacts. It has also been used on pottery outside of Egypt. In 2009, Mary Ownby and Dafydd Griffiths carried out a SEM and XRF analysis on Marl C pottery from Egypt to determine if the argillaceous inclusions were natural or added intentionally. As more SEM analyses are performed on Egyptian pigments, the results can be compared to other pigments used on pottery.

**Comparative Collection for the PXRF Analysis of the Pigment**

A comparative pigment collection was created based on materials from the Institute of Egyptian Art and Archaeology (IEAA) collection, the Earth Sciences department of the University of Memphis mineral collection, Geological Specimen Supply and Kremer pigments. This pigment collection was analyzed with pXRF to create a comparative sample to compare against the C-ware pigment samples. The clay part of the pigment collection contained a raw marl clay sample, a marl clay decorated ware fragment from Nagada II, a marl clay ceramic fragment from the Middle Kingdom, a marl clay bowl from the New Kingdom and a marl clay ceramic fragment from the eighteenth dynasty. The kaolin clays are mentioned below. The four different marl clay samples were taken was to get a range of what elements the clay all may contain since each clay source may have a different chemical signature. The ceramic samples were selected after a visual analysis because they did not have any modern coatings on them, did not appear to have heavy mineralization, had a non-slipped area and were composed of marl clay.

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20 Nanakoudis, “EDX Analysis with SEM.”

An unfired marl clay sample was obtained by Suzanne Onstine from Deir el Ballas in 2021. The sample used was broken off from the original sample into three small chunks (Figure 4). The fired clay samples were all held in the museum. The Nagada II ovoid jar fragment (1988.14.58) was donated by the Egypt Exploration Fund to IEAA and has no provenience (Figure 5). The Middle Kingdom fragment (1994.4.2u) was donated to IEAA from Glenn White and has no provenience (Figure 6). The New Kingdom marl clay bowl (1988.14.69) was donated to the IEAA and has no provenience (Figure 7). The 18th dynasty fragment (1988.14.17) was donated to IEAA by the Egypt Exploration Fund and is potentially from Tell el-Amarna (Figure 8). All of the ceramic fragments and the bowl had a calcium carbonate and fine to medium grained sand temper.

The mineral samples of the pigment collection were taken from the University of Memphis Earth Science department’s mineral collection, except for the red ochre, yellow ochre and huntite. All of the minerals were already pulverized into powders in order to obtain a more homogenous mixture of the minerals. The mineral samples of the collection contained calcium carbonate, gypsum, kaolin clay, English kaolin Ng clay, kaolinite, dolomitic limestone, huntite, magnesium carbonate, calcite, red ochre and yellow ochre (Figure 9–Figure 19). There are three different types of kaolin samples is the same as the four marl clay samples as these were taken to get a range of what elements the clay may contain since each clay source may have a different


chemical signature. For the rest of the minerals, the magnesium carbonate was sampled in the event that a huntite sample was not obtained. The red ochre was the control in order to make sure the pigment samples taken on the white cross-lined ware vessels are not contaminated from the red ochre wash on them.

Most of the minerals in the collection did not have a provenience and some were from the University of Missouri geology collection before coming to the University of Memphis collection. The kaolin clay was from Warren County, Georgia. The powdered huntite was purchased from Kremer Pigments and both of the ochres were from Geological Specimen Supply (Figure 15 and Figure 18–Figure 19). The yellow ochre is from White Side Mine, a historic silver and lead mine, Inyo County, California and the red ochre is from San Bernadino County, California.26 The rest of the materials did not have a provenience.

The pXRF analysis of the comparative collection took place on March 24, 2023 and March 30, 2023. Ryan Parish and Gary Stinchcomb from the Earth Sciences department of the University of Memphis brought the pXRF and demonstrated how to carry out the analysis. The pXRF was a Bruker Tracer 5i. The pXRF was last calibrated a few years ago. Even though the pXRF was no longer calibrated, qualitative analyses can still be carried out on the data retrieved. Therefore, large differences in the elements counts between the different materials can be used within this collection since they all used the same pXRF. The presence and absence of elements from this collection can be compared with XRF results from the two C-ware samples but not the specific element counts. The sample size was 3mm and the pXRF was held for a duration of 30

seconds on each sample. The kV was set at 15 and µA at 24. The atmosphere was put on air mode because a vacuum sealed chamber was not used for testing. The proximity sensor was turned on for all of the ceramic samples, except for the Middle Kingdom ceramic fragment because the curvature of the fragment did not allow the tip to get close enough without setting off the sensor. It was also turned off for the mineral samples, except for the huntite sample, in order to read through the plastic container that they were poured into. The pXRF intensities were measured in cps. Any peaks from rhodium or argon were not factored into the data because it is from the tip of the pXRF.

The marl clay samples and huntite were analyzed first. The flattest spot was found on the ceramic fragments in order to press the tip of the pXRF flat against them to get an accurate reading. In addition, the spot had to be clear of markings, mineralization, slips and washes. The powdered minerals, except for the huntite, were poured into a clear, plastic container that was placed on top of the pXRF. The huntite was poured into an acid-free cardboard box and the tip of the pXRF was pushed into it. Notes were taken on paper and documented where the tip was placed on the samples. Photographs were taken afterwards of the ceramic samples and the huntite sample with a white box and camera. The mineral samples were photographed on a table with a phone camera.

This part of the collection was analyzed on March 24, 2023. The results of the marl clay sample’s pXRF intensities can be seen in Figure 20. The raw marl clay had the highest amounts of aluminum (6,538 cps), iron (224,007 cps) and titanium (14,536 cps) compared to the fired marl clay samples. The closest in aluminum is the Nagada II jar fragment at 4,090 cps, in iron is the New Kingdom bowl at 204,277 cps and in titanium the eighteenth dynasty fragment at 13,949 cps. The Middle Kingdom fragment had the lowest amount of magnesium compared to the
others including the unfired clay. The Nagada II jar had the lowest amount of calcium (127,287 cps), iron (178,178 cps) and potassium (16,900 cps) within the ceramic samples. The ceramic samples had a similar intensity range in silicon, iron and calcium. The raw clay sample was similar to the ceramic sample’s ranges in calcium, iron, magnesium, phosphorus, silicon and titanium.

All of the minerals were analyzed on March 30, 2023, except for the huntite sample, which was analyzed on March 24, 2023 with the ceramic samples. The results of the mineral sample’s pXRF intensities can be seen from Figure 21 to Figure 27. All of the samples have unique signatures that make them identifiable. The kaolin clay, red ochre and yellow ochre all contained high peaks of iron but the cps varies between them. The three kaolin clays all followed the same general trend with peaks of iron, nitrogen and calcium, despite most likely being from different clay sources. Although, the English kaolin had the highest iron peak at 65,703 cps, which makes it stand out among the other two kaolin clays, which were between 26,000 and 27,000 cps. The calcium carbonate and its two other forms, calcite and dolomitic limestone, all had the same peaks but had varying amounts under the calcium peak.

Out of all of the potential candidates examined in the comparative collection, the marl clay samples were the closest to the elements listed from Ritchie’s HCL analysis. They contained calcium, iron and silicon, as seen in Figure 20, while Ritchie reported that the pigment consisted mainly of sodium, calcium, silicon and magnesium with one of the fragments containing iron.27 Although, the iron could have been due to the red ochre as mentioned above. No magnesium was detected while sodium was outside of the scope for the pXRF settings used. Even though the kaolin clays also contained calcium and iron, they did not contain any silicon or magnesium but

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this could be due to the clays being from different sources than Egypt. The other two main potential candidates, calcium carbonate and gypsum, also did not contain silicon. None of the minor potential candidates contained silicon either.

Based on the review of the potential candidates, the marl clay with or without other materials added is the most likely candidate. It was used in Lower Egypt before the Predynastic period and knowledge of the clay could have been communicated between the different groups that settled along the Nile river. It also would have been accessible to the potters as it is found along most of the Nile river. It contains three out of the five elements reported by Ritchie. It may have been applied as a slip or colored slip with additional materials such as huntite that could explain the lack of magnesium. A supplementary colorant would also explain how the potters achieved a consistent white to yellowish white color. Between a review of the different potential candidates and a preliminary pXRF analysis of a comparative collection, marl clay with or without other materials is the most likely candidate.
Chapter Three: Results

The C-ware collection results consist of the visual, XRF, FTIR and SEM/EDS analysis of the samples at the MFA Boston. It also includes the visual and pXRF analyses of the samples from the University of Pennsylvania Museum. The two C-ware collections were compared between the visual analysis and the XRF analyses. The FTIR and SEM/EDS analyses from the MFA Boston were used to identify the form that the elements were in from the XRF analyses.

MFA Boston and University of Pennsylvania Museum Samples Visual Analysis

The first part of the C-ware sample was formed from five vessels at the MFA Boston. These were all excavated from tombs in Mesaid by the joint Harvard University and MFA expedition between 1910 and 1913. Their accession numbers are: 11.306, 11.309, 11.315, 11.320 and 13.3934. All have been reconstructed and restored.

A visual analysis was carried out on June 5, 2023. The C-ware samples were measured, photographed and color matched to Munsell sheets. The lab lights had a blue tone, which may have affected the Munsell readings to trend towards cooler tones. The color of the red slip and white paint varied based on preservation. The first vessel is a small vase and is accession number 13.3934 (Figure 28–Figure 30). It is from tomb 789 in Mesaid and has plant designs.1 The base of the vessel is 5.6 cm by 6.05 cm. The rim is 11.7 cm by 11.9 cm. The height is 4.25 cm. The red slip on the inside was between 7.5 YR 3/3 dusky red and 10 R 3/3 dusky red. The red on the outside was not matched to a Munsell color sheet because of uneven coloring from restoration and black spots from firing. The unfaded white paint was 5 YR 8/4 pink while the faded paint

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varied between 7.5 YR 8/2 pinkish white and 7.5 YR 8/3 pink. It is clear that the potter applied the white paint on top of the red slip after firing as the slip is visible where the paint has flaked off (Figure 31). However, it has left behind a negative impression. Horizontal burnishing marks were barely visible on the inside.

The next vessel is accession number 11.320. It was excavated from tomb 29 in Mesaid. It is an oblong bowl with chevrons, straight lines, diagonal lines, rectangles and circles painted on it (Figure 32–Figure 34). The rim has an oblong shape and is 16.1 cm by 22.5 cm and the height varies between 4.4 cm and 6.1 cm as it does not sit flat. The red on the outside was between 10 R 4/4 weak red and 2.5 YR 4/4 reddish brown while the inside was between 2.5 YR 4/4 red and 2.5 YR 4/6 reddish brown. The color towards the center of the inside of the vessels appears more orange because the slip was thinly applied. Large white mineral inclusions were visible on the backside in the fabric. The white paint was almost completely gone and a negative impression was left behind. The negative impression of the white paint was 10 R 5/3 weak red. Burnishing marks going lengthwise were visible on both sides.

The third vessel is accession number 11.309. It is from tomb 41 in Mesaid and was found with 11.306. It is a vase with dots, vertical lines and a spiral painted on it (Figure 35–Figure 37). The diameter of the base is 5.2 cm. The rim is almost a perfect circle and is 16.2 cm by 16.3 cm. The height is between 5.8 cm and 6.35 cm. The red on the outside was 10 R 4/4 weak red while on the inside, it varied between 10 R 4/4 weak red and 7.5 R 4/4 weak red. The unfaded paint was 2.5 YR 6/4 light reddish brown and the faded areas of paint was 10 R 5/3 weak red. The

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white paint was applied thickly and protrudes off of the vessel (Figure 38). The potter may have been using a dense paint mixture or applied the paint on heavily. Where the paint has faded, a negative impression has been left behind. Horizontal burnishing marks are visible on both sides. On the back side, a grayish brown patch is visible from firing.

The fourth vessel is 11.315. It was excavated from tomb 39 in Mesaid.\(^4\) It is a vase and has triangles filled with cross-hatching painted on it (Figure 39–Figure 41). The base is not a perfect circle and is 6.2 cm by 7 cm. The rim is also not perfect and is 16.2 cm by 16.99 cm. The height varies between 7.6 cm and 8.6 cm. The red slip on the inside varies between 10 R 3/4 dusky and 10 R 4/3 weak red while the outside is consistently 10 R 4/4 weak red. The back side had some mottling with orange patches. The unfaded paint is 10 YR 9/1 white and the faded paint is 7.5 YR 7/3 pink. Burnishing marks are visible on both sides but on the back side, the marks run vertical instead of horizontal.

The last vessel is accession number 11.306. It is from Tomb 41 in Mesaid and was found with 11.309.\(^5\) It is a narrow vase with plants painted on it (Figure 42–Figure 44). The width is 5.7 cm and the height is 16 cm.\(^6\) The outside varies between 7.5 R 3/4 dusky red and 10 R 4/3 weak red. The inside was not slipped but the fabric was 2.5 YR 5/6 red. The fabric appears to be the same color was the slip visually but the lack of luster gives it a different Munsell color. The unfaded paint was 7.5 YR 8/3 pink and the faded paint was 5 YR 8/2 pinkish white. Vertical burnishing marks are visible on the outside. An almond shaped black mark along with several


\(^6\) MFA Boston, “C Ware Jar.”
smaller dark patches are also visible on the outside.

The second part of the C-ware sample is formed from seven vessels and a vessel fragment at the University of Pennsylvania Museum. These were all excavated from graves in Nagada, except for possibly one, by Sir Flinders Petrie through the Egyptian Research Account. Their accession numbers are: E1411, E1412, E1413, E1415, E1416, E1417, E1418 and E1419. Some of the vessels and vessel fragments have been reconstructed and restored. This is noted in the descriptions.

The visual analysis at the University of Pennsylvania Museum was conducted between June 13 and 14, 2023. Jennifer Wegner assisted in the analysis. Measurements and photos were taken along with the samples’ colors being matched to Munsell color sheets. The lab lights had a neutral tone. The color of the red slip and white paint varies based on preservation. The first vessel is E1419. It is from grave 1628 in Nagada.\(^7\) It is a vase that has two chevrons and five horizontal lines painted on it (Figure 45–Figure 47). The base is almost a perfect circle and is 5.8 cm by 5.9 cm. The rim is also almost a perfect circle and is 10.1 cm by 10.2 cm. The height is 16.1 cm. The red slip on the outside is fairly consistent in color and varies between 10 R 3/3 dusky red and 7.5 R 3/3 dusky red. The black top on the outside has shiny patches and is Gley 1 2.5/N black. The unfaded paint varies between 10 YR 8/3 – 8/4 very pale brown. Where the paint has faded, a negative impression is left behind. The inside was not compared to the Munsell sheets. Some of the surface on the vessel has been abraded away over time. There are faint vertical burnishing marks on the outside surface. On the inside, turning marks can be seen on and by the rim from where the coil was attached and smoothed on to the body. The inside is not slipped and blackened. According to conservation records, in 2019, the vessel was cleaned with

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ethanol and acetone.\(^8\) The base had white and gray material that may have been used to stabilize the vessel for display removed by a scalpel.\(^9\) No further work has been done to the vase.

The second vessel is accession number E1413. It was excavated from grave 1621 in Nagada with E1417.\(^{10}\) It is a small vase with chevrons and two horizontal lines painted on it (Figure 48–Figure 50). The base is 4.1 cm by 4.2 cm. The diameter of the rim is 5.2 cm. It is 5.5 cm tall. The red slip on the outside is consistent and varies between 10 R 4/3 – 4/4 weak red. The unfaded paint is 5 YR 8/4 pink while the faded paint is Gley 2 8/1 5B light bluish gray. A negative impression of the design was left behind where the paint has faded completely. The inside was not compared to the Munsell color sheets because they did not fit inside in order to get a close and accurate reading of the color. Horizontal burnishing marks are visible on the outside. On one side of the vessel, the white paint has a blue tone and the red slip has lost its sheen. It may have sat in water as white speckles from salt blooms or mineralization has taken place on the same side inside the vessel. The inside is not slipped and has turning marks, which cover a 0.9 cm wide area on and by the rim.

The third vessel is accession number E1412. It is from grave 1823 in Nagada.\(^{11}\) It is a vase with chevrons, diagonal lines, triangles and four horizontal lines painted on it (Figure 51–Figure 53). The base is 5.4 cm by 5.8 cm. The rim is 12.4 cm by 12.7 cm. The height is 5.6 cm. The outside red slip is 2.5 YR 4/3 reddish brown. The paint barely has any fading and is 2.5 Y 9/2 very pale yellow. A negative impression is barely visible where the paint has faded completely. A chip was present in the rim and was matched to 5 YR 6/6 reddish yellow. The


\(^{9}\) University of Pennsylvania Conservator, Conservation Work in 2019.


center of the vase on the inside is not slipped by due to the angle of the vase, the Munsell chart did not fit inside and casted shadows that made an accurate reading of the color difficult. The unslipped center appears to have been pinched into shape and lightly smoothed with a tool that leaves fine, incised lines. The inside has horizontal burnishing marks. The outside is unburnished.

The fourth vessel is accession number E1416. It was excavated from grave 1574 in Nagada.\textsuperscript{12} It is a vase that has vertical lines, diagonal lines and rows of chevrons painted on it (Figure 54–Figure 56). The base is 4.85 cm by 5.1 cm. The rim is 5.5 cm by 5.7 cm. The vase is 18 cm tall. The red slip on the outside is consistent and is 10 R 4/4 weak red. The unfaded paint varies between 7.5 YR 8.5/2 pinkish white and 10 YR 8.5/2 very pale brown. The faded paint is Gley 2 8/1 10 B light bluish gray. The paint has faded patches across the entire vessel. The potter appears to have painted the chevrons on the body of the vase by starting at the vertical lines that border the chevron and then working inwards as there is a blob at the tip of the chevron where the brush was lifted up off of the vase. The blobs all have a 0.2 cm diameter, therefore, the tip of the brush used by the potter has an approximately 0.2 cm diameter.

On one side of the vase, two patches of the red slip are discolored, which may be due to restoration work or it laying on its side. One of the patches has a greenish brown hue to it and is crackled while the other has a purplish tint and the discoloration creates the outline of an oval. The University of Pennsylvania Museum’s records do not indicate that any restoration work was done by their conservators but it may have been done prior to their acquisition of the vase. The outside of the vase is vertically burnished. The inside of the rim is slipped but not burnished while the rest of the inside is not slipped.

The fifth vessel is accession number E1415. It is from grave 1599 in Nagada.\textsuperscript{13} It is an oval shaped bowl with oval lines and chevrons painted on it (Figure 57–Figure 59). The rim is 10.4 cm by 14.8 cm. The height is 3.7 cm. The base was rounded and has no defined flat spot to measure. The red slip on the inside is 7.5 R 3/3 dusky red. The color is consistent but has a textured look like the weaving of clothing close up because the horizontal burnishing marks give the red slip almost three different colors that are woven together. The back side is unburnished and has two different colors. Above the accession number, it is 7.5 YR 5/3 – 5/4 brown while below the number is 2.5 YR 5/4 reddish brown. The unfaded paint is 2.5 YR 8/4 pink. The faded paint is Gley 2 8/1 10 B light bluish gray. The paint is mostly faded and leaves behind a negative impression. Both sides of the bowl were horizontally burnished but the backside is not slipped. The back side also has a few dark patches and appears slightly mottled. A chip on the rim was re-adhered to the vessel during restoration work in 2019.\textsuperscript{14} In addition, some of the paint was consolidated to the vessel by 1% methylcellulose mixed with de-ionized water.\textsuperscript{15} The vessel was also cleaned with de-ionized water and acetone.\textsuperscript{16} No further work has been done to the bowl.

The sixth vessel is accession number E1417. It was excavated from grave 1621 in Nagada with E1413.\textsuperscript{17} It is potentially a lid and has three chevrons painted on it (Figure 60–Figure 62). The rim is 2.3 cm by 2.4 cm. The lid is 1.2 cm tall. The outside red slip is 10 R 3/3 dusky red. The inside does not have a red slip and is between 7.5 YR 6/4 light brown to 7.5 YR 5/4 brown. The paint is thick enough that it protrudes off of the lid and is 7.5 YR 9/2 pale brown.


\textsuperscript{14} University of Pennsylvania Conservator, Conservation Work in 2019.

\textsuperscript{15} University of Pennsylvania Conservator, Conservation Work in 2019.

\textsuperscript{16} University of Pennsylvania Conservator, Conservation Work in 2019.

yellowish pink. The potter may have been using a dense paint mixture or applied the paint on to the vessel heavily. The paint that remains barely has any fading and where it is gone, the slip is also gone so it cannot be determined from the visual analysis if the paint would have left behind a negative impression like the other vessels. However, since it is from the same site as the other vessels, it most likely would have left a negative impression. The outside is horizontally burnished. The inside is not slipped or burnished and has a black spot. The chip on the inside has a light color than the center of the inside. An old accession number was scratched out on the inside.

The seventh vessel is accession number E1411. It is potentially from el-Deir but also could be from Nagada as mentioned by Jennifer Wegner. It is a vessel fragment that consists of two pieces glued back together (Figure 63–Figure 65) The designs include vertical lines, two giraffes and a plant. The longest part of the fragment is 20.9 cm while the shortest is 0.2 cm. The widest part is 12.9 cm and the thinnest is 1.7 cm. The thickest part of the rim is by the giraffe and is 1 cm while the other side is 0.9 cm thick. The body is 1 cm thick under the rim and narrows down to 0.7 cm thick at the end of the body. The outside red slip is 10 R 3/2 dusky red while the inside red slip is 10 R 3/3 dusky red. The color is consistent except for lighter patches around the giraffe on the outside and the plant on the inside. The paint is thick enough to protrude off of the vessel on both sides and is 10 R 8/2 very pale brown. As with the previous vessel, the potter may also have been using a dense paint mixture or heavily applied the paint on the vessel. The paint also barely has any fading and a negative impression is left behind where it has faded. Both sides of the vessel have horizontal burnishing marks. Fine scratches from burnishing or smoothing remain on the outside. The rim was constructed from a coil added to the body as the outlines of

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the coil still remain visible in the body and side profile.

The last vessel is accession number E1418. It was excavated from grave B102 in Nagada.\textsuperscript{19} The double necked vase was reconstructed from fragments (Figure 66–Figure 70). It has triangles, giraffes and a person painted on it. The base is 4.9 cm by 15.9 cm. Both of the rims have a 6.7 cm diameter. The height is 22.5 cm. The widest part of the vessel is 20.5 cm. The shoulder is 7 cm tall and the necks are each 5.4 cm tall. The red slip on the outside is 7.5 R 3/3 dusky red – 10 R 4/3 weak red. The color on the front side is mostly even and is lighter near the rims. The back side is mottled. The unfaded paint is 2.5 YR 8/4 pink and the faded paint is 7.5 YR 8/4 pink. At least half of the paint on the front side is worn down or faded but it leaves a negative impression behind. The paint is mostly gone on the back side and has discoloration around it the majority of it. There is some discoloration around the triangles on the front side. There are a few dark patches around the sides and back side.

Both sides of the vessel were burnished in a U-shape that follows the shape of the vessel. On the insides of both of the rims, turning marks are visible and cover a 2.3 cm wide section from the rim down (Figure 71). The insides of the rims are also slipped but not burnished. The inside of the vessel is not slipped or burnished. The vessel has been repaired twice in the past before the 2019 restoration.\textsuperscript{20} The conservators took apart the shoulder and body fragments and re-adhered them a glue composed of 25% w/v paraloid B72 in acetone.\textsuperscript{21} No further work has been done to the vessel.

Out of the 12 vessels and the vessel fragment visually analyzed, five vessels had the same


\textsuperscript{20} University of Pennsylvania Conservator, Conservation Work in 2019.

\textsuperscript{21} University of Pennsylvania Conservator, Conservation Work in 2019.
red slip color of 10 R 4/4 weak red (11.309, 11.315, 11.320, E1413 and E1416). Another four vessels (11.306, 11.315, E413 and E1418) had the color next to it, which is 10 R 4/3 weak red, while three more vessels and the vessel fragment (13.3934, E1411, E1417 and E1419) had the color 10 R 3/3 dusky red. On the 7.5 R sheet, four vessels (13.3934, E1415, E1418 and E1419) had 7.5 R 3/3 dusky red. Some of the vessels had colors close to the ones listed above such as 10 R 3/2 dusky red (E1411), 10 R 3/4 dusky red (11.315), 7.5 R 3/4 dusky red (11.306) and 7.5 4/4 weak red (11.309). Only one vessel (E1412) has a red slip color that is not part of the 7.5 R and 10 R sheets and is 2.5 YR 4/3 reddish brown. These counts include vessels that had more than one color for their slip. In general, the red slip color was fairly consistent among the vessels and the vessel fragment even though they are from different sites. This suggests that the potters from both of the two sites were following the same or similar slip recipe and firing the vessels using the same or similar process.

The white paint color varied more than the red slip among the vessels and vessel fragment. Only two vessels (E1415 and E1418) had 2.5 YR 8/4 pink and another two vessels (13.3934 and E1413) had 5 YR 8/4 pink. The rest of the vessels did not have the same color. The unfaded paint varied from 2.5 YR 6/4 light reddish brown (11.309), 2.5 Y 9/2 very pale yellow (E1412), 7.5 YR 8.5/2 pinkish white (E1416), 7.5 YR 8/3 pink (11.306), 7.5 YR 9/2 pale yellowish pink (E1417), 10 R 8/2 very pale brown (E1411), 10 YR 8.5/2 very pale brown (E1416), 10 YR 8/3 very pale brown (E1419) and 10 YR 8/4 very pale brown (E1419). Six of the vessels had pink undertones or were pink while last three vessels all had very pale brown from the 10 YR sheet. Only one of the vessels (11.315) had a pure white color, which was 10 YR 9/1 white. The rest may not have a true white color because of deterioration, depositional processes or the material used to create the paint was not white. These possibilities also could account for
the wide variation of colors for the unfaded paint among the vessels and vessel fragment. Even though the color of the red slip is not affected very much by the former two events, the white paint is more vulnerable to them because it was applied after firing on top of the red slip and is not attached as well to the vessel as the slip.

For the faded paint, only one color (10 R 5/3 weak red) had two vessels (11.309 and 11.320). The rest of the faded paint varied from 5 YR 8/2 pinkish white (11.306), 7.5 YR 7/3 pink (11.3015), 7.5 YR 8/2 pinkish white (13.3934), 7.5 YR 8/3 pink (13.3934), 7.5 YR pink 8/4 pink (E1418), Gley 2 8/1 5B light bluish gray (E1413) and Gley 2 8/1 10 B light bluish gray (E1415 and E1416). The reason there may be so much variation between the vessels in paint color is because of deterioration and depositional processes. These counts include vessels that had more than one color for their paint.

Almost all of the vessels and vessel fragment left behind a negative impression where the paint flaked off. This may indicate that the same or similar paint recipe was used by the potters from both of the sites but different recipes could also yield the same results. The vessels and the vessel fragment excavated from Nagada fit into the Nagada area group because the paint appeared to have flaked off in long sections and left behind a negative impression as mentioned by Finkenstaedt above. However, Mesaid is placed under the Abydos area group in a different spelling as Mesa’eed and the paint is reported to leave a dim negative impression or none at all even though four of the vessels at the MFA Boston left behind a clearly visible negative impression. The fifth vessel (11.320) has a dim negative impression.

Although, how visible an impression is to the viewer is subjective as it depends on the

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person, unless a clear set of definitions are given. Two of the vessels (11.309 and 11.306) have a granular paint, which fits the general trend of C-ware from Mesaid.\textsuperscript{24} If both parts of the criteria were need to be met, then four out of the five vessels would not fit the pattern, based on the negative impression or potentially three vessels based on the granular paint. The vessels that do not fit the Mesaid group characteristics may have been traded in or the paint recipe changed over time to account for the different way the paint flakes off and leaves a clear negative impression.

**MFA Boston and University of Pennsylvania Museum Samples XRF Analyses**

The XRF analysis of the C-ware samples at the MFA Boston took place on June 5, 2023. It was conducted in the XRF room in the MFA Boston research lab. Mr. Richard Newman operated the XRF, which was a Bruker Artax micro-XRF. The pXRF was not used because the museum required their own XRF to be used on their objects. The duration was 60 seconds. The settings were 40 kv and 400 microamps. The tube has a 0.065 mm diameter and is made of rhodium, therefore any rhodium was not accounted for in the data. No filters were added. The sample locations were marked on photos (Figure 72–Figure 76). Each sample also had a close-up photo taken on the XRF. The sample location was chosen based on where the most amount of paint was left. The red slip samples were taken as controls. A total of 16 samples were taken.

The graphs are separated by white paint and red slip (Figure 77 and Figure 78). No fabric samples were taken.

Between the white paint and red slip graphs, the most noticeable change in elements is in calcium. All the calcium counts from the white paint samples are much higher except for where it has been heavily worn down in samples 5 and 7 than in the red slip samples (Figure 77 and Figure 78). The rest of the elements (potassium, magnesium, lead, sulphur, strontium, titanium

\textsuperscript{24} Finkenstaedt, “Painting Style and Place Association,” 38.
and zinc) do not have large changes between the white paint and the red slip. This indicates that the white paint is calcium based. The other elements may be part of the pigment or may be from the red slip underneath the paint. Even though the XRF did not analyze the red slip for iron, it would have been present since the slip is composed of red ochre. In the samples taken from the University of Pennsylvania Museum, it is present in the pXRF analysis as seen below. The machine either cannot detect iron or the setting it was on did not allow it to examine the slip for iron.

The pXRF analysis of the C-ware samples at the University of Pennsylvania Museum was carried out on June 13, 2023. The samples were analyzed with the same Bruker Tracer 5i that was utilized for the comparative collection at the Art Museum of the University of Memphis. The first two samples (17 and 18) were taken in the same location in order to make sure the correct soil setting was selected. Initially, the nutrisoil3_20 setting was selected, then after the first test, the vacnutrisoil3_20 was chosen, even though it was not in a vacuum sealed setting because it had the correct kv. However, the settings switched automatically to custom when the pXRF was used. The duration was moved to 60 seconds instead of 30, in order to match the time used for the XRF analysis at the MFA Boston. The kv was at 40 instead of 15, in order to have the same kv setting used at the MFA Boston and the µa at 20. The atmosphere was put on air mode. The sample size was 3mm. The proximity sensor was turned on for all of the samples. Any peaks from rhodium or argon were not factored in because they are from the tip of pXRF.

The samples were analyzed in a research room in the museum. The sample locations were marked on photos (Figure 79–Figure 89). Each sample also had a close-up photo taken on the XRF. The sample location was chosen based on where the most amount of paint was left. The red slip samples were taken as controls. Fabric samples were taken when a fresh break was
present. A total of 42 samples were taken. The graphs that have more than 10 samples are not labelled by sample number in order to show the general trend since the lines all show the same peaks. The graphs are separated by white paint, red slip and fabric (Figure 90–Figure 93). The white paint graphs are separated by calcium cps as some of the paint had less than 50,000 cps and others had more than 60,000 cps. The white paint samples that had over 60,000 cps in calcium were all taken from areas that had well-preserved paint and a wide area of paint. This graph most likely accurately depicts what the white paint is composed of from Nagada. The calcium peaks in both white paint graphs are generally higher than compared to the red slip and fabric calcium peaks, therefore, the white paint is composed of calcium. It also contained peaks of iron, sulfur, silicon (which is mostly likely in the form of silica) and titanium with trace amounts of aluminum, chlorine, cobalt, manganese, nitrogen, palladium, potassium, phosphorus, strontium and zinc. Some of these elements may be coming from the red slip and the pXRF.

The blackened red slip sample from E1419 was included in the red slip graph because it followed the same trend as the rest of the red slip samples even though it underwent an additional firing process. The red slip and fabric samples both mainly consisted of iron. Although, the cps of the iron are significantly higher in the slip samples than the fabric samples. Both of the slip and fabric samples contained peaks of calcium, silicon (which is most likely in the form of silica), sulfur and titanium with small amounts of aluminum, chlorine, cobalt, manganese, nitrogen, palladium, potassium, phosphorus, strontium and zinc. In general, the red slip and fabric graphs follow the same general trends within their set of samples and between each other. The slip from Nagada may be composed of the fabric with red ochre added which would explain the similar peaks and the higher amount of iron.

Both of the sets of samples indicated that the white paint is composed of mainly calcium.
It had the highest cps in almost all of the white paint samples between the two museums. The samples from the University of Pennsylvania Museum had higher calcium counts than the MFA Boston samples because the paint was better preserved on the vessels and led to more accurate readings. The rest of the comparable elements from the white paint samples only showed slight changes in amounts. In the comparative collection, only the marl clay samples, calcium carbonate, dolomitic limestone, calcite, gypsum and huntite contained high amounts of calcium. The kaolin clay samples, magnesium carbonate and yellow ochre did not have any or displayed small amounts of calcium. Therefore, they are not the source material for the pigment. The minor elements cannot be compared as they are not the same between the samples and the comparative collection. Only the calcium counts can be compared to determine that the material is one of the calcium-based candidates.

The red slip samples taken from the University of Pennsylvania Museum helped complement the samples from MFA Boston as it showed the presence of iron from the red ochre in the slip. As mentioned before, the XRF at MFA Boston did not look for the iron and therefore, did not show it as being present in the slip. The rest of the comparable elements from the two analyses did not show much change. In the comparative collection, red ochre was examined as a control since it was known that the slip was most likely iron based. The high iron count in the University of Pennsylvania Museum red slip samples confirm that the slip was composed of red ochre. After determining that the white paint was calcium based, a further analysis was needed to determine what form was the calcium in when it was used as a pigment.

**MFA Boston Samples FTIR and SEM/EDS Analyses**

The transmitted FTIR microspectroscopy and SEM/EDS analysis was carried out in June 2023 by Richard Newman at the MFA Boston. Small amounts of the white pigment were
removed from the vessels to be analyzed. Only three out of the five vessels had enough pigment left to determine its composition. From Figure 94 to Figure 98 show the sampled areas on the vessels. No exact points were documented. From Figure 99 to Figure 103 are photomicrographs of the FTIR wave numbers. He reported that while the SEMS/EDS gave some new information, which the pXRF did not reveal, the FTIR analysis gave the most conclusive and detailed results. From the FTIR analysis on 11.306, the composition of the white pigment was from calcite and aragonite that was potentially mixed with clay. However, it may also be containment from being buried. Calcite was also present on 11.309 but potentially mixed with or used alongside gypsum. The third vessel, 11.315, contained only calcite. The white pigment on 11.320 was too thin to obtain an accurate analysis. The pigment on the last vessel, 13.3934, was too adhered to the ceramic to analyze it without pulling off the red glaze or fabric below it. The three vessels that had enough pigment to be analyzed all contained calcium in the form of calcite.

The pXRF and FTIR analyses both lead to a calcium-based material with the latter identifying it as primarily calcite. Some gypsum, aragonite and clay were also observed. The SEM/EDS added similar but not as much information the FTIR. The visual analysis aided with defining the tones of the white paint, which followed typical colors seen in calcite. The tones of

26 Newman, Five Predynastic Egyptian Ceramics, 2.
27 Newman, Five Predynastic Egyptian Ceramics, 2.
29 Newman, Five Predynastic Egyptian Ceramics, 5.
30 Newman, Five Predynastic Egyptian Ceramics, 6.
31 Newman, Five Predynastic Egyptian Ceramics, 7.
the white paint ranged from pink to pale brown.
Chapter Four: Conclusions and Future Research

Based on the four analyses, calcite was the major component used for the white paint on white cross-lined ware. It also used gypsum, aragonite and clay but some of these materials could be impurities. Without the analyses being performed, a list of seven potential candidates were possible for the source based on previous research and assumptions as mentioned in the literature review. The results of these tests confirmed for the two sites examined what was used to create the pigment.

Calcite is documented as a pigment used on Predynastic objects but not on pottery until the Dynastic period. As mentioned above, Heywood’s analysis of Predynastic objects concluded that the pigment was calcium based but the type of objects was not stated. This makes it the earliest known use of calcite as a pigment for painted pottery in ancient Egypt. Even though the pure form of calcite was rarely used as a pigment during Dynastic period, it was utilized in this way in the Predynastic period, as seen with the FTIR results. However, one sample is not enough to confirm it is an outlier or part of a general trend. The other two samples contained either gypsum or aragonite which may be impurities in the calcite or intentionally added materials to the pigment.

Even though gypsum was only found in one of the FTIR samples, it may be an ingredient commonly used in the white paint. If it was frequently added in the white paint, then it would also be its earliest known use as a pigment for Egyptian pottery. Gypsum had been used to decorate pottery since the Dynastic period. Before then, it has been used as a white pigment for

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Egyptian rock art and on other objects.

The white paint on the vessels from the University of Pennsylvania Museum may also be composed of mainly calcite. The way the paint flaked off both sets of samples was the same as mentioned above. Even though, according to Finkenstaedt, they should have flaked off differently because they are from two different regions (Abydos and Nagada), which had distinct processes of the paint falling off the vessels but these may not have been included in her survey or are outliers. ³ Also, the paint matched to the Munsell sheets were similar with a majority of them coming out as pink or pale brown. Thirdly, both the pXRF and XRF analyses had high peaks of calcium and contained almost all the same minor elements. Therefore, the white paint may be composed of the same material between the two sites.

In comparison to Ritchie’s HCL and spectrographic analyses of the pigment, the chemical composition of the two samples is different. He concluded that each of the fragments he tested all had different materials used to create the paint. These were yellow ochre mixed with silica, calciferous clay and a light-colored clay.⁴ The clays mainly contained sodium, calcium, silicon and magnesium.⁵ All of these elements, except for sodium, are also present in the pXRF tests from both of the sites. Since each of his results are different, the paint recipe used at El Mahasna may been different from the one used between Mesaid and Nagada.

If the paint was the same from Mesaid and Nagada, then the potters from the two sites would have interacted with each other or been trained in the same way for making white cross-lined ware. The consistency of the elements present indicate that the potters were selecting a

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³ Finkenstaedt, “Painting Style and Place Association,” 37–38.


specific material each time for the paint because they were trained to on how to find and process that material. All of the potters may have even gathered the material from the exact same source. The red slip was also fairly consistent in color and chemical composition, which may show that the entire process of making white cross-lined ware was knowledge that was shared among the two villages and the other villages that produced the ware. Furthermore, only certain potters may have been allowed to make this type of ware since its designs may hold special meanings and was buried with elite individuals.

However, if the materials used by the potters for creating the white paint is the same across all the sites that contain white cross-lined ware, then the chemical composition of the paint cannot be used to determine where a vessel came from. The slight variations within the chemical data between them may have come from the vessels sitting in different depositional environments within the two regions outlined by Finkenstaedt, the degradation of materials or impurities in the calcite use. These variations could include the binding agent used to adhere the paint to the pottery if one was used. Instead, only the motifs and styles can be used to decide which region the vessel was from and if it has been traded.

In conclusion, the white pigment used for white cross-lined ware between the two sites was mainly composed of calcium based on the pXRF and XRF analyses. The FTIR analysis showed that the calcium used on the vessels in the MFA Boston collection was in the form of calcite but also contained some gypsum and aragonite. The SEM/EDS analysis of the MFA Boston vessels had the same results. The process of creating the white pigment would have been the same or similar since potters from both of the sites utilized calcium-based materials.

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6 Finkenstaedt, “Painting Style and Place Association,” 37–38.
Future Possibilities

Further research is needed on white cross-lined ware, in order to understand how it was manufactured, used and what its iconography meant. Some of the motifs may be site or family specific as mentioned by Ana Navajas or regionally specific as hypothesized by Finkenstaedt. They could also designate certain events. Therefore, a database of all known motifs on provenienced pieces would need to be made.

Also, more pigment analyses using a variety of techniques on the white pigment are needed to create a comparable database of pigments to see if more than one paint recipe was used among the potters. This analysis started the work by documenting the pigment from two different sites. However, additional work will need to be done in order to have a better and larger database to use for cross-comparisons and identification potential trade networks between sites if different paint recipes were used. In addition, it can be used to examine if the presence of gypsum and aragonite are from impurities in the calcite used by the potters or if those two materials were purposely added to the paint mixture. It can also document if there are other impurities present in the calcite obtained for the pigment or other materials added to the paint. Furthermore, it may be used to find the source that the potter mined to obtain the material based on its impurities.

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Appendix: Figures

Figure 1: Map of Predynastic and Early Dynastic Sites (Diana Craig Patch, “Introduction,” in *Dawn of Egyptian Art*, ed. by Diana Craig Patch (New York: The Metropolitan Museum of Art, 2011), 7).
Figure 2: Sir Flinders Petrie’s Predynastic pottery classification (Petrie, *Diospolis Parva*, front piece).
Figure 3: Sir Flinders Petrie’s sequence dating chart (Petrie, *Diospolis Parva*, Plate II).
Figure 4: Marl clay sample from Deir el Ballas.

Figure 5: Nagada II jar with sample location marked with a black circle (IEAA 1988.14.58).
Figure 6: Middle Kingdom fragment with sample location marked with a black circle (IEAA 1994.4.2u).

Figure 7: New Kingdom bowl with sample location marked with a black circle (IEAA 1988.14.69).

Figure 8: Eighteenth Dynasty fragment from potentially Tell el-Amarna with sample location marked with a black circle (IEAA 1988.14.17).
Figure 9: Calcium carbonate.

Figure 10: Powdered gypsum from the University of Missouri geology collection.
Figure 11: Powdered kaolin clay from Warrant County, Georgia.

Figure 12: Powdered English kaolin Ng clay.
Figure 13: Powdered kaolinite.

Figure 14: Powdered dolomitic limestone.
Figure 15: Powdered huntite from Kremer pigments.

Figure 16: Magnesium carbonate.
Figure 17: Powdered calcite from University of Missouri geology collection.

Figure 18: Powdered yellow ochre.
Figure 19: Powdered red ochre.

Figure 20: Marl clay samples pXRF intensities (cps).
Figure 21: Calcium carbonate pXRF intensities (cps).

Figure 22: Gypsum pXRF intensities (cps).
Figure 23: Kaolin clay pXRF intensities (cps).

Figure 24: Huntite pXRF intensities (cps).
Figure 25: Magnesium carbonate pXRF intensities (cps).

Figure 26: Yellow ochre pXRF intensities (cps).
Figure 27: Red ochre pXRF intensities (cps).

Figure 28: Inside of vase (MFA Boston 13.3934).
Figure 29: Backside of vase (MFA Boston 13.3934).

Figure 30: Side of vase (MFA Boston 13.3934).
Figure 31: Close up of white paint (MFA Boston 13.3934).

Figure 32: Inside of bowl (MFA Boston 11.320).
Figure 33: Back side of bowl (MFA Boston 11.320).

Figure 34: Side of bowl (MFA Boston 11.320).
Figure 35: Inside of vase (MFA Boston 11.309).

Figure 36: Back side of vase (MFA Boston 11.309).
Figure 37: Side of vase (MFA Boston 11.309).

Figure 38: Close up of white paint (MFA Boston 11.309).
Figure 39: Inside of vase (MFA Boston 11.315).

Figure 40: Back side of vase (MFA Boston 11.315).
Figure 41: Side of vase (MFA Boston 11.315).

Figure 42: Outside of vase (MFA Boston 11.306).
Figure 43: Rim of vase (MFA Boston 11.306).

Figure 44: Base of vase (MFA Boston 11.306).
Figure 45: Side of vase (University of Pennsylvania Museum E1419).

Figure 46: Inside of vase (University of Pennsylvania Museum E1419).
Figure 47: Base of vase (University of Pennsylvania Museum E1419).

Figure 48: Top of vase (University of Pennsylvania Museum E1413).
Figure 49: Side of vase (University of Pennsylvania Museum E1413).

Figure 50: Base of vase (University of Pennsylvania Museum E1413).
Figure 51: Inside of vase (University of Pennsylvania Museum E1412).

Figure 52: Side of vase (University of Pennsylvania Museum E1412).
Figure 53: Base of vase (University of Pennsylvania Museum E1412).

Figure 54: Side of vase (University of Pennsylvania Museum E1416).
Figure 55: Rim of vase (University of Pennsylvania Museum E1416).

Figure 56: Base of vase (University of Pennsylvania Museum E1416).
Figure 57: Inside of bowl (University of Pennsylvania Museum E1415).

Figure 58: Side of bowl (University of Pennsylvania Museum E1415).
Figure 59: Base of bowl (University of Pennsylvania Museum E1415).

Figure 60: Outside of potential lid (University of Pennsylvania Museum E1417).
Figure 61: Side of potential lid (University of Pennsylvania Museum E1417).

Figure 62: Inside of potential lid (University of Pennsylvania Museum E1417).
Figure 63: Inside of vessel fragment (University of Pennsylvania Museum E1411).

Figure 64: Outside of vessel fragment (University of Pennsylvania Museum E1411).
Figure 65: Side of vessel fragment (University of Pennsylvania Museum E1411).

Figure 66: Front side of double necked vase (University of Pennsylvania Museum E1418).
Figure 67: Back side of double necked vase (University of Pennsylvania Museum E1418).

Figure 68: Side of double necked vase (University of Pennsylvania Museum E1418).
Figure 69: Double necked vase (University of Pennsylvania Museum E1418).

Figure 70: Base of double necked vase (University of Pennsylvania Museum E1418).
Figure 71: Turning marks by the rim on the inside of the double necked vase (University of Pennsylvania Museum E1418).

Figure 72: Samples 1–4 (MFA Boston 13.3934).
Figure 73: Samples 5–7 (MFA Boston 11.320).

Figure 74: Samples 8–10 (MFA Boston 11.309).
Figure 75: Samples 11–13 (MFA Boston 11.315).

Figure 76: Samples 14–16 (MFA Boston 11.306).
Figure 77: MFA Boston white paint pXRF intensities (cps).

Figure 78: MFA Boston red slip pXRF intensities (cps).
Figure 79: Samples 17–23 (University of Pennsylvania Museum E1419).

Figure 80: Samples 24–27 (University of Pennsylvania Museum E1413).
Figure 81: Samples 28–30 (University of Pennsylvania Museum E1412).

Figure 82: Samples 31–33 (University of Pennsylvania Museum E1412).
Figure 83: Samples 34–36 (University of Pennsylvania Museum E1416).

Figure 84: Samples 37–40 and 42 (University of Pennsylvania Museum E1415).
Figure 85: Sample 41 (University of Pennsylvania Museum E1415).

Figure 86: Samples 43–45 (University of Pennsylvania Museum E1417).
Figure 87: Samples 46–48 (University of Pennsylvania Museum E1411).

Figure 88: Samples 49–51 (University of Pennsylvania Museum E1411).
Figure 89: Samples 52–58 (University of Pennsylvania Museum E1418).

Figure 90: University of Pennsylvania Museum white paint pXRF intensities (cps).
Figure 91: University of Pennsylvania Museum white paint pXRF intensities (cps) with higher than 60,000 cps in calcium.

Figure 92: University of Pennsylvania Museum red slip pXRF intensities (cps).
Figure 93: University of Pennsylvania Museum fabric pXRF intensities (cps).

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Figure 100: MFA Boston 11.309 FTIR wavenumbers (cm-1) ©Museum of Fine Arts, Boston.
Figure 101: MFA Boston 11.315 FTIR Wavenumbers (cm\(^{-1}\)) ©Museum of Fine Arts, Boston.

Figure 102: MFA Boston 11.320 FTIR Wavenumbers (cm\(^{-1}\)) ©Museum of Fine Arts, Boston.
Figure 103: MFA Boston 13.3934 FTIR Wavenumbers (cm⁻¹) ©Museum of Fine Arts, Boston.