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Documenting Cordage Impressions on Archaeological Ceramics: A Methodological Comparison of Casting and Digital Representation

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DOCUMENTING CORDAGE IMPRESSIONS ON ARCHAEOLOGICAL CERAMICS: A METHODOLOGICAL COMPARISON OF CASTING AND DIGITAL REPRESENTATION

by

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ABSTRACT

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by

Nicole Brittany Bodenstein

The University of Wisconsin-Milwaukee 2019
Under the Supervision of John D. Richards, Ph.D.

The analysis of cordage and fabrics from the impressions and markings on pottery has traditionally been conducted by casting the pottery sherds with a plastic or liquid media to make a positive. This positive is then analyzed by measuring attributes under a low-power microscope with calipers. Original Sculpey® is one casting media that has been popular because of its price, accessibility, detail of cast, and permanency of the casts after curing. However, it has been found to impart an organic chemical signature on the sherds, which would bias residue analyses. Further, the plasticizer in Original Sculpey® can soften certain plastics, notably Paraloid B-72, which is often used on pottery as a consolidant. 3D scanning, then, theoretically can be used to create digital representations of the impressions and markings in pottery, while avoiding damage to the sherds and other conservation concerns. The NextEngine 3D laser scanner was tested in the analysis of seven sherds with varying qualities of impressions and markings. Results revealed that the method one uses depends not only on the quality desired and the conservation of the sherd, but also cost, time, and expertise available to the researcher. While the NextEngine itself may not be able to achieve the level of detail needed to match casting methods, the technology can be nonetheless useful for impressed sherd documentation in the near future.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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I dedicate this thesis to those who are survivors of and those who fight against harassment, violence, abuse, and bullying in the field of archaeology and beyond.

#metoo

I tried really hard

But polygons just do not

Replicate the world.

--Nicole Bodenstein, 2020

Chapter 1: Introduction

Perishable items like fabrics represent an important part of the material culture of many prehistoric groups but are under-represented in the archaeological record. Although likely ubiquitous in daily life, poor preservation has led to the absence of fiber perishables in many recovered archaeological assemblages. Cord impressions and markings on pottery represent a proxy for the cordage, netting, or fabrics used to produce the designs preserved on fired ceramics. When present, analysis of these impressions offers an opportunity to greatly increase our knowledge of prehistoric fiber technologies. Traditional methods of analyzing textile impressions on pottery require creating a positive cast of the impressions which is then examined with a low-power microscope and measured with calipers to obtain attribute data on the fabric and/or cords used to create the impressions/markings. In addition to being tedious and time-consuming, this process can be destructive as particles of the sherd surface may adhere to the cast and the casting media may leave unwanted chemical signatures on the sherd. Consequently, this technique is unsuitable for analysis of sherds with friable paste or sherds bearing organic residues due to the possibility of contamination. A potential solution may be the use of 3D scanning devices to produce 3D representation of the impressed surface. 3D scans should be non-destructive and offer the advantage of digital manipulation of the resulting mesh in order to facilitate analysis. In addition, 3D files are easily shared among researchers via the internet. At question in this thesis is whether the scanned images are sufficiently detailed to allow a comprehensive analysis comparable to that possible with traditional casting media. This thesis presents results of a comparative evaluation of a traditional, casting-based method of analyzing cord impressions/markings on pottery and analysis conducted on 3D representations of the same impressions created from a laser scanner. The comparison will evaluate: cost, ease of use

(including time required per sherd), quality of results (determined by comparison of attribute data), damage to the sherds, time required, and permanency of the data.

Fiber perishables are a class of material culture that includes basketry, fabrics, ropes, and other implements made of fibrous materials. The analysis of fiber perishables is important because it can answer questions about food, clothing, art, trade, culture-group participation, social organization, and many other important aspects of life. As Good states, the use of fiber can address all three of the human needs of food, clothing, and shelter (Good 2001) Fiber perishables can be made of bast fibers (obtained from the stems of plants like hemp or nettle), bark, animal sinew, fur, wool, seed fibers like cotton, or other organic fibers. However, fiber perishables in antiquity can be difficult to study because, as the name "fiber perishables" implies, typically do not preserve well under most conditions. Fiber perishables and other perishable materials, like wood or leather, likely made up a major portion of the material culture of prehistoric groups, yet these materials are not often factored into archaeological interpretations. Because of this, Hurcombe refers to this class of material culture as "The Missing Majority" (Hurcombe 2014).

Favorable conditions for fiber preservation include arid environments/desiccation, being charred, submerged in water, contact with metals (pseudomorphs), or being encased in permafrost (King 1978; Peterson 1996; Drooker 2004; Hurcombe 2014). If recovered, fiber perishables must be treated carefully in the field and in the laboratory. A lack of knowledge of the appropriate procedures by the field archaeologist in terms of how to handle fiber perishables adds to the issue of the "tyranny of preservation" (Adovasio 2010). To use the regular field collection strategy of placing an artifact in a paper bag or even an aluminum packet will likely lead to further damage to the fiber perishable, so special procedures, like placing fabric remains

in a rigid box, must be used to best ensure their intactness enroute to the lab (Kuttruff and Strickland-Olsen 2000).

If a depositional environment is not favorable for direct preservation of fibers, indirect evidence may serve as a proxy for the former presence of fiber-based objects. Some of the earliest evidence of fiber perishables comes from indirect evidence, or sometimes the only evidence of a fiber industry is from cord impressed pottery. For instance, impressed pottery from the Gravettian site of Dolní Vestonice I, in the Czech Republic, dated to about 25,000-27,000 B.P. (Soffer, et al. 2001). Other indirect evidence includes a range of tools used in weaving, sewing, and spinning such as spindle whorls (Alt 1999), plummets, eyed needles and awls, matting needles, and other fiber-related tools. In addition, fiber technologies are evidenced by the presence of beads, skeuomorphs (Hurcombe 2014)), depictions of fiber use, plant and animal remains (as possible raw materials for fiber production), and preserved negatives in more durable materials.

Cord markings, cord impressions, and fabric impressions on ceramic containers are the most common kinds of evidence for prehistoric fiber work in the United States. Though some regions, particularly the arid Southwest and Great Basin, have excellent conditions for preservation of perishables (Webster 2006), other regions, like the Midwest, must depend primarily on data gathered from cord and textile impressions on pottery sherds (King 1978). While there are many limitations to the analysis of fabrics and cordage through negatives on pottery (discussed further in Chapter 2), the analysis of markings and impressions can still answer questions about fabric structure and possible function (Drooker 1992), culture-group participation (Minar 1999, 2001), and other questions one might have about the function and place of fabrics (and/or the pottery they're impressed into) in the past. The data gathered from

the impressions or markings is especially potent when combined with the data from pottery analysis or other media (Drooker 2000).

Traditionally, in order to conduct an analysis of these impressions, one makes a positive of the impressions using a plastic media like plasticine, polymer clay, latex, air-dry clay, or even native clay. Positives are necessary because the structure of the fabric or cordage used to impress is generally not very clear in negative form. Indeed, a sherd may initially appear to have single-cord impressions, but in the positive cast it may become clear that the impressions were actually produced by a woven fabric. Additionally, sometimes the impressions or markings are smoothed over, further obfuscating the situation. The negative impressions and markings reverse into positives in the plastic media and can then be measured using calipers, a low-power microscope, and moveable lighting to best show features (Drooker 2000).

In choosing a media for casting negatives in pottery, Drooker states that the primary concerns are the speed and ease of use, quality of reproduction, and potential for shrinkage (Drooker 2000). The present thesis research was additionally concerned with the cost, physical damage to the sherds, damage to conservation treatments, and shareability of the final product. Drooker (Drooker 1992), Minar (Minar 1999), and Rieth (Rieth 2004) used polymer clay products from Sculpey® (Original Sculpey® and Sculpey III®, respectively) to make casts of sherds for analysis. Sculpey® is a polymer clay manufactured by the Polyform Products Company that is inexpensive (~$12 a pound in 2019) and common at many craft stores. While valuable data was gathered from their research, both Minar and Rieth noted that Sculpey® II and III® leaves residue on the sherds (1999, 2004). Original Sculpey® is no different; most polymer clays leech plasticizer and possibly other organic residues into porous objects. “Plasticizer” is an additive used to “impart flexibility, softness, and extensibility to rigid polymers” (Shashoua

2008:59). Organic residue can bias residue analyses and may be difficult to remove. Residue analyses should then occur prior to casting, though both Drooker (Drooker 2000) and Rieth (Rieth 2004) note that this often affects the sample size one can cast for analysis. Additionally, sherds that are friable are especially prone to damage from casting media, and sherds that have noticeable residue (especially on the exterior from overboiling) are not suitable for casting. If one has a very large sample of sherds to cast, then the cost to purchase casting materials even as inexpensive as Sculpey® could be in the hundreds of dollars. Finally, casts made from polymer clays like Sculpey®, must be cured in an oven while monitoring the temperature for a half-hour to one hour per curing cycle. Therefore, it is this thesis's goal to explore another way to obtain an analyzable positive representation of the cord impressions on pottery that does not damage the pottery or its residue.

Archaeologists have recently been exploring 3D technology for a variety of purposes, including virtual reconstruction of artifacts (Rasheed and Nordin 2015), visualization (Means et al. , digitizing collections (Kuzminsky and Gardiner 2012), digital curation (Means, et al. 2013), and morphometric analysis (Selden Jr. 2016). Of particular note, in 2016 Schroeder, Pfaffenroth, Lee, and Taylor presented a paper at the Midwest Archaeological Conference describing use of Structure from Motion (SfM) photogrammetry to create 3D representations of Mississippian textile impressed salt pan sherds. Their method is low-cost and effective but required up to two days of processing time per sherd. However, the method was able to isolate the cordage and produce 3D prints.

The focus of this thesis is to assess the use of a NextEngine 3D laser scanner in the analysis of cord impressions and markings on selected pottery sherds from the University of Wisconsin-Milwaukee Archaeological Research Laboratory (UWM-ARL) collections. The

sample chosen represents a variety of cord impressions including cord-wrapped stick, cord marking, and single cord impressions. In addition, all sherds in the sample possess clear impressions and well-fired, non-friable pastes. The NextEngine is a low-cost laser 3D scanner that comes with its own proprietary software. Its setup and interface are relatively easy to navigate. In macro mode, scans can take ~45 minutes, which is less time-consuming than other methods. The NextEngine is also a portable machine and can be used for a variety of purposes in an archaeology lab. 3D representations are easily shared, and scanning poses less of a physical and chemical risk to the pottery sherds than using casting media. Finally, while one must buy more casting media for as many casts, a single NextEngine can potentially scan hundreds of sherds for the cost of the scanner, a computer, and accessories.

For the present project, sherds were first cast in Original Sculpey® polymer clay and then cured using an inexpensive toaster oven. Attributes were then measured from the casts with calipers. The attributes measured included cord diameter and final twist direction. Cordage and/or textile attributes were then measured using integrated measuring tools in Meshlab, a free, open source software package. Details of the casts were examined under a Dino-lite digital microscope

Thesis Organization

In chapter 2, I discuss previous fabric research and notable changes in methods. I then discuss conservation issues surrounding making casts of prehistoric pottery. Finally, I briefly discuss a variety of archaeological research that utilizes 3D technology.

In chapter 3, I have outlined my methods. I first discuss the NextEngine and the settings used for this project. I then discuss the structured light scanner, the GoMeasure3D HDI R1X,

graciously operated by Dr. Kevin Garstki. Finally, I discuss the method by which I made Original Sculpey® casts and cured them using the toaster oven.

In chapter 4, I evaluate each method used based on cost, ease of use, quality of results (attribute data), and permanency of data. I discuss the results of the attribute analyses. I also discuss issues specific to creating positives of Sherd #7.

In chapter 5, I provide conclusions and recommendations based on the resulys of the present research. Finally, I discuss Reflectance Transformation Imaging (RTI) as a method of documentation for future research.

In Appendix A, I have defined terms that are used throughout this thesis, for the sake of clarity.

Chapter 2: Analysis of Archaeological Fabrics: A Historical Review

Early fabric research focused on description and grouping observed differences, though some experiment did occur. Holmes brought attention to the study of cordage and fabric impressions on pottery of the United States in a report to the Bureau of Ethnology in 1884. Holmes thought markings and impressions were as good as having the fabric or cordage in hand, which in later literature is not a shared sentiment. In any case, Holmes was among the first to approach the study of Native American prehistoric fabrics through impressions on pottery. Holmes made positives of the sherds he examined (Figure 2.1) and took photos of the sherds alongside their positives. Holmes doesn't state what kind of clay he used. Holmes was among the first to refute the notion that cord marked/impressed pottery was from basket or fabric molds (Miner 1936). The approach he takes to study the impressions is like that taken much later by Hurley (Hurley 1979) in that both strove to recreate the original structure of the textiles. Holmes did not do the re-creations himself; Instead, Kate C. Osgood recreated a variety of textiles observed by Holmes using cotton cordage. Since the recreated textiles could not be committed to paper, diagrammatic illustrations of the textiles and proposed weaving methods were drawn. Holmes did establish that one can learn much from impressions on pottery, that making positives is worthwhile, that sacrificial bags or baskets were not fired with the vessels, and he established the connection between pottery and fiber perishables. Holmes does not discuss the kind of clay that was used to make positive casts, nor the impact that it may have had on the original sherds. In 1901, Holmes elaborated more on cordmarked pottery and further denounced the notion that baskets or bags were commonly used as molds. Holmes also re-created a cord-marked bowl (Figure 2.3) and compared it to a cord-marked bowl from a North Carolina mound (Figure 2.2).

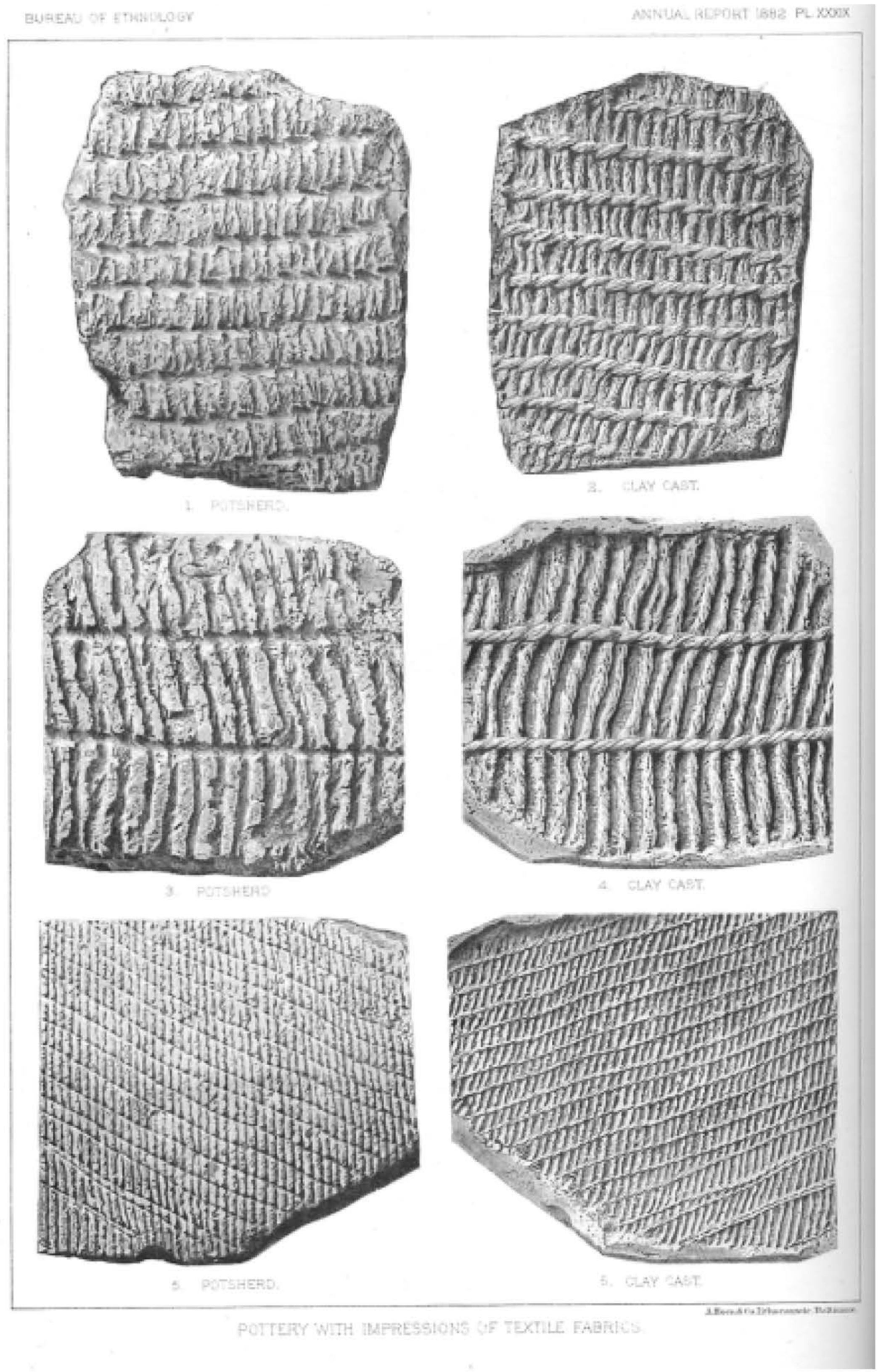

Figure 2.1. Casts of cord impressed pottery produced by Holmes (Holmes 1884)

Figure 2.2. Bowl from North Carolina mound (Holmes 1901)

Figure 2.3 Holmes's recreation of North Carolina mound bowl (Holmes 1901)

Mason produced two volumes on basketry in 1904 (Mason 1988), in which he asserted that basketry was the precursor to the loom and other textile arts. He also asserted that women were the ones mostly responsible for basket weaving, meaning that he felt the fiber industry first came forth from women's hands. He was among the first to suggest this division of labor. He placed basketry as the precursor to later technologies such as the loom. In his analysis, there are two main types of baskets: hand-woven basketry (which he considered to be the precursor to later loom weaving) and coiled basketry (which he considered the precursor to sewing). In 1894,

Mason asserted that raw fiber materials were always best utilized by women of any culture or class. He also noted the resilience of the fiber arts among women, as well as the high intelligence the “savage” or “primitive” woman must have had to be able to make such elaborate baskets with the variety of materials available across the globe. Of note, he states that basketry requires a certain grasp of number and geometry (Mason 1927)—something that modern fiber artists must know through having to count rows and stitches in knitting, crochet, and other fiber arts in order to create certain shapes, patterns, and/or textures in their work.

Miner (Miner 1936) studied prehistoric fabrics from the eastern United States. Miner was able to demonstrate that differences in technique inherent in fabrics can denote differences in culture. As far as impressions and markings on pottery, Miner called them “actual positive duplicates” but then noted that cord markings can be easily confused with fabric or single cord impressions (Miner 1936). Additionally, Miner added that one might not be able to match an impression of fabric with a specific technique (1936:183), thus Miner was one of the first researchers to note that observing the positive of a negative impression would not be the same as observing the actual fabric. Miner noted this as an issue, as well as the lack of consistent terminology used by researchers working with fiber perishables in the Eastern U.S. Miner was also discussed the significance of S and Z twists and attributed variation in distribution of he trait to “culturally determined habits of work” (1936:189), rather than handedness or other factors. He also demonstrated the importance of measuring attributes, or “textile dimensions” by comparing the diameter of twined elements from the Central Basin with twined fabrics from elsewhere (1936:190).

Hall published a seminal study of Woodland pottery from Wisconsin (Hall 1950). Hall’s goal was to conduct a style-based analysis of Woodland pottery focusing on variation in cord

impressions. The analysis was then used to define three broad, style trends with both geographic and temporal significance. The styles he discusses are the pseudo-cord style, incised over cord-marked (Hall 1950), and a cord-decorated style. Hall examined various collections and focused only on the styles, rather than the pastes or "types" of pottery. None of the cords he examined had three strands; they were all 2 or 4 ply (Hall 1950). Hall used plasticine to make his positives.

Carol Rachlin (Rachlin 1955) pioneered the "rubber mold technic" using latex to create a mold of the surface of ceramic sherds. Latex has a relatively low viscosity, settles easily into surface irregularities and thus creates finely detailed molds. However, Rachlin states that the process can take two weeks to create a completed mold, including drying times between applications of layers of latex. When finished, the mold needs to be cleaned and trimmed. She makes no mention of any particles that have been removed from the sherd. She then submerges the molds in kerosene, which enlarges the cast. The cast must be turned regularly to ensure even stretching. This is perhaps the first instance of a researcher discussing methods of enlarging the view or cast to be able to get a look at the finer details contained within the cast. While latex molds last longer than the immediacy of a plasticine cast, the stretching and enlarging process the molds do not possess the original dimensions and cannot be used for measurements. Rachlin made plaster casts of the stretched rubber mold.

In 1966, Irene Emery published a comparative analysis of archaeological textiles that implemented a standard way of discussing fibers, yarn, and fabric (Emery 2009). Previously, archaeologists had been using many different terms (and still do sometimes), which creates issues when one is looking for keywords and correlates in other people's research. For example, Holmes thought twining was a kind of knotting, though the structure he was describing was not "knotting" as it is usually defined. Emery's book has since become a critical reference in fiber

perishables analysis, effectively standardizing the way we discuss cords (or yarns—see Appendix A for glossary of terms used in this thesis) and fabrics.

Hurley (Hurley 1975) expanded the scope of cordage analysis in his monograph on the Sanders and Bigelow effigy mound sites. He discussed the “form, construction, and spatial-temporal significance of the cord-marking” (1975:85) as part of his larger study of the Bigelow and Saunders sites, supplementing lithic and other analyses. He established ten different kinds of fabric impressions that appear on varieties of the Madison Fabric Impressed type. One of his goals, when looking at the impressed pottery, was to divine the fabric that created the impression. Hurley rejected describing the final twist of the cordage as “clockwise” or “counter-clockwise”, and instead describe the levels of spin, twist, and ply in the cords using letter pyramids (see Fig. 2.4). While the letter pyramids made for awkward line spacing in his monograph, they clarified the structure of the cordage he described. Further, he also included “unraveled” views of the cordage, like an exploded diagrammatic view (Fig. 2.4). Hurley used plasticine to make his positives but provides no discussion of his method. He incorporated Emery’s terminology to describe ten sub-categories of the Madison Fabric Impressed type. Descriptions of these fabrics include their orientation as compared to the lip of the vessel, so oblique-twined fabrics may have been regular twined fabrics, rotated a bit, then impressed. This monograph, and Hurley’s sub-types, are still used today as a reference for cord-impressed pottery from Wisconsin.

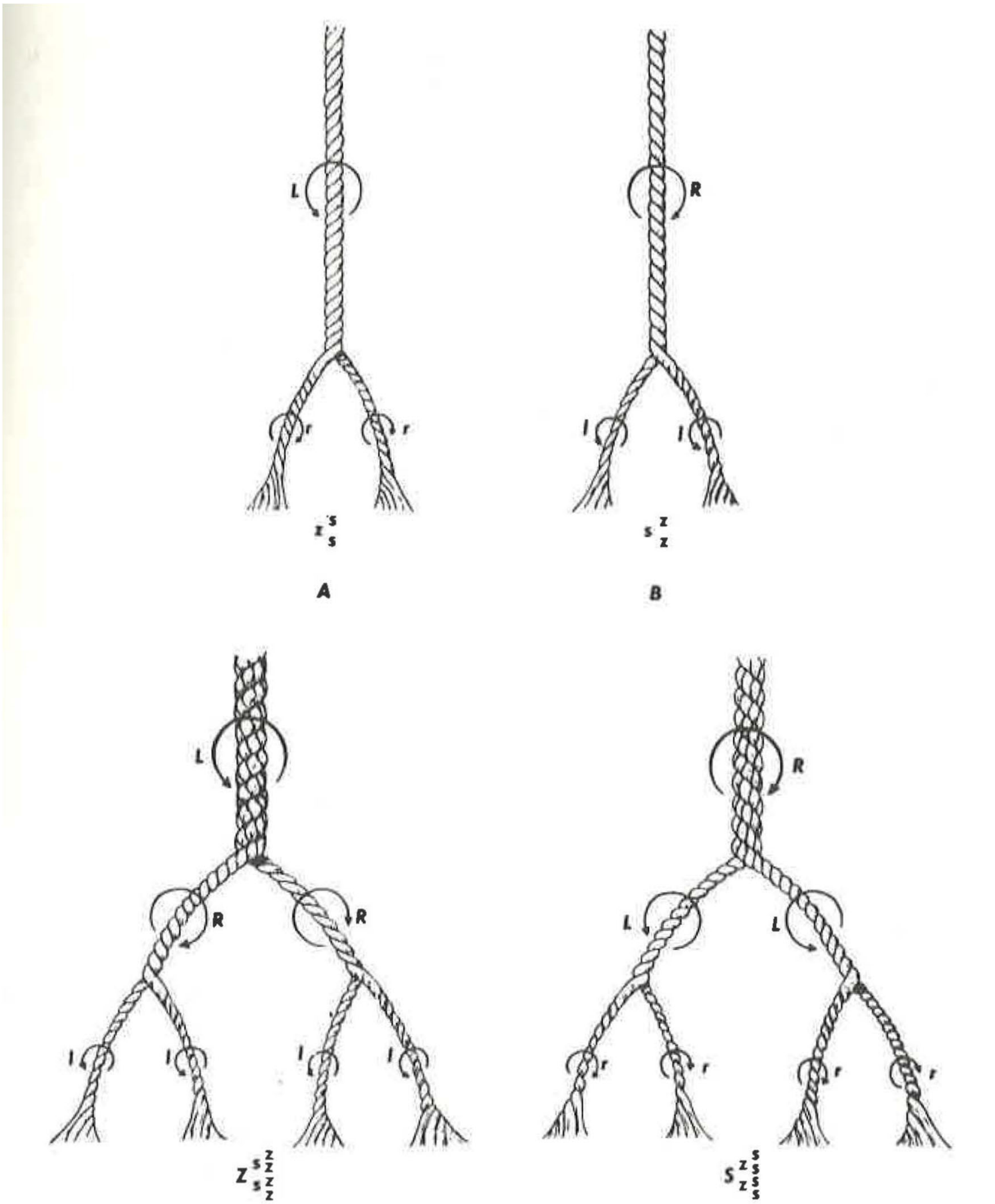

Figure 2.4. Hurley's descriptive S/Z pyramids (Hurley 1975)

Adovasio's *Basketry Technology*, has become a critical reference guide for the study, identification, and analysis of baskets and related objects (like grass-woven sandals) (Adovasio 2010). He discusses the antiquity of basketry, the literature until 1977 (though he expands on this

in the 2010 updated edition to account for 35 more years of fiber perishable research), and proper lab and field procedures to maximize recovery and conservation. In addition, Adovasio provides information on various structures of baskets, how to measure attributes, and sample attribute sheets. Basketry is sometimes found as impressions on clay, so he discusses how one can use "modelling clay" (plasticine), latex, or plaster of paris to make a positive. Of note, though, Adovasio stated "Consolidating the surface of the impression before casting minimizes the adsorption of extraneous materials by the casting medium and facilitates separation of the cast from the impression" (Adovasio 2010).

In 1978, King published an article that discussed the methodology and theory of analyzing prehistoric textiles. Since much of what was known about fabrics were from impressions rather than the fabric itself, King discussed the limitations of this approach. She provided thirteen instances of how impressions are limited. While all were important considerations, some were more obvious (such as that textile color cannot be distinguished), while others had not been considered in previous publication. King does not discuss casting techniques or conservation issues. These are all important considerations when making casts. It should be noted that Drooker was able to distinguish individual fibers in casts and, if very clear, to distinguish plant from animal fiber (Drooker 2000).

Hurley's 1979 monograph *Prehistoric Cordage* is essential for the study and identification of cord impressions. It was written as a "cookbook", in that Hurley intended it to be used as a resource to help determine how an impression was created. The book contains illustrations of many kinds of cord and cord-wrapped stick impressions, both rolled across the surface of clay and singly impressed. Then, based on impressions on Wisconsin pottery, Hurley illustrates fabric types in exploded views (Hurley 1979). Hurley elaborates on issues involving

studying fabrics from impressions on pottery. First, the impressions are delicate and are easily compromised by erosion of the surface. Details can easily be lost as particles are removed from the surface of the sherd. Second, "idiosyncratic elaborations or embellishments increase the number and variety of possible executions of a technique", which also means that there is a variety of techniques one could employ to accomplish the same fabric impression. Third, if a fabric has unequal cordage diameters, then sometimes only the thicker cords are seen (Hurley 1979). Hurley notes also that "Identification of the techniques is hampered by inability to examine the other surface of the fabric for knots or structural features" (Hurley 1979). His illustrations (see Fig. 2.5), therefore, have an element of educated conjecture, due to many of the issues brought up by King (King 1978).

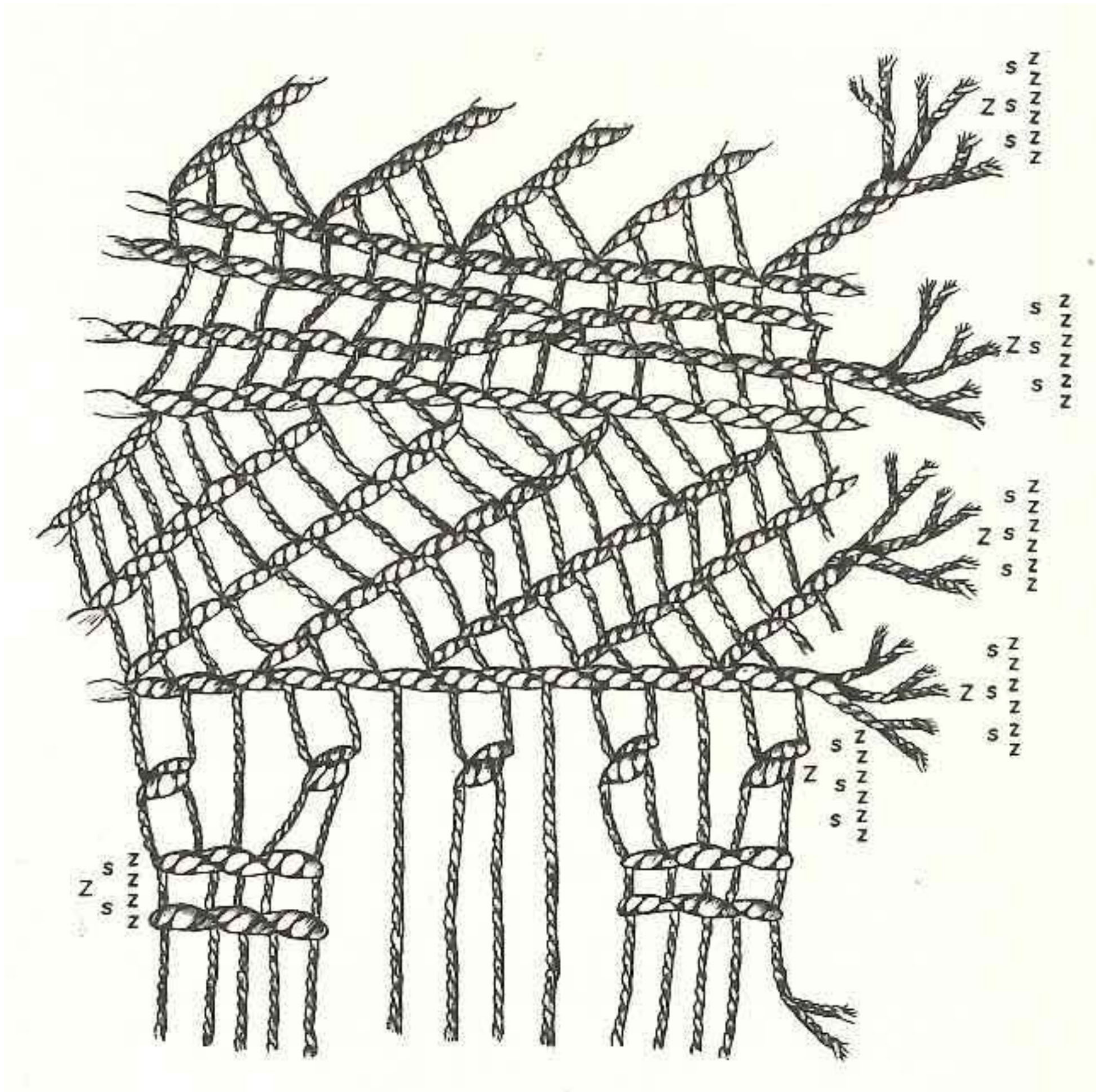

Figure 2.5. Fabric 30 (Hurley 1979:119)

These factors show how limiting studying fabrics from impressions can be (King 1978), but it does not make their study pointless. Hurley’s fourth and fifth points suggest that the person who is studying the fabric impressions should have a good understanding of fabric structures, but I would add that personal experiment with fibers and testing the various iterations of fabrics for impression would also be helpful.

In 1988, Kuttruff examined Caddo textiles and developed a metric measure called the "textile production complexity index" to interpret status from the textiles. Kuttruff analyzed actual fabrics, rather than impressions, so many of the attributes she measured (like coloration and charring) are not applicable to most archaeological fabric samples, but see Johnsen 2003 for a discussion of the use of this index with charred textiles. Kuttruff was among the first to apply a statistical analysis to the study of fabric and cordage attributes. This built a foundation for others to be able to measure the differences in the fabrics they observed and then analyze the results.

In 1992, Drooker published a dissertation on Mississippian village textiles at the Wickliffe Mounds site in Kentucky. Drooker's analysis relied on Original Sculpey® to make casts of Mississippian salt pans marked with fabric impressions. Drooker describes Sculpey® as providing a "fine-grained" impression (Drooker 1992). Sherds with a fine layer of dirt still adhered to the surface allowed for cast removal, though if too clean, sherds were dusted with talcum powder. For measurements, she employed a "6x comparator with a reticle scale graduated to 0.1 millimeter" (1992:252). To aid in visibility, she used a manipulable light source, which is critical for highlighting textures. Finally, she notes that while she did have the positives, she would examine and measure the positives while the original sherds were present.

Most fiber perishable research had focused on structure and description when Jakes, Sibley, and Yerkes presented their research on creation of a comparative fiber collection (Jakes, et al. 1994). A comparative collection allows one to identify the fibers found archaeologically and obtain a sense of the difficulty of processing those fibers. The Jakes et al. study included over 800 fiber samples that were tested for their strength and pliability. Such a comparative collection had not been present before this study, and it allows one to be able to better identify archaeological fibers under a microscope. This allowed researchers to make connections between

the natural environment and the people who lived in it by knowing what resources they were using to make cordage and fabrics.

Peterson's edited volume, *A Most Indispenable Art* (Peterson 1996), is a sourcebook for the study of fiber perishables east of the Rockies. Most of the contributing authors using casting as part of their research only briefly mention what casting materials were used. However, Maslowski reported using latex or plasticine to make casts of impressed sherds (Peterson 1996). Peterson used plasticine and silicone, though Hamilton, Peterson, and McPherron report using plasticine and Dow Corning 3110 RTV silicon rubber catalyzed with Dow Corning RTV Catalyst (Peterson 1996). These authors used Helios needle-nosed dial calipers to take measurements.

Minar (Minar 1999) examined cord-impressed pottery of the Alachua, a Late Woodland group located in north central Florida. Minar analyzed attribute data from a variety of sites in the Alachua region to investigate Alachua origins. Minar used Sculpey® II (which is no longer produced by Sculpey®) to make casts. This is one of the few instances, in addition to Rachlin (Rachlin 1955) and Drooker (Drooker 1992), where the casting method is discussed at length. Minar's methodological discussion is thorough. His reasons for choosing Sculpey® II include it being "inexpensive, readily available, easy to use, and can be baked to produce a permanent record of impressions for future comparisons" (Alt 1999). Regarding the casting process, Minar included details about avoiding accidental impressions from other than the sherd, avoiding distortion of the cast, and also mentioned that talc or cornstarch was used to protect the sherd and aid in the mold release. Finally, the biggest issue that Minar discovered when using Sculpey® II was that radiocarbon dating or residue analysis was not possible after a sherd had come into

contact with Sculpey® II. Later scholars (Drooker 2000, Rieth 2004) cite this issue as a reason to only cast a sample of the collection.

Beyond Cloth and Cordage, edited by Drooker and Webster (Drooker and Webster 2000), is a crucial volume for the study of textile research in the Americas The chapters bring the many different perspectives of fiber perishable research into one tome, though unlike Peterson's edited volume (Peterson 1996), *Beyond Cloth and Cordage* includes chapters discussing fiber perishable research conducted throughout the Americas (for New Mexico see Hyland and Advovasio; for Chile see Rodman). Of note is the chapter by Kuttruff and Strickland-Olsen that establishes best practices for maximizing fabric preservation during the archaeological process, something for which most field archaeologists lacked a resource. In Chapter 3, Jakes discusses how to study the fiber itself through microanalytical techniques, something that aids in the identification of the fiber.

Drooker synthesized research focused on studying fabric impressions in pottery (Drooker 2000). This summary discusses common methods and theory, issues other researchers must be aware of, and provides examples of research that utilizes the data from impressions in pottery. Drooker notes that, rarely, one can even see individual fibers, and distinguish a plant fiber from an animal fiber (Drooker 2000). As Hutcheson (2000; as cited in Drooker 2000) notes, the pottery would have shrunk during the firing process, so the measurements taken from the sherd will never have the same measurements as the fabric. Additionally, different clay compositions, firing techniques, and firing conditions have different shrinkage rates, so it is possible that the dimension of the impressions and markings might differ in the same batch of fired pottery, even if they come from the same cords or fabrics.

Johnsen wrote a thesis on textile remains from the Aztalan site (Johnsen 2003). Johnsen had three goals in the analysis of these fabrics from a burial context at Aztalan: description and typing, determing the minimum number of fabrics, and then to interpret how these fabrics were used and the cultural relationships as compared to other fabrics from elsewhere. As in Kuttruff's Textile Complexity Index (Kuttruff 1988), similar attributes were measured with digital calipers and the data was analyzed using statistical software. Modifications on this Index were made based on the fabrics. For instance, color was not quantified, as the fabrics varied in color based on postdepositional processes (Johnsen 2003). The yarns used to make the fabrics were predominately final 2-ply S twist with a base Z spin. While a few yarns were Z twist, S spun, it was hypothesized that these represented separate fabrics, as both final twists were not found in the same sample (2003:95). It is possible that this small sample of Z twist, S spun represents a different community of practice than those who made the rest of the fabrics at Aztalan, following Minar's research (Minar 2001). The Textile Complexity Index for this sample from Aztalan was then compared with Indices form Spiro Mounds, Ozark Bluff, and Wickliffe. Additionally, the author made regional comparisons with other sites in the Great Lakes region. The fabrics and mats at Aztalan were found to be mostly functional in nature. Johnsen suggested further research into the Late Woodland pottery at Aztalan, as well as at Cahokia to further examine relationships between these sites and their components.

Based on methodological tools like the Textile Complexity Index and modified versions of it (ie. Drooker 1992) as well as the theories established for the interpretation of fiber perishables (like the conservation of twist), Johnsen and other researchers (ie. Thompson 2003, Pappas 2008, Rieth 2004, and others) have been able to move beyond the description of fabrics

and cordage and towards interpretations of function and style, complexity, and inter- and intra-site comparisons.

In 2009, Karroll analyzed the Swennes nettle bag found in La Crosse County, Wisconsin for a Bachelor's Thesis project. The bag is made of nettle fiber and Karroll has characterized its woven structure as "Open 2 Strand S-Twist Alternate Pair Weft-Twining", and it is possibly of the Oneota tradition (Karol 2009). A preserved textile like this bag is rare in Wisconsin because of poor preservation conditions; the bag was found in a rockshelter in La Crosse county (Thompson 2003). Karroll created a partial reconstruction of the bag in order to investigate the bag's construction. Based on the reported recovery context as well as a comparative analysis of archaeological and ethnographic examples, Karroll concluded that the bag may date to the Oneota cultural period in western Wisconsin

Hutcheson's work on basket impressed pottery from the Bahamas required a casting material that was portable, lightweight, and easy to use. Additionally, the sherds did not leave the Bahamas. Hutcheson used Jeltrate Plus Fast Set, an alginate, to cast the sherds. The powder could be mixed with water on site, then the sherds can be casted. Then, Vel-Mix dental stone is poured into the alginate molds to represent the sherds. Like Sculpey® and other casting media, Hutcheson reported that alginates also can leave unwanted surface resides (Hutcheson 2011).

Archaeological Use of 3D Technology

The use of 3D technology in archaeology has resulted in many new ways of documenting, visualizing, reconstructing, analyzing, and sharing data about the past. However, it is important to realize that these technologies are co-opted (Garstki 2016), and their successful use depends on many things. This discussion is meant to give a brief overview of the

applications of 3D technology to cultural resources, issues and warnings, a brief overview of how scanning can be used with pottery, and then a brief view into efforts in scanning fabrics.

A task such as 3D digitization of a collection represents a surprising amount of choices and each of those choices requires one to understand how the technology works. It can be so complex that Budak et al. developed a system for cultural professionals selecting a digitization method (Budak, et al. 2019). Their selection process includes common considerations as the reflectivity of the material, dimensions, geometric complexity, visual texture, accessibility of the material, and mobility (2019:1).

Tocheri wrote a chapter about laser scanning for biological surfaces, though the conclusions are easily applicable to any archaeologist interested in 3D scanning (Tocheri 2009). This chapter delineates the common frustrations and concerns one might encounter. For instance, Tocheri felt that measurements taken from the real object were preferable, as 3D models are an approximation of the object (2009:89). The precision of the approximations produced are dependent on the laser scanner, the software, the algorithms, and the user's expertise at each step (2009:94). But scanning can preserve the integrity of the original object by reducing how much that original object is manipulated. Preserving that integrity is even more possible with laser scanners that have automatic turntables or scanners that swivel around the stationary object. 3D meshes (which are the collection of points, vertices, and faces created by 3D software that represent the "approximation" of the object) are easily manipulated and one can simulate a variety of lighting conditions within the visualization program (like Meshlab). Finally, through Tocheri's personal experience completing a dissertation that used laser scanning, it is noted that if one wishes to use a laser scanner (or any 3D scanner) for their research project, one needs to expect to dedicate a "significant portion of research time" into being an expert at it. This includes

understanding file type differences, experimenting with different post-scanning visualization programs to work with the meshes, and knowing how the scanning software created the approximation that it did.

Garstki suggests that 3D scans of objects are more accurately viewed as "virtual representations", rather than true copies. This terminology is echoed in other literature, and it is also used here. This concept is very similar to Tocheri's use of "approximation" (Tocheri 2009). The distinction is important. As digitization efforts continue, the cultural resource professional must remember that these representations do not take the place of the original. Just like with photography, one must consider the various factors that lead to how the representation is.

The Virtual Curation Laboratory (VCL) at Virginia Commonwealth University uses the NextEngine scanner to scan a variety of archaeological objects (Means, et al. 2013). Objects that have been scanned can then also be 3D printed so that both images and printed objects can be shared in the world. For instance, at the 2018 Society for American Archaeology meeting in Washington D.C., Means was handing out Venus of Willendorf figurines that were printed in an extrusion-type printer. They were pocket-sized and made excellent souvenirs by which to remember the conference. The VCL also maintains what they call "virtual archaeological collections" of the cultural material they have scanned from a variety of contexts (2013:1). Some of what they have scanned is available to view and/or download at https://sketchfab.com/virtualcurationlab. 3D prints were also used for public interpretation purposes, as well as for museum exhibits. Object representations can also be loaded onto a tablet and used for interpretation. The representations and prints then serve as an avatar for the actual object in education, interpretation, and even analysis, thus aiding in preservation of the original (2013).

Counts, Averett, and Garstki used a custom structured light scanner setup in an effort to create a 3D digital repository to examine materials from the Athienou-*Malloura* site on Cyprus (Counts, et al. 2016). Much of the very large collection is fragmentary, been repurposed, or removed from the original context, and the authors had limited access to the collection which is held at the Larnaka District Archaeological Museum in Cyprus. The authors' scanning solution allowed 3D representations to take the place of actual on-site analysis.

Garstki, Schulenberg, and Cook used Structure from Motion (SfM) photogrammetry to document excavations at the Guard site (12D29) in Indiana (Garstki, et al. 2018). They took a minimum of 32 photos for each model and processed them in AgiSoft's PhotoScan. They were able to georeference the 3D models in Esri ArcMap and create orthophotos of plans and profiles of excavation units. The extra photos did not take long in the field, and a regular DSLR camera was used as well as a phone camera.

Kuzminsky and Gardiner discussed the uses of laser scanners, including the NextEngine, in the digitization and conservation of human skeletal collections in museums (Kuzminsky and Gardiner 2012). While 3D scanning creates a representation of the object, it provides enough information to conduct morphometric analysis. This means that skeletal material, a particularly fragile object class, does not have to be repeatedly handled to obtain measurements. Skeletal material may be housed in such a way that it requires one to disturb other skeletal material in order to obtain the object one needs, so if one can reduce the amount that all skeletal material is disturbed, that is preferable. However, many files produced by the Next Engine, especially using the highest resolution setting (HD), were larger than1 gigabyte. They reported that a cranium scanned at the highest setting produced a file that was 6 gigabytes (Kuzminsky and Gardiner

2012). The color capture can be turned off in order to reduce the size as well as compressing the file.

In 2015, White wrote about the NextEngine for *Archaeology International* and the potential it bore for archaeological use. For instance, geometric morphometrics was expanding in use at the time, and having 3D scans of multiple artifacts would be beneficial for mass analysis. One limitation White mentioned is that the NextEngine cannot scan small, flat objects like coins, something with which Means also reported having issues (2019, Personal Communication).

An early example of computer-aided textile analysis is the work by Cork, Cooke, and Wild (Cork, et al. 1996). The Cork et al. study used a video microscope to create magnified images of the weave of the textiles (1996:338). The images were then manipulated using an algorithm in an image analysis software in order to emphasize the angle of twist visible in the imaged samples. This allowed a reduction in how much the textiles were handled during analysis.

A very similar effort to the project at hand was conducted by Schroeder, Pfaffenroth, Lee, and Taylor at the University of Wisconsin-Madison, who presented their work at the 2016 Annual Meeting of the Midwestern Archaeological Conference in Iowa City, IA. Schroeder et al. (Schroeder, et al. 2016) used Structure from Motion (SfM) photogrammetry to record cord impressions on pottery. There results suggested that this method is inexpensive compared to the NextEngine and requires the use of equipment most are already familiar with—a lazy susan, a laptop, and a DSLR camera. Other 3D scanning methods, like laser-triangulation or structured light, require special equipment or setups. While resolution is adequate for analysis, a single scan may take more than 48 hours reducing the cost-effectiveness of the method.

Chapter 3: Methods

Sample

Seven sherds were selected from the University of Wisconsin-Milwaukee Archaeological Research Laboratory (UWM-ARL) collection. Sherds chosen include six rimsherds and one bodysherd. For the purposes of this study, the sherds were arbitrarily numbered 1-7 (see Figs. 3.2-3.8 for sherds). A variety of sizes, kinds of cord impressions (cord-marking as a surface treatment and cord-impressions as a decoration are included in the sample). All sherds exhibited well-fired pastes. No sherds in the collection were of a friable quality. Sherds 1, 3, 6, 5, and 4 are from 1966 UWM excavations at the Cahokia site in southern Illinois (11MS2). Sherd 2 is from the Thompsen Village site (11CA0010) in Northern Illinois. Finally, Sherd 7 is from the Point Sauble site in northeast Wisconsin (47BR0101) and was given to Dr. John Richards by Robert Hall.

. Each sherd was photographed using a Nikon D5200 DSLR camera. Four lights surround the camera setup in UWM's ARL darkroom. Multiple lighting configurations were used for each sherd to help illustrate the cordage impressions. The photos that showed the best detail were chosen.

Sherd 1 (Fig. 3.1) is from the UWM-ARL type collection, catalogue # 66-571. It is from the Cahokia site (11MS2). Type is Kane Cordmarked (Vogel 1975:70). It is a round sided bowl. The paste is earthenware tempered with limestone. It has a direct rim and flat lip. The exterior surface is completely cordmarked while the interior surface is smoothed. This sherd is undecorated throughout.

Figure 3.1. Sherd 1. Kane Cordmarked rimsherd, limestone temper, interior shown to left, orifice dia. approximately 20 cm. Sherd represents approximately 12% of the vessel orifice.

Sherd 2 (Fig. 3.2) is part of the UWM-ARL type collection, catalogue #F-74 Ca-10. It is from the Thomsen Village site (11CA10). It is a rimsherd of a bowl. Pottery type is Naples Stamped, variation Dentate (Griffin 1952). Earthenware paste with grit temper. The interior is smoothed. The interior lip margin possesses perpendicular stick impressions. Lip is undecorated and flat. Exterior surface is cordmarked. Exterior decoration has punctates 2 cm below lip, as well as parallel dentate impressions 3.5-5.5 cm below the lip.

Figure 3.2 . Sherd 2. Naples Stamped; var. Dentate rimsherd, grit temper, interior shown to right, orifice dia. approximately 9 cm. Sherd represents approximately 12% of the vessel orifice

Sherd 3 (Fig. 3.3) is part of the UWM-ARL type collection. Provenience is unknown. It is a rim sherd of a jar, possibly of the Aztalan Collared type (Howell 2001, Baerris and Freeman 1958). Grit tempered earthenware. Smoothed interior. Lip contains cord-wrapped stick impressions. Exterior is totally cordmarked. No exterior decoration.

Figure 3.3. Sherd 3. cf. Aztalan Collared, interior shown to right, orifice dia. approximately 8 cm. Sherd represents approximately 6% of the vessel orifice

Sherd 4 (Fig. 3.4) is part of the UWM-ARL type collection, catalogue # 66-69/3. It is from the Cahokia site (11MS2). It is a rim sherd of a jar of the Cahokia Cordmarked type (Vogel 1975:96).. It is an earthenware tempered with shell. The interior is smoothed. The lip is rounded, and it has an everted rim. The exterior is cordmarked throughout. No exterior decoration present.

Figure 3.4. Sherd 4. Cahokia Cordmarked rimsherd, shell temper, interior shown to right, orifice dia. approximately 15 cm. Sherd represents approximately 9% of the vessel orifice.

Sherd 5 is from the UWM-ARL type collection, catalogue # 66-601/12. It is from the Cahokia site (11MS2). It is a rim sherd of a jar. The pottery type is Loyd Cordmarked (Vogel 1975:113-114). It is an earthenware past with grog temper. The interior is smoothed. The lip is direct with a flattened lip. The exterior surface is smoothed to 7cm below the lip, then cordmarked. No exterior or interior decoration.

Figure 3.5. Sherd 5. Loyd Cordmarked rimsherd, grog temper, interior shown to right, orifice dia. approximately 10 cm. Sherd represents approximately 5% of the vessel orifice.

Sherd 6 (Fig 3.6) is from the UWM-ARL type collection, catalogue # 66-463/11. It is from the Cahokia site (11MS2). It is a body sherd from a jar. Pottery type is Bluff jar (Vogel 1975:80-87). The interior surface is smoothed. The exterior surface has a zone of about ~2cm that is smoothed, the rest is cordmarked.

Figure 3.6. Sherd 6. Bluff jar body sherd, grit temper, orientation unknown.

Sherd 7 (Fig. 3.7) is a rimsherd from a jar of the type Point Sauble Collared (Baerreis and Freeman 1958). Paste is grit-tempered with large inclusions of a dark mineral, possibly gabbro. Interior surfaces are smoothed with exception of the upper interior rim margin which is decorated with roughly vertical cord impressions extending down from the rounded lip approximately 1.5 cm. The exterior surface is heavily decorated with twisted cord impressions applied over a cord-roughened surface. Collar decoration consists of opposing sets of diagonal single cord impressions arranged in parallel rows. The cord impressions extend from the lip downwards over the exterior surface of the collar. Below the collar, a 4 cm wide band of single cord impressions is arranged as opposing diagonals. The juncture of each opposing set of

diagonals is marked by tooled stamps arranged so as to suggest a running series of triangles filled with parallel rows of single cord impressions. Below this band, a series of 1 cm wide corded stamps are arranged in vertical columns that appear to continue around the vessel's circumference. Final twist of visible cordage appears to be a Z-twist.

Figure 3.7. Sherd 7. Fabric-imressed rimsherd, grit temper, interior shown to right, orifice dia. approximately 10 cm,. Sherd Represents approximately 2.5% of the vessel orifice.

Two different 3D scanners were employed in this research: a NextEngine and a GoMeasure3D HDI Advance R1X. The NextEngine is a multistripe laser scanner that uses laser triangulation to create a 3D image of the scanned object. The GoMeasure is a structured light scanner that uses digital photogrammetry to create a model of the scanned object.

Slizewski and Semal reviewed three 3D scanning methods, including the NextEngine, for use at the Neanderthal Museum (Slizewski and Semal 2009). They compiled a table (Figure 3.9) comparing different methods of 3D scanning, which is useful for other researchers looking into scanning options. However, it is important to note that the information contained within is already eleven years old at the time of the completion of this thesis.

	Structured Light		Structured Light Laser	Laser		Multi Laser	
Company	Breuckmann	Breuckmann	DEIOS	Descam	Descam	Nextengine HD	Nextengine HD
Model	OptoTop-HE	smartSCAN 3D	Prototype	Model Maker Z35	Microscribe / RSI	Scanstudio HD	Scanstudio HD PRO
Self-calibration	no	no	yes	yes	yes	yes	yes
automatic scan	yes	yes	no	no	no	yes	yes
Texture					yes		
Gray	yes	yes	yes	yes	yes	yes	yes
RGB	yes	yes	yes (recomposed)	yes	yes	yes	yes
Filtered	yes (optional)	yes (optional)	yes (each 10 nm)	no	no	yes	Yes (7 values)
Resolution							
Camera	5 Mp colour	1.4 Mp colour	1 Mp mono-chrome	CCD		CMOS 3.0 Mp colour	CMOS 3.0 Mp colour
Accuracy (µm)	+/- 5 µm bis 100 µm	+/- 10 bis 50 µm		+/- 18 µm bis 148 µm	+/- 200 µm	+/- 120 µm bis 360 µm	+/- 120 µm bis 360 µm
Min. depth resolution	2 µm	2 µm					
Acquisition Time	1 sec	1 sec	10 sec	23000 points/sec	28000 points/sec	35 - 150 sec	15 - 105 sec
Mode Small							
Field of View	60 mm diag.	90 mm diag.	50 mm diag.	35 mm stripe		180 mm diag.	180 mm diag.
Max. resolution	15 µm	50 µm	50 µm	25 µm	100 µm	120 µm (0,05 inch)	60 µm (0,0025 inch)
Speed at max. resolution	1 sec	1 sec	10 sec	23000 points/sec	28000 points/sec	150 sec	105 sec
Mode Medium							
Field of View	600 mm	300 mm	225 mm	70 mm stripe	100 µm	200 mm diag.	200 mm diag.
Resolution	200 µm	180 µm	225 µm	50 µm	28000 points/sec	130 µm (0.005 inch)	130 µm (0.005 inch)
Speed	1 sec	1 sec	10 sec	23000 points/sec		150 sec	105 sec
Mode Large					100 µm		
Field of View	1500 mm diag	600 mm diag.	600 mm diag.	140 mm stripe	28000 points/sec	350 mm diag.	800 mm diag.
Resolution	500 µm	360 µm	600 µm	100 µm		190 µm	380 µm
Speed	1 sec	1 sec	10 sec	23000 points/sec		150 sec	105 sec
Accessories							
Rotating Plate	yes, but not included	yes, but not included	no	no	no	yes	yes
Measurement arm	robot (optional)	robot (optional)	--	7 axes arm	7 axes arm	--	--
Software included	OPTOCAT	OPTOCAT	--	Kube	Muse	ScanStudio HD	ScanStudio HD Pro
3D alignment	yes	yes	yes	yes	yes	yes	yes
3D post processing	yes	yes	no	yes	yes	yes	yes
export	STL, PLY, VRML	STL, PLY, VRML	OBJ	STL, ASCII, IGES	STL, ASCII, IGES	STL, PLY, OBJ, VRLM	STL, PLY, OBJ, VRLM
import	STL, PLY, VRML	STL, PLY, VRML	OBJ	STL, ASCII, IGES	STL, ASCII, IGES	STL, PLY, OBJ, VRLM	STL, PLY, OBJ, VRLM
max triangles	100 Mio	100 Mio	unknown	unknown	unknown	4 Mio	4 Mio
Price	about 80000 €	about 50000 €	100000 € (not yet available)	about 93000 €	about 26000 €	about 2300 €	about 3100 €

Figure 3.8. Comparative data on various scanners from Slizewski and Semal (Slizewski and Semal 2009)

Conservation

According to Sease (Sease 1994) in order to reduce mechanical damage to sherds, it would be best to consolidate the entire surface of a cord marked or impressed sherd before

committing to any casting. Consolidation is the process of how fragile materials are joined and strengthened by adding a foreign substance (1994:27). This foreign substance must be a good adhesive, durable, stable, and reversible. PVA resin or Acryloid B-72 (or Paraloid B-72 in the UK) are good consolidants for a variety of materials. One creates a low-percentage emulsion of these materials in acetone or toluene and applies it with a brush or dropper to the object in need of consolidation. Once that dries, a slightly higher percentage emulsion can then be applied, and then also allowed to dry. Higher percentages are applied until the object is stable enough (Carpiaux 2018). Consolidation is only done when necessary, and sherds that require any residue analysis are unsuitable for consolidation as it can throw off the results.

NextEngine

The NextEngine is owned by the UWM Archaeological Research Laboratory and is housed in a room dedicated to its use (Figure 3.1). The NextEngine connects to a computer using a USB cable, but it also has its own independent power supply. The NextEngine setup consists of the scanner, the Multi Drive turntable, the ScanStudio™ Proscan software, and a dedicated laptop. One does not need a separate laptop to work with the NextEngine and another to work with the files, but that was the way it was setup in the laboratory. The laptop used with the NextEngine was a Dell Precision 3510 with an Intel Core i5 vPro processor with 16 GB of RAM and an AMD FirePro W5130M graphics processing unit.

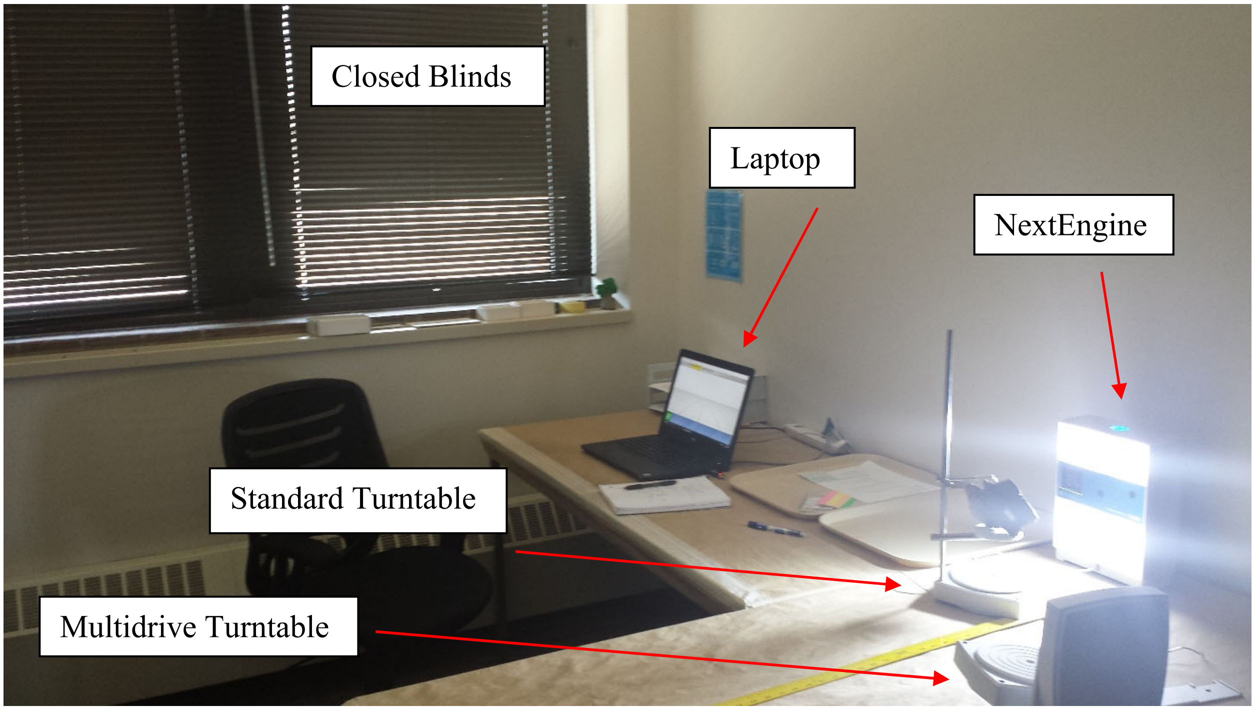

Figure 3.9. NextEngine setup in UWM-ARL.

In order to scan the sherds, the lights of the room that the NextEngine was in were turned off and the blinds were pulled over the windows, so as to minimize ambient light (Lemeš and Zaimović-Uzunović 2009) (NextEngine n.d.), so turning off the lights may have been an unnecessary precaution. The NextEngine also has its own lighting system. The laptop and NextEngine were plugged into a protected powerstrip in order to minimize any powersurge issues, and, when not in use, were both unplugged entirely. The NextEngine, once plugged into the laptop and an outlet, turns on automatically once the ScanStudio™ software is opened on the laptop. Sherds were placed into the part gripper of the multidrive. The part gripper consists of a rubber nub on a metal arm. The multidrive is placed 9.5" away from the scanner, which is the ideal distance for scanning objects with Macro Mode. Macro Mode is a setting that allows the scanner to have a raw output density of up to 268,000 points per square inch in an area that is up to 5.1"x 3.8". It is a focal length meant for small objects and fine details. The platform is also

made of a rubber material. The part gripper arm can be adjusted up and down and screwed into place. The pressure between the two points is used to keep the sherd in place (Figure 3:3).

Figure 3.10. Closeup of NextEngine in use.

After placing the object in the part gripper, necessary settings in ScanStudio™ ProScan must be adjusted. Because this study is only concerned with the shape of the cordage impressions, the color of the pottery sherd was intentionally ignored. This was done by setting the “Scan Settings” to “Monochrome”, which prevented color capture, allowing for a faster scan and a smaller file size. Additionally, under “Preferences”, the “2D Texture Display” was set to “Full Resolution”. Next it was necessary to calibrate the multi-drive. Calibration ensures that the multi-drive is lined up with where the program expects it to be, instead of being rotated too much or tilted off-center. This also helps with the auto-alignment feature. Calibration usually takes about twenty minutes. Calibration is not necessary for the rest of the sherds; calibration is only

necessary once per scanning session after powering on the NextEngine and multi-drive. It is necessary to have an object on the platform for calibration, as the scanner produces a test scan as part of the process. Once calibration has been completed pressing the "Start Scan" button will allow selection of scanning options (see Appendix C for settings used for each sherd). The ScanStudio™ sartup screen is shown in Figure 3.4

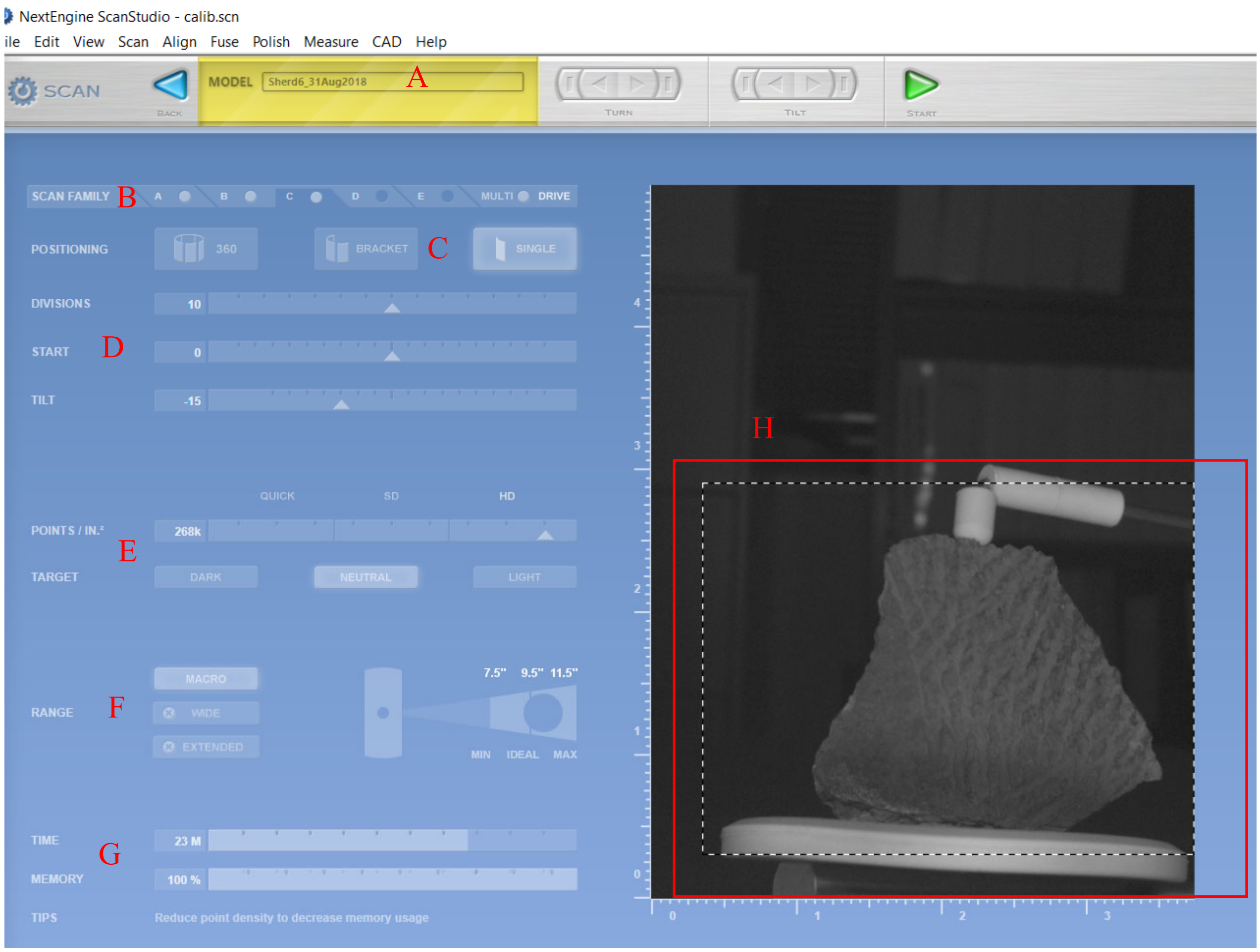

Figure 3.11. The NextEngine scan setup interface.

Three scan families ("B" in Fig. 3:4) were selected. The "families" are individual scans; they are of the same object but at different Y axis tilts. The different scan families are automatically aligned at the end of the scan, provided the multi-drive is calibrated and there are distinct reference points visible on the scanned object. Each scan family scans the sherd with a different

tilt: neutral, 15 degrees forward, and 15 degrees backward (Letter "D" in Fig. 3:4). The platform rotates, and the number of divisions dictates how many times the scanner scans for every 180º rotation of the platform. So, if ten divisions are selected, then the platform rotates 18 degrees every division. Ten divisions were used per scan family for this project. Each scan family creates one scan that must be aligned with other scans of the same object. The view option was set to "single" (Figure 3.4), since the scan was only concerned with the surface of the sherd bearing cordage impressions.

For points per inch, the highest setting "HD" was chosen for each scan ("E" in Fig. 3:4). The target was set to "neutral", which refers to the color of the original object. If an object's surface is too reflective, it is necessary to dull it in order to produce a useable scan. If too dark, NextGen advises that the surface be lightened with powdered talc. It is unclear what counts as "neutral", "dark", or "light" in NextEngine standards (Lemeš and Zaimović-Uzunović 2009) but the sherds in the study sample did not require any surface treatment.

The NextEngine has three field of view settings (the "Range" setting in the scan settings, "F" in Fig. 3.4): Extended, Wide, and Macro. The range was set to "macro", which allows for close-up, detailed scans. The field of view for macro mode is only 3" x 5", so anything that is larger than that will be truncated or the ProScan program may have issues. In the program, one can click and drag a bounding rectangle to narrow the field of view, and the computer will ignore everything outside of the box (Letter "H" in Fig. 3.4). The center of the multidrive platform was positioned 9.5" from the scanner, which is the ideal distance for the field of view and focus that Macro mode needs. Finally, once these settings have been entered, the program will provide an estimate of how much time the scan will require and how much RAM memory will be used by the computer (the laptop was built with 16 GB of RAM just for this reason). Typically, sherd

scans required 30-45 minutes, and due to intensive RAM requirements, no other program could be run while scanning was in progress. During this time, one is free to work on other pursuits, since the scanning, movement of the object, and alignment are all automatic. The author had access to two laptops to maximize research productivity.

After the sherds were scanned and aligned, it was sometimes necessary to "trim" the part gripper and the platform from the model, a process that deletes the data related to the shape of those objects. This process involves manually highlighting unwanted data points and deleting them, a process that can take about 20 minutes. Narrowing the scanning field ("H" in Fig. 3.5) to only what is necessary shortens the trimming process significantly.

After trimming, the scan is complete and can be saved. The ScanStudio™ program automatically saves the file in a native format, which can only be reopened with ScanStudio™. However, files can also be exported as a variety of other file types, such as .ply, .obj, .stl, and other 3D file types that can be manipulated in other software programs. The scan files for this project were saved as both .stl files (encoded in ASCII) and .obj files, though only the .stl files were used in the present project. The process of saving took about ten minutes, as these files range in size from .5-1.5 GB. The files were then saved to a jump drive as well as to a server that is available to all UWM anthropology graduate students. It should be noted that the files should have been saved as .stl files encoded in binary. Encoding them in ASCII increased file size unnecessarily and is actually meant for those who wish to edit the code of their file manually. The .stl format was chosen because it does not contain textural data, which wasn't collected in the first place (Chakravorty 2019)

When Sherd 1 was scanned for the first time, the entire exterior surface was selected, as the sherd took up the entirety of the Macro Mode window. The ProScan software would scan the

object, but when it came to automatic alignment, the software presented an error message (see Fig. 4.3) or shut down completely without saving. This happened multiple times (twenty minutes each) and the error screen did not clarify the issue. Finally, small balls of Original Sculpey® were temporarily attached to the scanned surface in and attempt to aid in alignment. This allowed the next scan to finish, but it appeared doubled upon itself, suggesting that the auto alignment still didn't work.

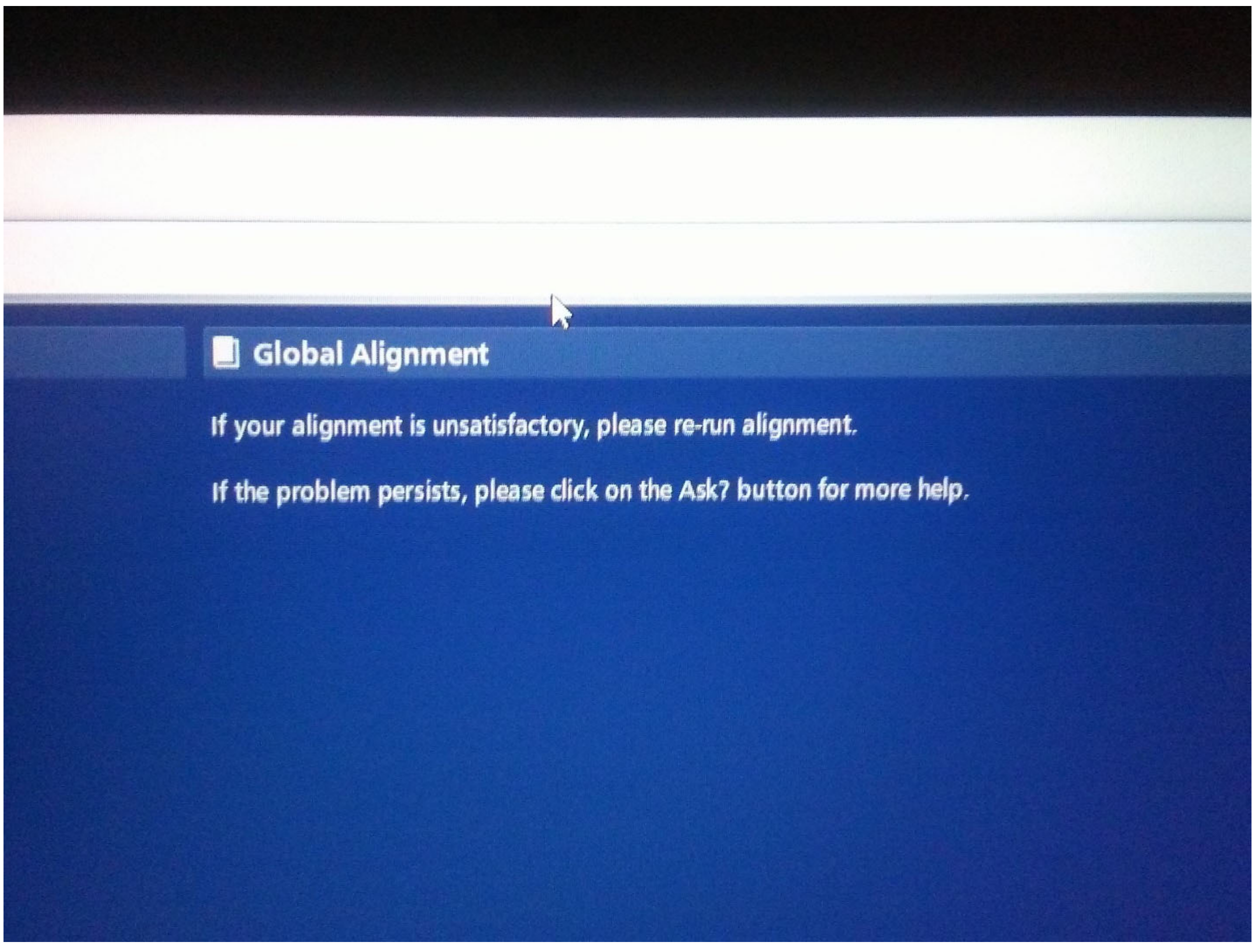

Figure 3.12. NextEngine error message from early efforts in scanning Sherd 1.

To solve this issue, tape was applied in a box around an arbitrary spot on Sherd 1. Since this sherd is totally cordmarked, it was assumed that any area of a reasonable size was representative of the cordmarkings on the entire sherd. A rectangle of approximately 7cm x 5.5cm was outlined in orange tape, then balls of Original Sculpey® were placed in the four

corners to add more dimension for the global alignment feature to work with (see Fig. 4.5). The rectangle was not too large as to exceed the Macro Mode area size, but not so small as to be a poor sample of the cordmarkings.

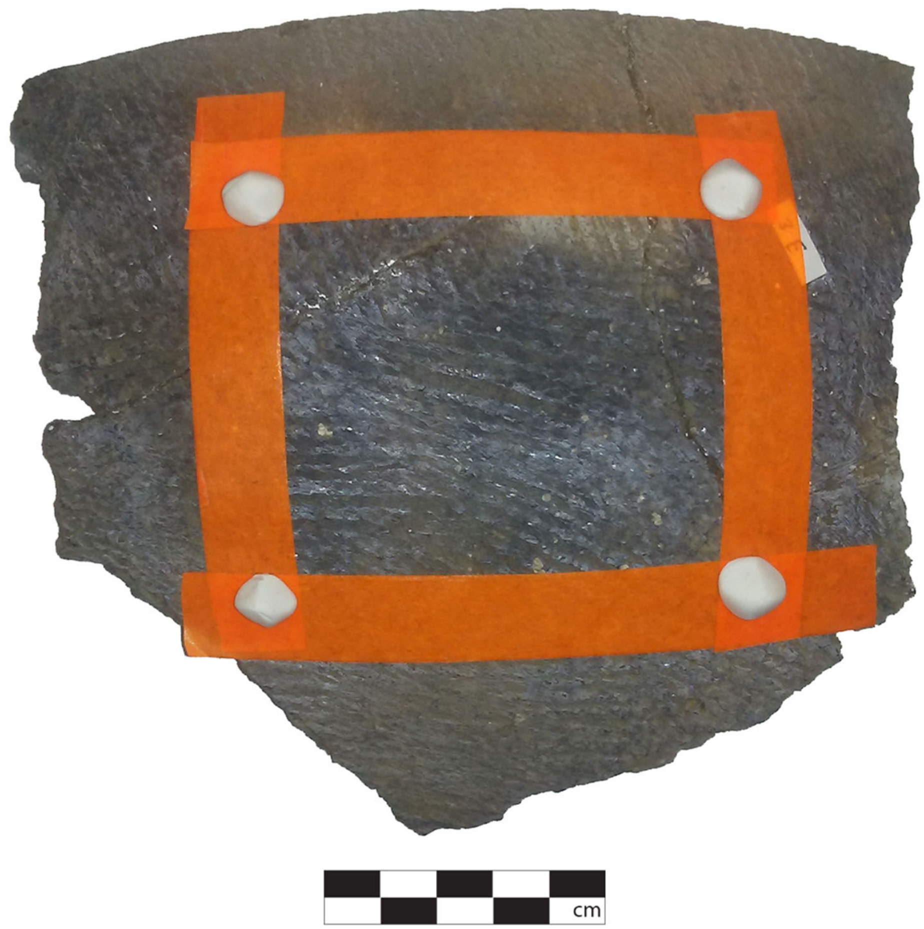

Figure 3.13. Sherd 1 modified for better alignment with NextEngine

This solution worked to a point. Three scan families were selected for each scan session of Sherd 1, to retrieve maximum data at a variety of angles to avoid too many holes. Prior to this modification, the software would crash after twenty minutes, during the portion of scanning that involved global alignment. After this modification, the software no longer crashed, but the software still would not appropriately align the three scan families from the three different angles

it was told to scan. However, one scan family contained enough points of the cordmarkings in the tape box that the best scan family was selected and the two others were deleted. All other sherds are three scan families fused into one mesh, however, Sherd 1 contains just one bracketed scan with no tilt forwards or backwards.

Scanning With the GoMeasure3D HDI R1X

The sherds were also scanned using a GoMeasure3D HDI R1X structured light scanner, made available by the UWM art history department and operated by Dr. Kevin Garstki. The unit consists of a projector, two cameras, a DSLR camera, a tripod, and a turntable. A structured light scanner uses two cameras to measure how much a projected light grid is deformed by an object's surface. Color is captured with a third camera. Scanner setup takes about one half hour to an hour. Then the scanner must be calibrated using a target with a surface covered by a black and white checker board pattern. The scanner must have the correct target in order to calibrate to the right size and focal distance. A target with small squares is used for fine details and smaller objects, while a target with larger squares is necessary to scan larger objects.

Both sherd surfaces were scanned with the GoMeasure, which meant that the uncorded interior of the sherd had to be deleted in the Meshlab software program, leaving just the exterior surface. This surface scan could then be lit from both sides using the "double" lighting setting, revealing the positive version of the cord marks or impressions.

A laptop computer was used to work with the 3D meshes produced by the NextEngine and GoMeasure3D. The unit was a Hewlett Packard Omen with an Intel® Core™ i7-6700HQ CPU @ 2.60GHz. The laptop had 8 GB of RAM and a 64-bit operating system. The unit was equipped with Windows 10 Home, version 1803 operating system. Finally, it possessed a NVIDIA GeForce GTX 960M.

The 3D scan file sizes were very large (Sherd 7 alone was over 1.4 million kb). To conserve storage space on the HP, files were uploaded to the UWM network servers. However, files could not be opened quickly across the UWM network, so all files were downloaded to the author's personal laptop hard drive. That way, the data did not have to be repeatedly downloaded, subject to the speed of the network, in order to work with raw scan files.

Meshlab

A program called Meshlab was chosen to work with the files. This program can visualize, manipulate, change the lighting of, and measure the 3D meshes. A "Mesh" is what one calls the total of the points and polygons that comprise a 3D model; when visualized in Meshlab or other programs, it looks like a net. Meshlab is an opensource program. Since the file sizes are so large as well as the number of faces and vertices, one cannot work in Meshlab after download. This has to do with the graphics processor. Laptops typically have two GPUs, one integrated and one meant for high-performance. One must tell the Meshlab program to use the high-performance processor (in this case, the NVIDIA GPU). To do this, one right-clicks on the Meshlab program, then mouse-over "Run with graphics processor", and then select "High Performance [insert processor name here] processor". One can also click on "change default graphics processor" to open the GPU control panel. Then, one can add the Meshlab .exe program and select the high-performance processor, and then Meshlab will always run with that processor. After completing this step, one must then go into the Meshlab program to modify the setting which limits how much of the GPU processor it uses. One can go to "Tools" and left-click on "Options". This opens the Global Parameters Window. Scroll down to "MeshLab::System::maxGPUmemDedicatedToGeometry" and change the variable value from the default of "350" to something much higher. The lower right corner of the program should

show how much GPU memory is being used as “Mem [percentage] [memory MB used]/[maximum GPU memory available]”. The NVIDIA processor has a maximum of 4096 MB (according to MeshLab), so the Variable Value in Global Parameters was changed to “3500”, which was both an arbitrary decision and also an attempt to leave some GPU memory for other possible needs on the HP Omen. This change allows the user to open large files. One of the largest files, Sherd 7, was ~1 GB. It took about 10-15 minutes for Meshlab to visualize the mesh, but when it did, it was able to be manipulated quickly. Prior to this change, the meshes for Sherd 1, 5, and 7 would not visualize and could not be worked with, so it is very important to have Meshlab use the appropriate GPU and increase the GPU memory that it uses.

When the Meshlab program is open, one can “Import Mesh” into a “New Project”. The process of importing a mesh can take a few minutes, depending on the size of the file. It is noted in the data collection how long it took to open a file and whether or not manipulating the mesh was choppy.

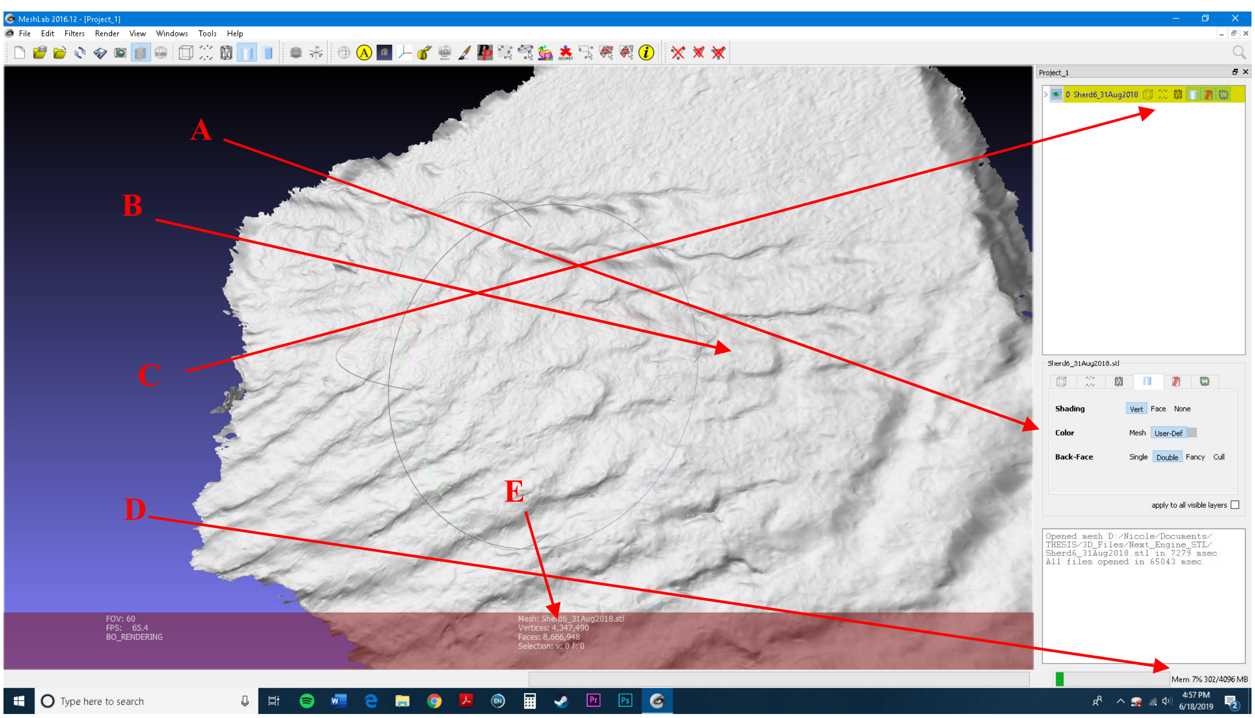

Figure 3.14. The Meshlab software interface.

When the mesh is first imported into the program, it is “lit” from the obverse of the sherd. One first must rotate the object by right-clicking and dragging the mouse to move the mesh around. In order to see the reverse, one must hold down shift+ctrl and use the mouse to rotate the light source. The object is set in a uniform light-grey, though this can be changed (“A” in Fig. 3.14; the color box next to “User-Def”). The light source can be moved to highlight what one wishes by holding down CTRL+Shift+LeftMouseButton and dragging the mouse around to the direction one wishes. The “lighting” direction will be shown as yellow lines. “Backface” (“A” in Fig. 3.14; underneath “Color”) also controls the lighting. “Single” can be selected for a single light source, or “Double” can be selected to light an object from both directions. One can toggle a “smoothed” model with the raw mesh by clicking the mesh button and unselecting the round cylinder in the top right (“C” in Fig. 3.14). “D” in Fig. 3.14 shows how much GPU memory is being used out of the total memory.

Sculpey® Positives

Casting media, whether it be latex, Sculpey®, silicone, or whatever else the archaeologist may choose, is not often discussed in great detail by researchers. Notable exceptions include, Drooker (1992, 2000) and Pappas (Pappas 2008) who report the specific brand of casting media used.Based on Minar’s and Drooker’s usage of Sculpey® products, Original Sculpey® was chosen as the casting medium for this project. However, Sculpey® is not the only possible choice. Table 3.1 summarizes information about various casting media. This is not an exhaustive list, nor does it consider all name brands or ways of using each kind of media. It is meant as a starting point for those who are choosing a casting media for a project. No all manufacturers provide the same level of technical information, so some data, particularly shrinkage, may be missing for a particular media.

Table 3.1 A Comparison of Various Casting Media

Type	Name Brands	Cost	Time	Shrinkage	Ease of Use	Damage	Comments
Polymer Clays	Original Sculpey®, Sculpey® III, Preemo!, Fimo, Kato Polyclay	\$0.63-0.47/oz. for Original Sculpey® from Sculpey® website	Instant casts, then needs to be cured at 275 degrees for 15 minutes for every ¼ inch. Cure time also depends on temp. consistency of oven used.	<0.01%	Requires at least a toaster oven and a probe thermometer to cure. Must be "conditioned", or kneaded to ensure maximum softness. Must be pressed into sherd for several minutes to ensure capture of details.	Plasticizer is known to "melt" PVC, or Type 3 recyclable plastics. Leaves organic compounds on sherds. Can settle into crevices. Talc, cornstarch, or excess dirt can be used to minimize damage to sherd.	Can be reused until cured. Requires an oven to cure. Contains organic residues. Sold at craft stores and marketed to hobbyists. Does not contain any clay minerals. Damages B-72.
Clay	Can be dug up and processed by self, Great Lakes Clay Supply, Blick Art Materials, can even buy raw materials and make own formulation of clay	Depends on source. Free if dug and processed by self.	Instant casts. Firing can take a whole day, given an electric kiln.	Varies with type of clay; but it is significant. Typically 5-12%.	Requires a kiln to fire; kiln requires special knowledge to operate properly for the given clay.	Depends on composition. Contains water, minerals,	Varies wildly based on composition of clay. Permanent if fired.

Table 3.1 A Comparison of Various Casting Media (continued)

Type	Name Brands	Cost	Time	Shrinkage	Ease of Use	Damage	Comments
Plaster of Paris	Dap	$0.04/oz.	Liquid plaster must cure on the sherd.	It actually expands a little during the curing process, but returns to original dimensions.	Liquid when poured; requires a container.	Sherd must be wet to avoid water leaking back into it and causing plaster to permeate the sherd.	Method recommended by Sease (Sease 1994) Typically available from local hardware store. Creates heat while curing. Rigid when set. According to Sease, the sherd must be totally wet and have a layer of soap upon it for this casting media to best work.
Plasticine, plastilina, modeling clay	Sargent Art	$0.19/oz., reusable.	Plasticine requires hand kneading to warm it up and soften, but otherwise instant.	None.	Does not require special equipment. Measurements must be taken immediately since it can warp quickly.	May leave organic residue. Can use talc, cornstarch, or excess dirt to minimize damage.	Cannot be made permanent; always soft. Oil-based. No potential for retaining cast long-term. Can contain sulfur, which limits the curing abilities of some resins, important if making casts of casts.

Table 3.1 A Comparison of Various Casting Media (continued)

Type	Name Brands	Cost	Time	Shrinkage	Ease of Use	Damage	Comments
Air-dry clay	Amaco	$0.07/oz. (Amaco)	Instant impressions, but 24 hrs. to dry	Water-based, so shrinkage is significant.	Very easy to use. Requires no special equipment. Can crack while drying.	May leave organic residue.	Available at most craft and even big box stores in the arts and crafts section. May contain gluten, to which some people are allergic.
Latex	Amaco rubber latex	$1.17/liquid oz.	Brushed on, allowed to dry, and brushed on again until desired thickness. Rachlin reported up to a two week process (Rachlin 1955).	Can shrink considerably, according to Sease (Sease 1994)	Must be layered on with support structures (like fabric strips)	Likely to lift particles from pottery matrix, especially since it shrinks on the sherd.	Some people have severe allergic reactions to latex.
Alginate	Alga-Safe (Smooth-On 2019), Jeltrate	$0.49/oz.	8-minute cure time, 5 minute pot time.	"Up to 8% in 2 months" (Drooker 2000)	Pours as a liquid, so it requires a mold box. Limited lifespan.	Sherd will be wet.	Meant to be temporary and have casts made from it. Does not need heat to cure.

Table 3.1 A Comparison of Various Casting Media (continued)

Type	Name Brands	Cost	Time	Shrinkage	Ease of Use	Damage	Comments
Vinyl polysiloxane	Reprosil	$11.09/oz., expensive.	6 minute set time.	Negligible.	2-part putty. No need for special equipment.	Unknown.	From online, mostly dental suppliers. Some suppliers require a dental license to purchase.
2-part Epoxy Putty	Milliput	$3.49/oz.	Hard in 3-4 hours.	Unknown, though likely negligible.	2-part putty, no need for special equipment	Very good adhesive; would likely cause great damage.	Cures hard. Untested for making casts of sherds.
Silicone, Tin-Cure	Smooth-On Poyo Silicone Putty	$1.21/oz.	Pot life of 5 minutes, cure time of 30 minutes.	0.003 in./in.	2-part putty spread across cast with 1cm thickness.	Talc could be used to reduce mechanical damage. Unknown if residue is left or if chemical analysis affected.	Does not cure hard; has some give.

Table 3.1 A Comparison of Various Casting Media (continued)

Type	Name Brands	Cost	Time	Shrinkage	Ease of Use	Damage	Comments
Silicone, Platinum Cure	Smooth-On Equinox Putty	$1.31/oz.	Comes with three pot lifes: 1 min. (7 min. cure time), 4 min. (30 min. cure time), and 30 mins. (5 hour cure time)	<0.0003in./in. Lower shrinkage long-term than tin-cure.	2-part putty that requires no special equipment.	Talc could be used to reduce mechanical damage. Unknown if residue is left or if chemical analysis affected. Food safe, though it's not clear if that also means it would not affect residue analyses.	Does not cure hard; has give. Has a much longer shelf life than tin-cure.

While there is no specific ingredient list available, Original Sculpey® contains primarily polyvinyl chloride (PVC; see Fig.), a kind of thermoplastic resin (Shashoua 2008:252; Polyform Products Company, Personal Communication 2020). Additives include fillers, plasticizers, and colorants (Polyform Products Company 2019). To fill in some of the information gaps, *Conservation of Plastics* by Shashoua was consulted. Fillers are “relatively unreactive, solid materials added to plastics formulations to modify their flow properties and handling during processing, as well as their tensile and compressive strengths, abrasion resistance, toughness, dimensional and thermal stabilities” (Shashoua 2008:61). Fillers can also add color and opacity (2008:62), so it is assumed that colorants also fall into this category. Original Sculpey® is an opaque white, though there are many things that could act as a white filler (calcium carbonate, talc, starch, to name a few (2008:58-62)). Plasticizer softens polymers by separating polymer chains from each other (2008:58). “PVC is the polymer most in need of plasticizers” and plasticizer can occupy 20-50% of a plastics formulation (2008:58-60). According to Shashoua, phthlalate esters are the most common kind of plasticizer (2008:61). The Vermont Public Interest Research Group did a study about the hazards of phthalates in polymer clays. The potential of hazard aside, they found that Sculpey contained between 3.5-4.4% mixed phthalates (VPIRG 2002), suggesting that the plasticizer they use are at least mixed phthalates, perhaps with other ingredients. According to Sculpey website, “Products comply with the CPSIA if they do not contain more than 0.1% of any of the six phthalates restricted or banned by the regulations. These six phthalates are: DEHP (Di-2-ethylhexyl phthalate) DBP (Dibutyl phthalate) BBP (Benzyl butyl phthalate) DINP (Di-isononyl phthalate) DIDP (Di-isodecyl phthalate) DnOP (Di-n-octyl phthalate)” (Polyform Products Company 2019).

Name/Abbreviation	Polyvinyl chloride (PVC)	
Major applications	Available as film, foam, tubes, pipes, thermoform, blow moulding and extruded mouldings.	
	Rigid PVC: window frames and sills, water pipe, gutter, replacement for wood.	
	Plasticized PVC: flexible tubing, garden hoses, vinyl flooring, shower curtains, roofing membranes, electrical cable insulation, waterproof and protective clothing, vehicle upholstery, medical devices, blood bags, intravenous bags and tubing.	
Optical properties	Transparent but not as glass-clear as acrylics or polyesters.	
	Refractive index (ND 20°C)	1.52_1.55
	Light transmission (%)	76–82
Physical and thermal properties	PVC is thermoplastic. In rigid, unplasticized form, PVC is stiff and brittle. Addition of external plasticizer imparts various levels of softness and flexibility. Copolymerization with flexible monomers also results in a softer product. Vinyl records or LPs comprise vinyl chloride/vinyl acetate copolymer.	
	PVC does not burn. In a fire, PVC cables form hydrogen chloride fumes as the major degradation product. The fumes scavenge free radicals thereby preventing the plastic burning.	
	Density (g/cm^3)	1.30–1.58
	Tg (°C)	75–105
	Tm (°C)	212
	Ignition time (s)	300 (unplasticized) 22 (plasticized)
	Tensile strength at break (MPa)	41_52(unplasticized) 19 (35% plasticized)
	Elongation at break (%)	40–80 (unplasticized) 270 (35% plasticized)
	Coefficient of thermal expansion $(°C)^{-1} \times 10^{-6}$	50-100
	Permeability of oxygen at 30°C ($10^{10} cm^3 s^{-1} mm\ cm^{-2} cmHg^{-1}$)	1.2
	Permeability to water at 25°C ($10^{10} cm^3 s^{-1} mm\ cm^{-2} cmHg^{-1}$)	1560
Chemical properties	PVC undergoes dehydrochlorination (production of hydrogen chloride gas) under exposure to heat and light. The acidic gas corrodes metals in the vicinity. The reaction is autocatalytic. PVC becomes darker in colour as degradation progresses. Plasticizers are usually esters and undergo hydrolysis in acidic and basic environments to form white crystals of acid or anhydride. The PVC polymer is resistant to acids and bases. It is resistant to most hydrocarbons, although polar solvents may extract plasticizer if present. Water swells the PVC polymer imparting an opacity which reverses on drying. PVC can be adhered using polyester, epoxy or polyurethane adhesives.	
	Degree of crystallinity (%)	5–15%

Figure 3.15. PVC optical, physical, thermal, and chemical properties (Shashoua 2008:252, no table number provided).

Since Original Sculpey® must be cured at 275° F for 15 minutes per ¼" of thickness, a consumer-level toaster oven was used. The unit used was a Toastmaster oven that was at least 10 years old. A current Toastmaster oven of similar quality is available from Walmart for $54.86 (Walmart 2019). A digital temperature probe (sold for home use) was purchased from Sur La Table for $29 (Sur La Table 2019).

The procedure used to make the casts was informed by a combination of the methods used by Drooker (Drooker 1992) and Minar (Minar 1999). First, the Original Sculpey® clay was softened by hand kneading. Original Sculpey® and other polymer clays can be softened by adding additional plasticizer, but that was not done for this research in order to reduce the amount of plasticizer for the sherds to absorb. Once the clay was soft enough, it was rolled out into a roughly ¼" slab with a wooden rolling pin atop a plastic polypropelene bag. The bag did not react with the plasticizer in the clay, and it also meant that one side of the slab was perfectly smooth. Before casts were made, a shrinkage test was deemed necessary due to Drooker's (2000) comments about the concern for shrinkage when choosing a casting material. Low shrinkage rates are desirable to maintain morphological integrity and allow reuse of the Sculpey® casts by future analysts. The same shrinkage test used by modern studio ceramicists to test new clay was employed in this study (Binns 1947). A small, even slab of Sculpey® (~1/4" thick) was rolled out. A 10 cm incised line was then incised into the uncured slab. The Sculpey® was then placed on parchment paper atop a metal tray and baked according to the manufacturer's instructions, which call for 15 minutes of bake time for every 1/4" of thickness at 275º F. Once the slab cooled, the incised line was re-measured. This measurement was then divided by 10 (to represent the original 10 cm line) and subtracted from 100. The results provide a measure of the percentage by which the Sculpey® has shrunk. As shown in Fig. 3.16 results produced a value of

10 cm, suggesting that shrinkage was negligible. Digital calipers were used to make impressions 10cm apart. This measurement remained the same after curing in the oven. Regular clays tend to drive off water during the firing process, but polymer clays undergo a chemical change when curing. The lack of shrinkage suggests that ingredients do not get driven off noticeably during curing.

Figure 3.16. Test tile used to conduct shrink test.

The sherds were lightly powdered with cornstarch, to allow better release from the clay and to minimize how much plasticizer leeched into the sherds. The clay and sherd were then held together, and the clay was pressed gently into the sherd. The clay was kneaded into the sherd for a few minutes, to ensure the most detail was captured from the cord markings and impressions.

The sherd was then gently removed from the clay while the clay was supported by the hand, so as not to deform the cast. Once the sherd was released, Following a suggestion provided by Allman (Allman 2019), the cast was placed on a bed of cornstarch with the impression facing up (Figure 3.17). The cornstarch supported the contours of the cast while in the curing process and prevented flattening.

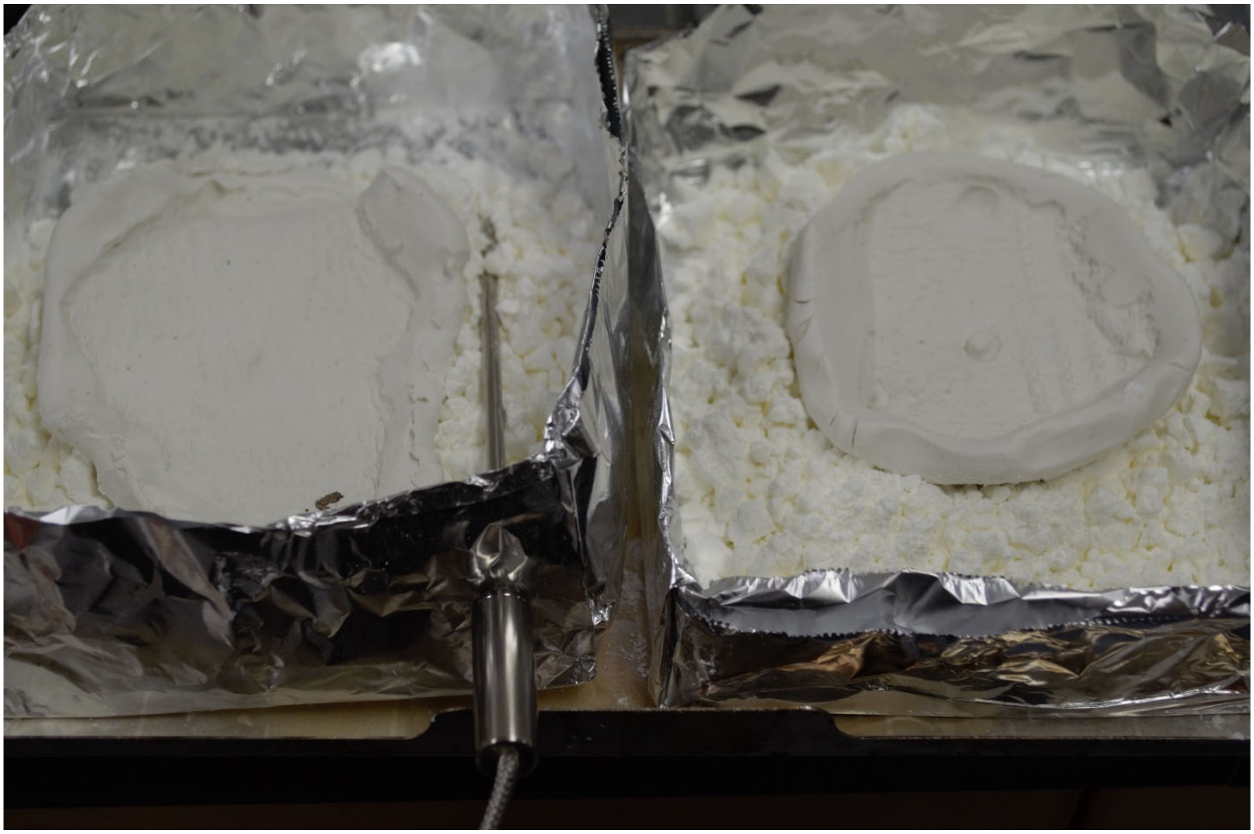
Figure 3.17. Original Sculpey® casts ready to be cured.

The casts were then placed into the toaster oven (Figure 3.18). A digital thermometer with a probe was used to monitor oven temperature during the curing process.

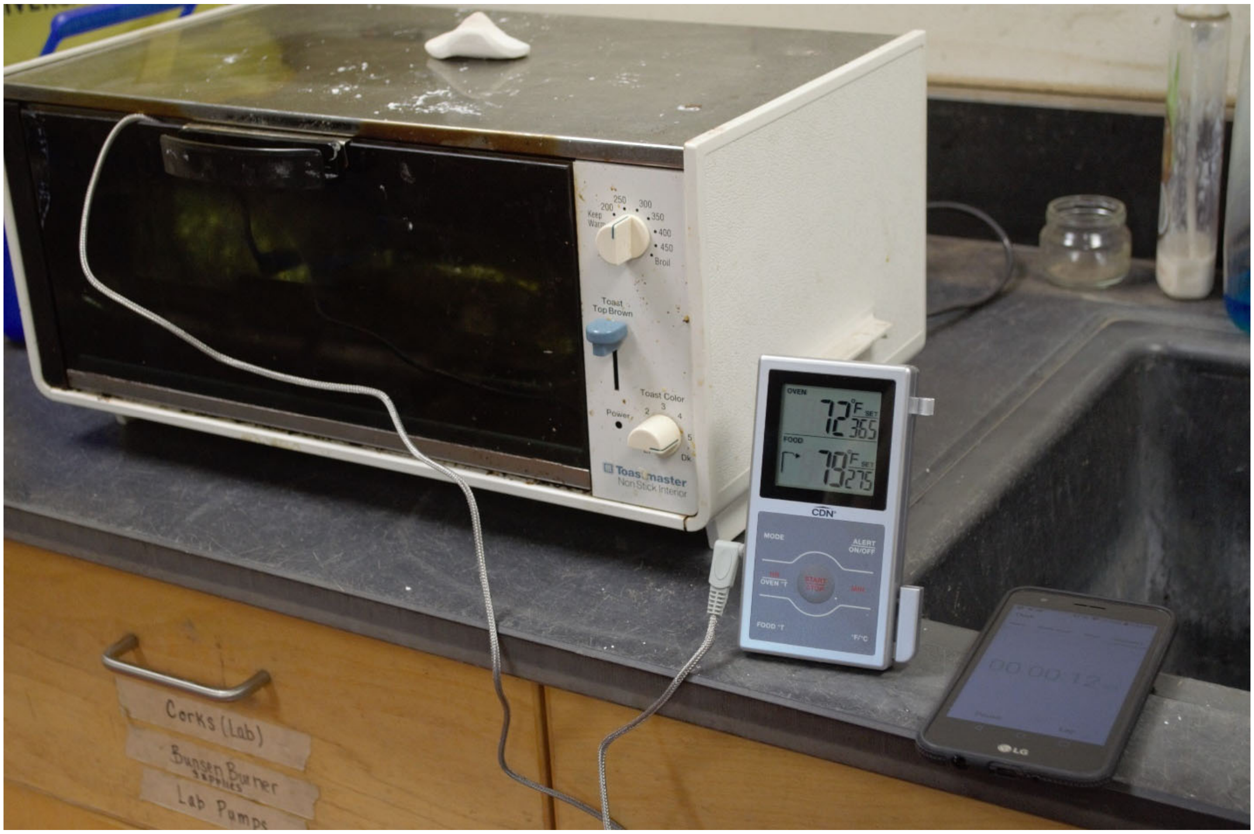

Figure 3.18. Original Sculpey® casts curing in oven with temperature probe and LG smartphone keeping time.

The temperature gauge was purchased after three rounds of failed tests produced casts that were either too burned (the clay will bubble and turn brown), not cured enough, or flattened. The toaster oven depends on elements in the ceiling of the oven for heat, which means anything close to them is going to be too hot and anything at the base of the oven is too cold. A basic heat shield of doubled aluminum foil was placed atop the cast's foil containers to prevent burning, much as one might also use foil to prevent the burning of a pie crust while continuing to bake the middle of the pie (Figure 3.19).

Figure 3.19. Foil shield used to protect the Original Sculpey® casts from direct heat.

Cordage Attributes

A variety of morphological and metric attributes were recorded in order to provide a comparison between the techniques explored in this study. Attributes recorded include:

- Markings, or impressions If impressions, what type (fabric, CWS, single cord, etc.) and how many? If impressions, how are the decorations zoned? If markings, were they clear, or smoothed over?
- Final twist direction of each kind of cord present, “S” or “Z” twist (Figure 3.20). Differences in twist may have implications for cultural associations and temporal placement (Maslowski 1996)
- Number of plies. Most of the sherds were cordmarked using 2-ply cord, but sherd 7, both 2-ply and 4-ply cordage.

- Cord diameter, measured at thickest part of a yarn twist (Emery 2009; Pappas 2008) three times on different locations on the sherd. The locations chosen are mostly arbitrary on sherds 1-6, but sherd 7 has zoned decoration that required more than three measurements.
- Twists per centimeter of cord.
- Warp and weft spacing. Impressions of a woven fabric were restricted to sherd 7.

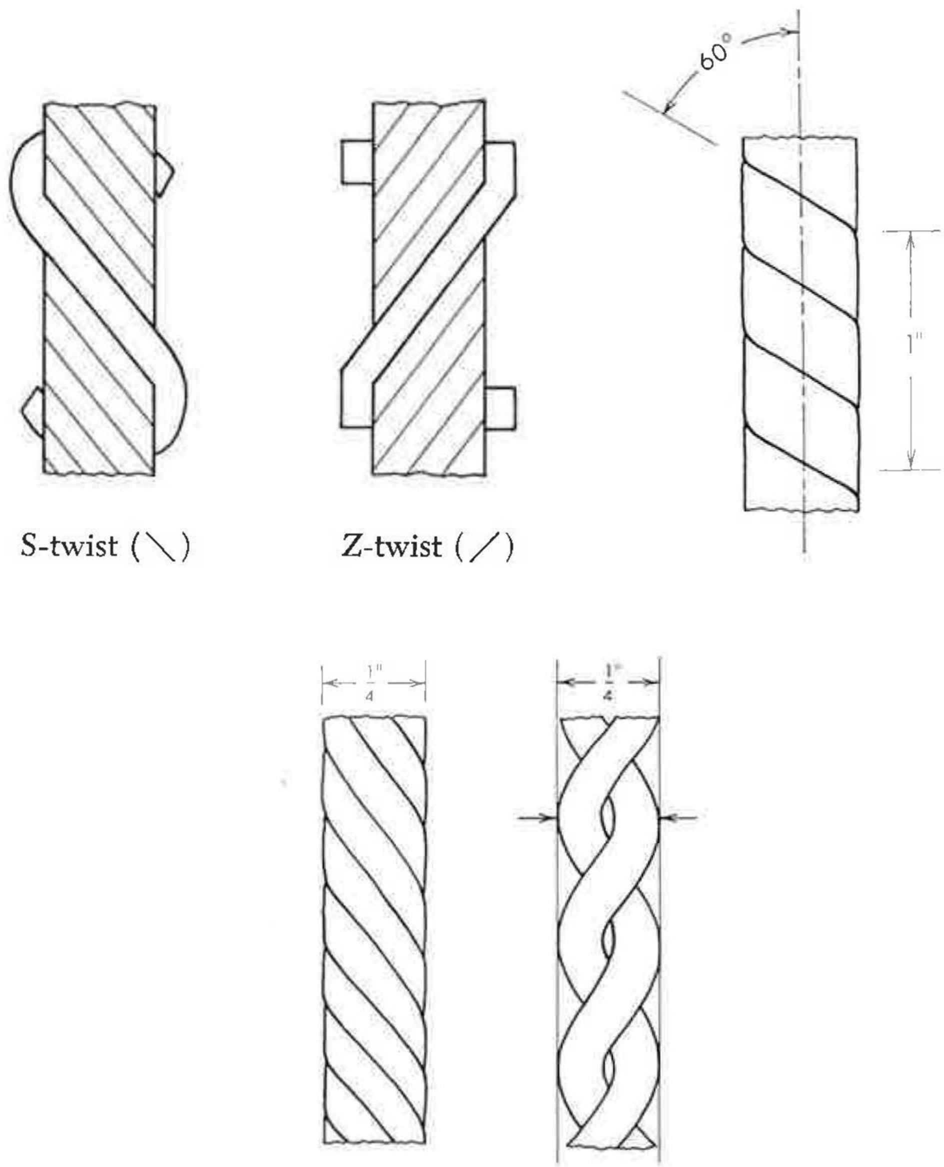

Figure 3.20. S/Z twists, angle of twist, and cord diameter measurements. From Emery (Emery 2009)

• Warp, weft diameter (only sherd 7; see Adovasio 1977, Hurley 1979, Pappas 2008), space between.

Metric attribute data was collected digitally using measuring tools built into the Meshlab program. Physical measurements of the Sculpey® casts were made using digital calipers. First, a measurement was taken in the Meshlab program0. Next, the same data was collected from the cast using digital calipers. Cast measurements could have also been taken with the measuring tools built into the DinoLite 2.0 program but this would have required two computers in order to have appropriate processing power. Finally, the digital microscope was then used to highlight the presence or absence of individual fibers, sherd damage, and any other issues (such as incompleteness) in the casts (see Appendix D).

Chapter 4: Results and Analysis

This section is organized by the method employed (headings in bold). Each method is evaluated for accuracy of method, amount of damage to sherds, cost per sample, ease of use, and permanency of data acquired. To aid in this discussion, Figures 4.1-4.7 provide images of each sherd as obtained by casting, scanning with the NextEngine, and with the GoMeasure3D HDI R1X.

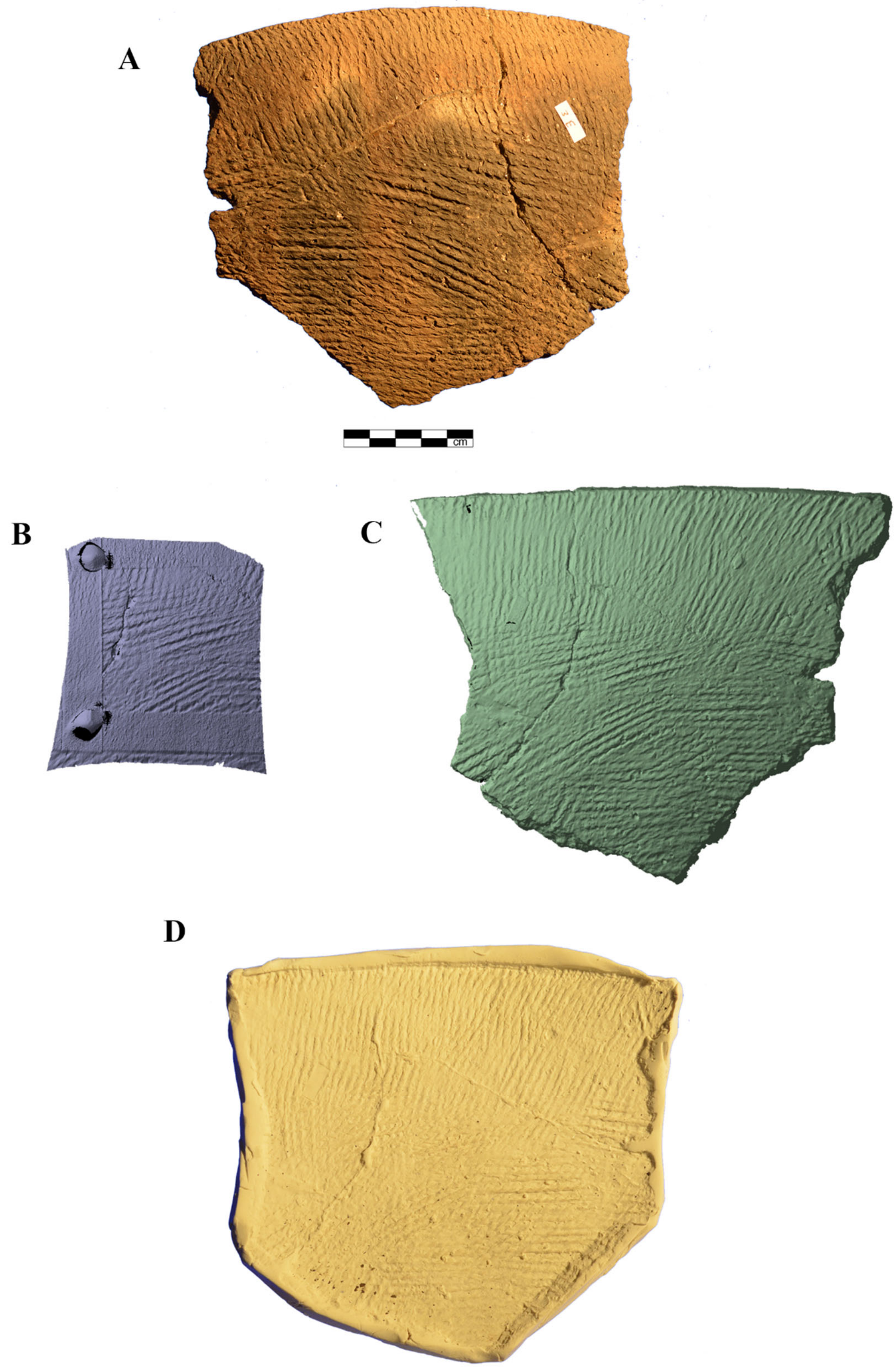

Figure 4.1. Representations of Sherd 1. A: Actual Sherd. B: NextEngine (note only portion of sherd; also see Fig. 4. C: GoMeasuree3D D: Original Sculpey® Cast.

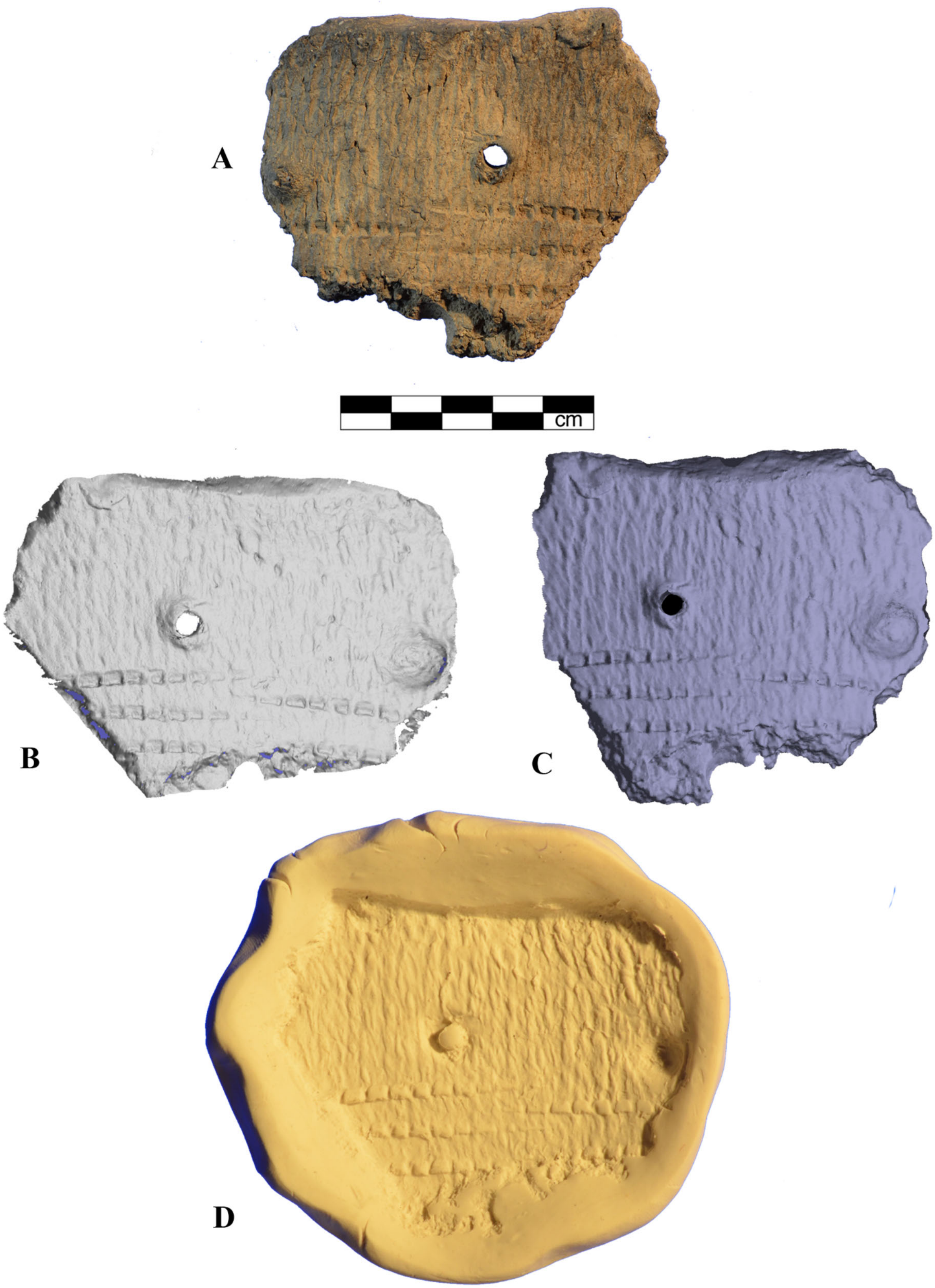

Figure 4.2. Representations of Sherd 2. A: Actual Sherd. B: NextEngine C: GoMeasuree3D D: Original Sculpey® Cast.

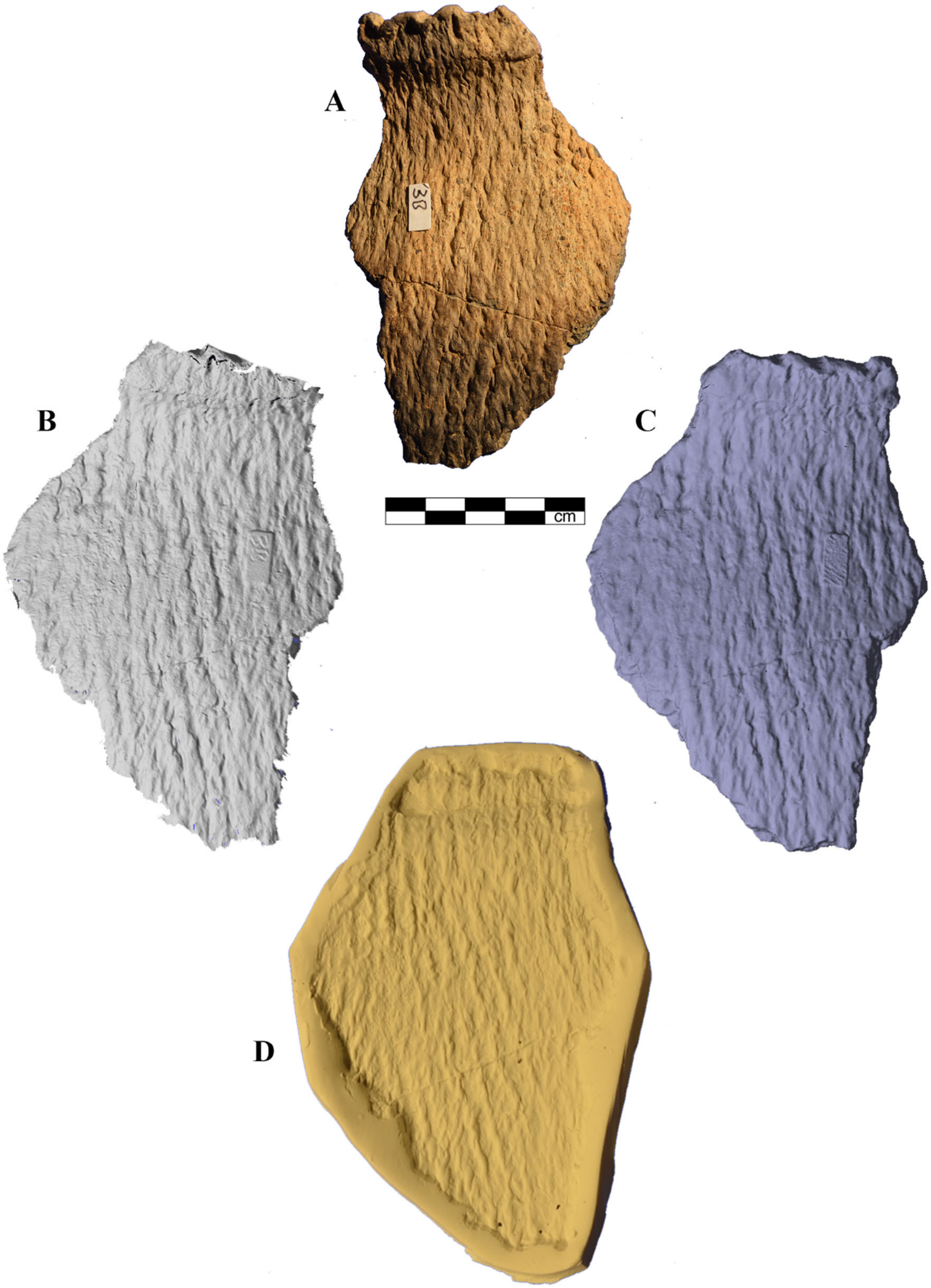

Figure 4.3. Representations of Sherd 3. A: Actual Sherd. B: NextEngine C: GoMeasuree3D D: Original Sculpey® Cast.

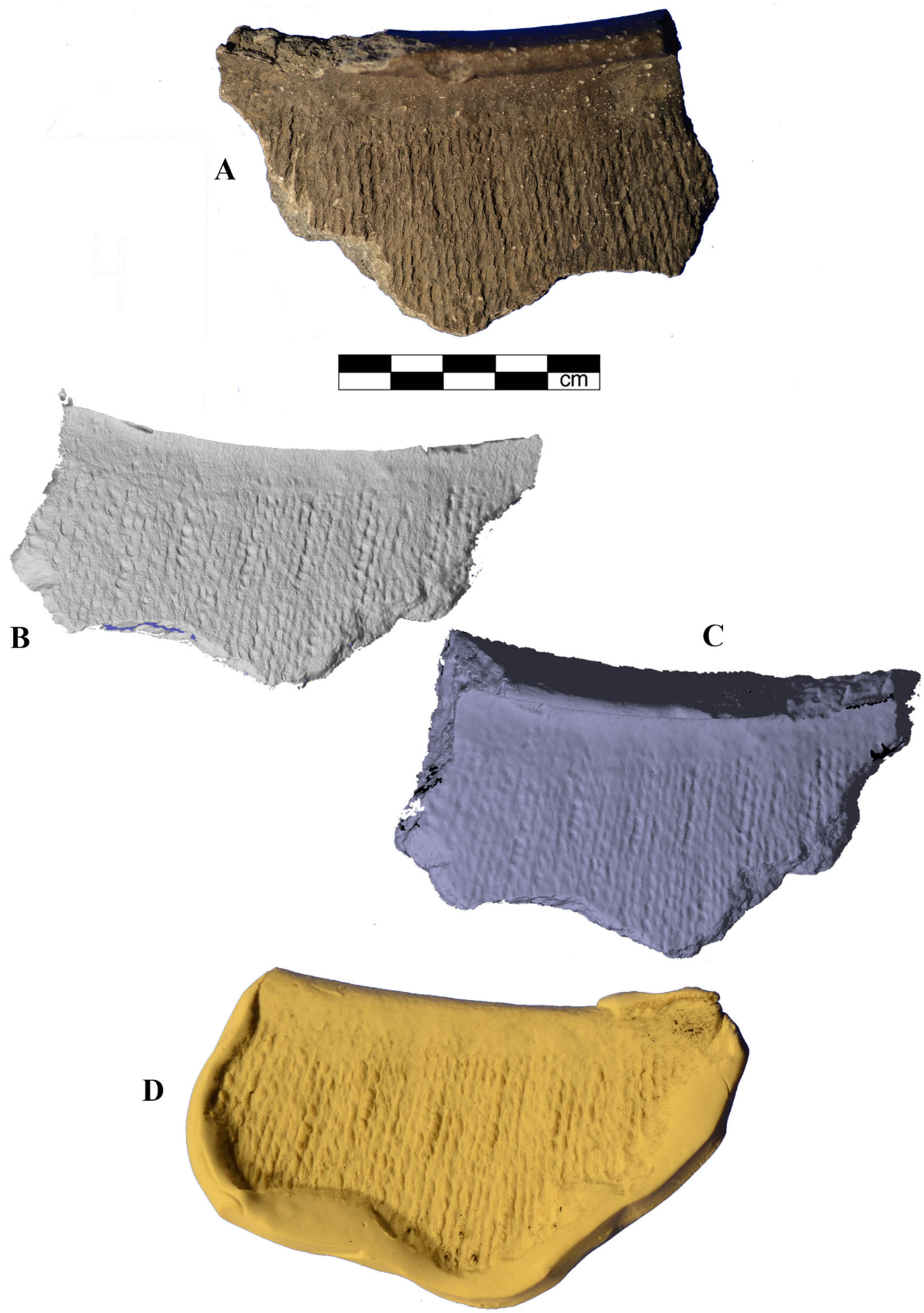

Figure 4.4. Representations of Sherd 4. A: Actual Sherd. B: NextEngine C: GoMeasuree3D D: Original Sculpey® Cast.

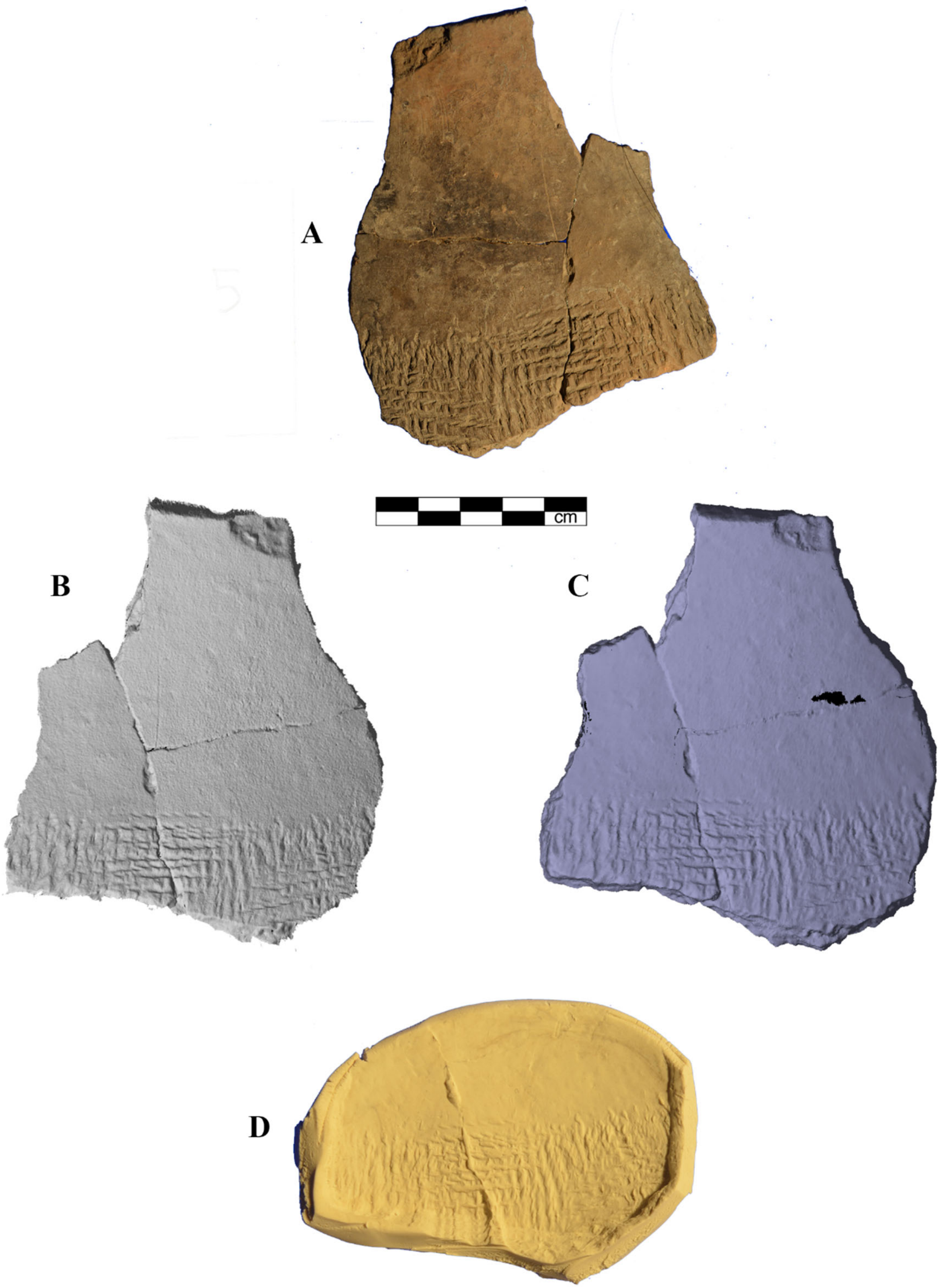

Figure 4.5. Representations of Sherd 5. A: Actual Sherd. B: NextEngine C: GoMeasuree3D D: Original Sculpey® Cast.

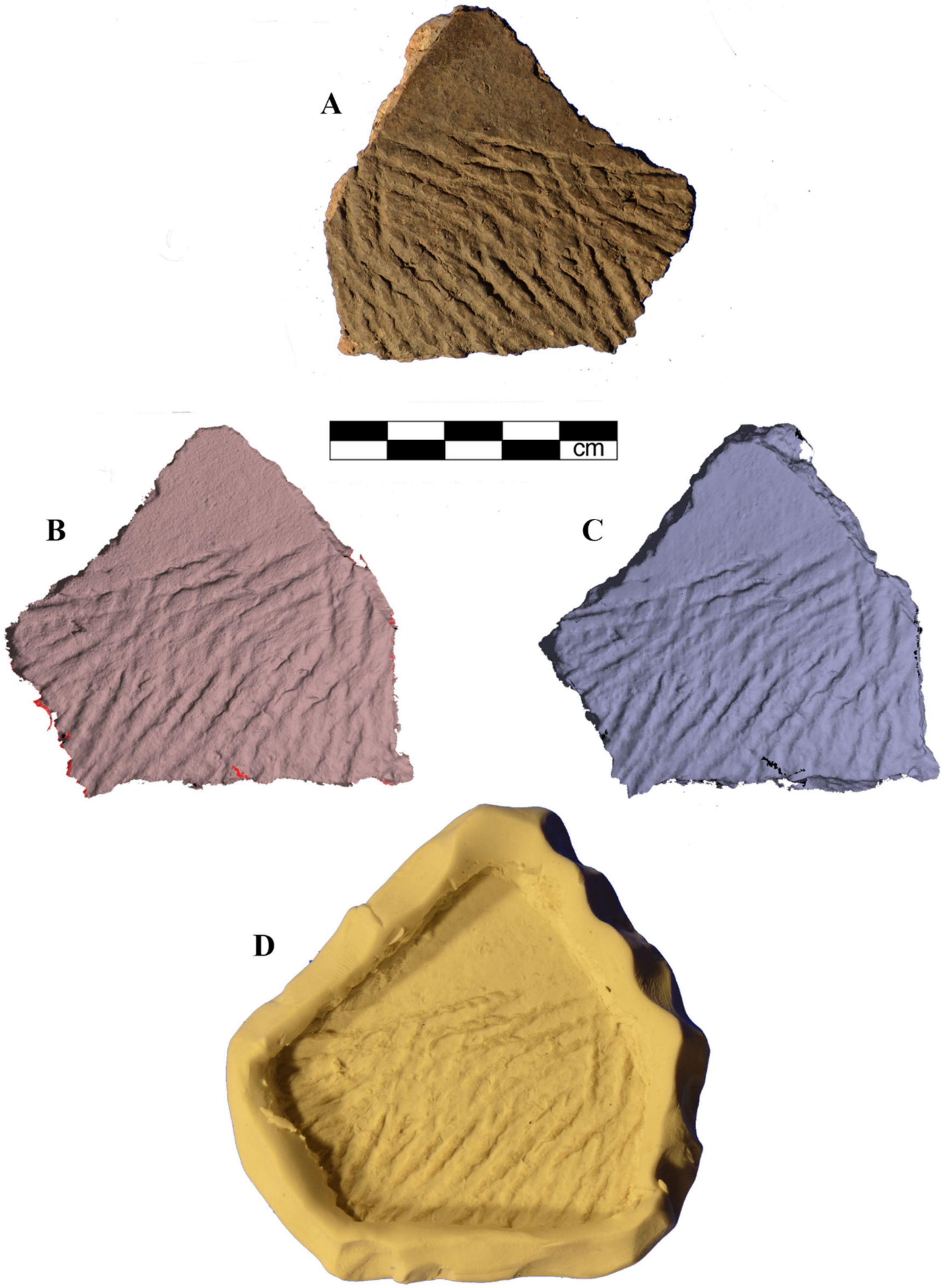

Figure 4.6 Representations of Sherd 6. A: Actual Sherd. B: NextEngine C: GoMeasuree3D D: Original Sculpey® Cast.

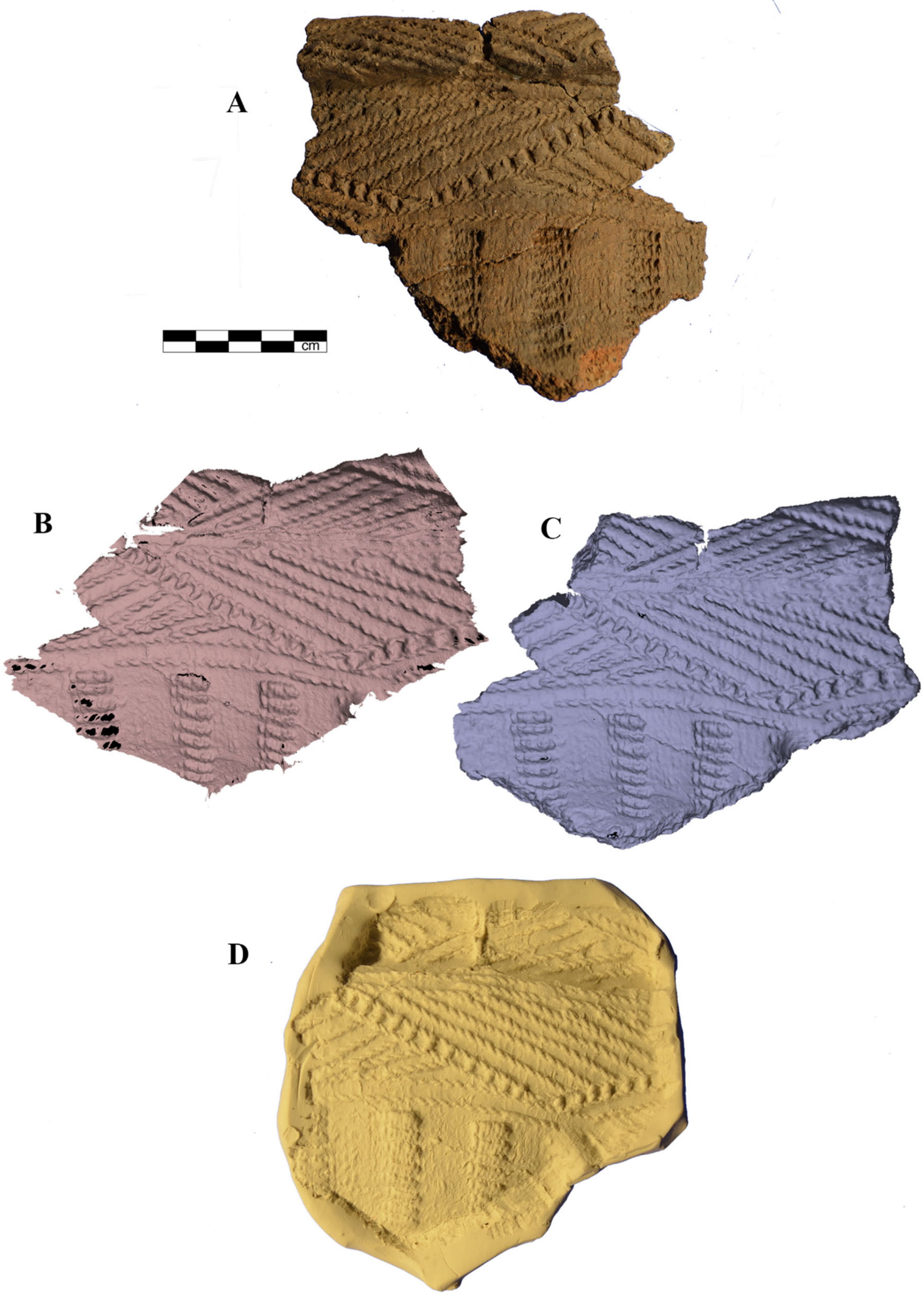

Figure 4.7 Representations of Sherd 7. A: Actual Sherd. B: NextEngine C: GoMeasuree3D D: Original Sculpey® Cast.

Sculpey® Casts

Accuracy of Method

All measurement recorded during this research are listed in Appendix B. Since Sculpey® was the basis for comparison in this study, differences in attribute measurements have been discussed under "NextEngine: Accuracy of Method" below.

Individual fibers were visible in some of the casts. If well-pressed, the casts offered an analyzable representation of the cordage. However, some distortion occurs when the cast is lifted from the sherd. Additionally, if the Sculpey® is not carefully pressed into the sherd, the cast may be incomplete. In some of the casts, areas are visible where the Sculpey® did not completely fill the cord markings and impressions, leaving flat spots. Because of the lack of shrinkage, measurements could be taken both before or after the curing process, but there is a risk of deforming the casts either by being too forceful with the calipers or by mishandling the uncured cast. Since the casts were stable when cured, measurement after curing was preferred.

Damage to Sherds

According to Allman (2019), the plasticizer in Original Sculpey® and other polymer clays can soften different plastics. For instance, a small piece of the Sculpey® used in this project had been stored on a plastic magazine organizer for some time, causing the plastic around the Sculpey® to soften, appearing "melted". This was the first time such a reaction was observed, and the discovery triggered an investigation as to what other plastic objects polymer clays might "melt". A concern grew that Sculpey® might have a similar effect on sherds mended with B-72, an adhesive commonly used in archaeological ceramic conservation (Koob 1986). A basic test was devised by simply sticking some B-72 in Sculpey® and leaving it for a week. This

test confirmed that the plasticizer in Original Sculpey® softened B-72, as a pool of B-72 formed in the Original Sculpey®. It was not clear what plastic was used on the sherds in this study, but labels that had once adhered to the sherds had been lifted off the sherds. It was also observed that an ingredient (likely the plasticizer) was almost immediately absorbed into the sherds (see Fig. 4.9). If that ingredient remains in the sherd, it would likely inhibit future consolidation efforts. Due to these discoveries, it is advised that researchers should thus use extreme caution in using Original Sculpey® or other polymer clays as casting media as these materials have the potential to weaken plastic-based conservation treatments. Reduction of the amount of time that the polymer clay is in contact with the sherd is the obvious solution, but some residue is transferred almost immediately. Additionally, the clay must be pressed gently into the sherd long enough to create a detailed enough cast. If not casted well, the clay must either be re-kneaded and recast or new clay must be pressed into the sherd, prolonging the time that the sherd is in contact with the clay anyway. Figure 4.9 shows clear discoloration on Sherd 5 immediately after casting. The darker area has been contaminated with the polymer clay, darkening it with leeched plasticizer and other liquid ingredients. It is known that the ingredients of Sculpey® and other polymer clays tend to soften plastics under recycling category 3 (Hallmer 2019; Kato Polyclay 2012). If the Sculpey® is undercured (and this can be difficult to determine), the plasticizer may still be active and can still soften certain plastics, so it is important to store the casts in polyethylene bags or containers, that will not be softened by the plasticizer. This information is in addition to the warnings Minar (1999), Rieth (2004), and Drooker (2000) supply regarding Sculpey® residue affecting compositional analyses and radiocarbon dating results. Finally, Sculpey® and other casting media tend to lift any loose surface particles of pottery, causing physical damage to the sherd (Figure 4.8, remaining photos of casts under the Digital microscope are in Appendix D.

Subsequent castings can lift additional particles, and multiple casting is occasionally necessary to achieve satisfactory results.

Figure 4.8. Pottery particles from Sherd 1 embedded in Sculpey® cast, shown under Digital microscope.

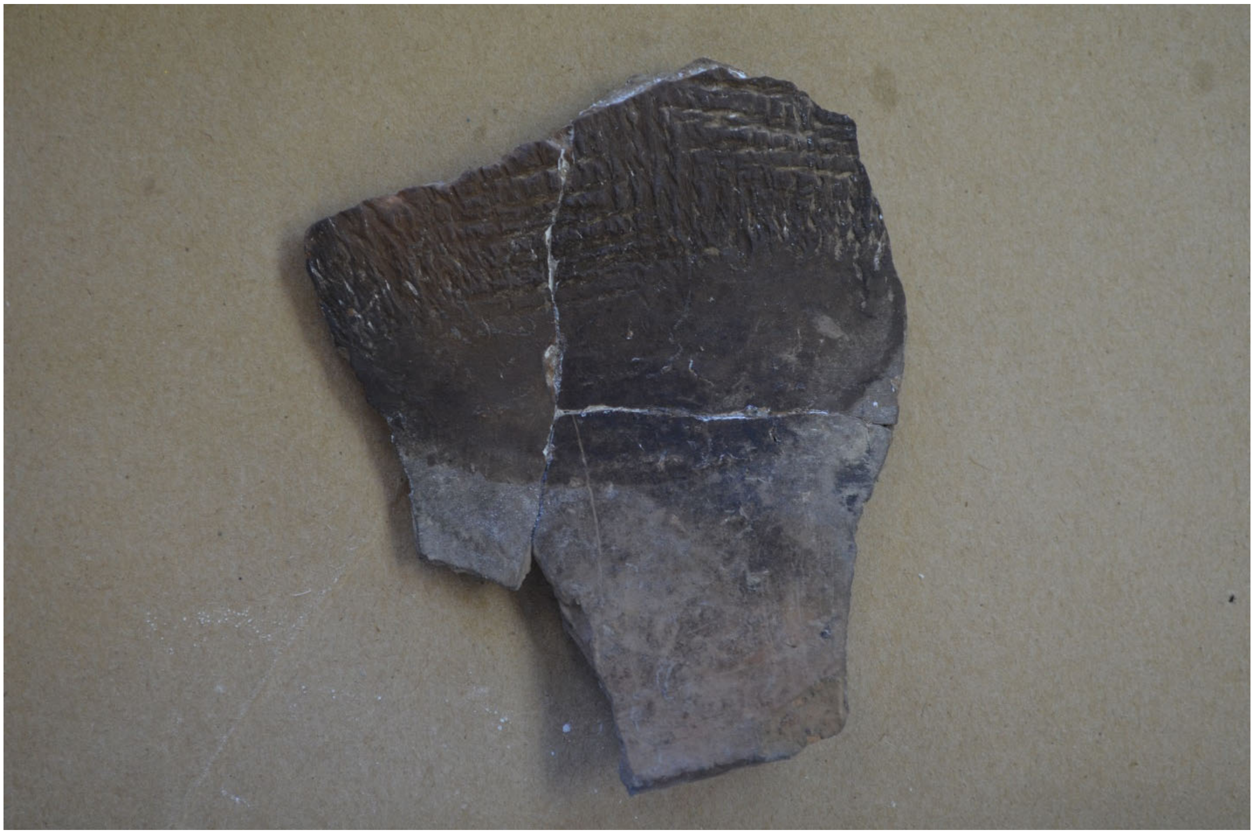

Figure 4.9. Sherd 5 immediately after casting.

Cost per sample

Three boxes of Sculpey® were purchased for this project, one of which was a 1 lb. box that was not properly contained in a polypropylene bag. Two of the boxes were 1 lb, and the last was 1.75 lbs, so a total of 3.75 lbs of Sculpey® was purchased for this project. Table 4.1 shows how much Sculpey® was used per sherd and how much Sculpey®, on average, is used per cm^2 of sherd. Ideally, one would have a ¼” thickness of Sculpey® covering the entire sherd surface, but the process of pressing the Sculpey® into the sherd can throw that off quickly. Approximate sizes of sherds are based on the maximum width multiplied by the maximum length of the sherd, though two of the sherds were not completely cast because they were not completely cordmarked.

Table 4.1. Amount of Sculpey® Used For Each Sherd				
Sherd Number:	**Weight of Casts**	**Approximate Size of Sherd**	**# of Casts**	**Sculpey® per cm^2**
1	353g	272 cm^2	1	1.29g
2	93.97g 80.78g 86.25g	52 cm^2	3	1.79g 1.54g 1.65g
3	137.31g 98.71g 86.71g	74.75 cm^2	3	1.85g 1.33g 1.16g
4	51.75g	38 cm^2	1	1.34g
5	54.46g 50.46g	32 cm^2	2	1.69g
6	49.52g	39 cm^2	1	1.25g
7	160g	105 cm^2	1	1.52g

If one purchases several 1 lb. boxes of Original Sculpey® at $12.49 a box and that the average sherd is 87.43 cm^2, this means that it costs $3.91 a sherd to cast. Figure 4.2 shows how much that would cost to cast up to 2000 sherds (or the number of sherds with surface area equivalent to 174,860 cm^2). At about 1300 sherds of average size (or the number of sherds with surface area equivalent to 113,659 cm^2), the NextEngine including components and software begins to provide a more cost-effective solution.

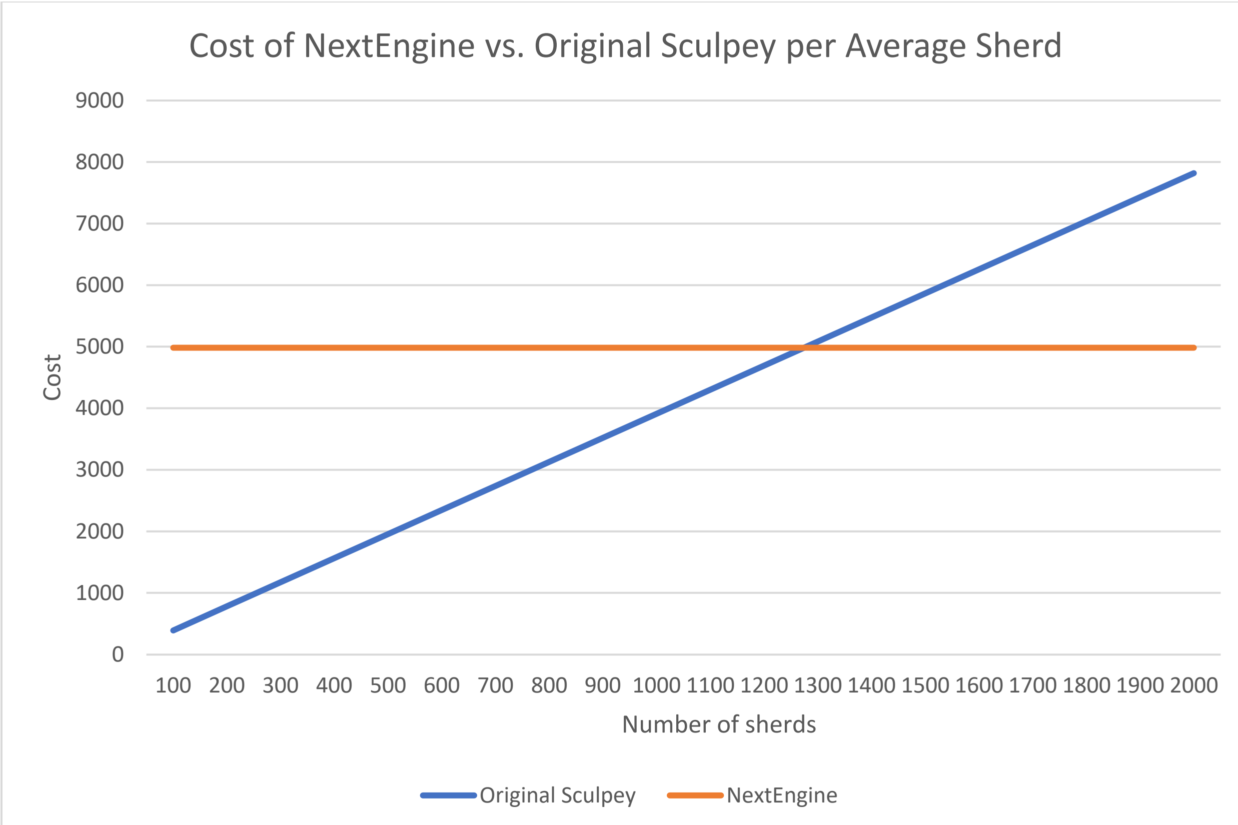

Figure 4.10. Cost of NextEngine vs. Original Sculpey®

Ease of Use

While Original Sculpey® may appear easy to use, it can be a surprisingly finicky medium. Users are encouraged to visit websites like the Blue Bottle Tree for helpful information if one cannot find what they need from the Polyform Products website. Polymer clays used to occupy the realm of craft, though as artists challenged and continue to elevate the medium, more technical information became available The Blue Bottle Tree is meant as a resource for polymer clay enthusiasts and goes more in-depth as to the various materials and their properties used for polymer clays, including an article about a brief test the author conducted to see which plastics different polymer clays would soften (Allman 2019). In short, it is precarious to work with a casting media when the company that produces it has not tested it for archaeological purposes. However, cost and ease of use may play a big role in conducting a large analysis. Additionally,

Conservation of Plastics contains important information about the properties of plasticized PVC (Shashoua 2008).

During the writing of this thesis the Sculpey® website was updated by replacement of a static "FAQ" section with a "Community" section placeholder. Although in development at the time of this publication, the new section appears to be an attempt to provide a platform for crowd-sourced information concerning Polyform's products. Additionally, it is of note that when the author emailed technical questions to the Polyform company, they typically responded either the same day during business hours or the following day (Personal communication, 2020).

The first 1.75 lb. box of Original Sculpey® that was used was purchased almost one year prior to use. The assumption was that the softness of the clay would remain the same if sealed in an airtight bag. However, the older clay required more conditioning than freshly purchased boxes. New boxes of Original Sculpey® were much easier to press into the sherds than the year-old material and provided better casts in general. However, one can store polymer clay in a polypropelene bag, away from sunlight, and in the freezer to maximize how long it will last. "Reducing the storage temperature from ambient to that of a domestic freezer slows the rate of diffusion of plasticizer from polyvinyl chloride (PVC) by a factor of 15" (Shashoua 2008:203). Less plasticizer means that the uncured polymer clay will be less plastic, so one might consider storing unused polymer clay in a freezer if the intent to use is not immediate.

When casting sherd #2 for the first time, the Sculpey® cast conformed to the contours of the sherd. Once placed on a metal pan lined with parchment paper prior to firing, the cast flattened. In order to prevent this the sherd was recast and it and all subsequent casts were placed in foil containers filled with cornstarch. Since cornstarch does not burn at 275º F degrees, it is an

ideal medium for supporting the contours of the clay while it is curing. If cornstarch is not available, baking soda will perform equally as well.

Some of the sherds required up to three casts before adequate results were obtained. Drooker (1992:292) also reported sometimes having to make multiple casts per sherd.

The process of preparing the Sculpey® and pressing it into the sherd takes 10-15 minutes. The amount of time it took to cure the casts, however, was much longer, and this was mostly due to the toaster oven used to cure the casts. The temperature on the dial of the Toastmaster oven does not align with the actual temperature inside the oven. The Sur La Table thermometer helped in this regard. Since the probe was placed as closely as possible to the Original Sculpey® casts inside the aluminum foil container as possible, it showed the actual temperature next to the Sculpey®. Typically, about 40-60 minutes was required for the temperature of the Sculpey® to reach 275° F. The toaster oven had to be monitored to ensure the temperature did not get too high and "burn" the Original Sculpey®. Overall, the process of heating up the oven and curing the casts took about 90 minutes per cure session. The size of the tray in the Toastmaster was 12" x 9", which meant, depending on cast size, that only a few casts could be simultaneously cured Sherd 1 was so large it was cured alone. This process could be greatly alleviated by having access to a larger oven with accurate temperature, though a digital temperature probe is still recommended due to the intolerance of the Sculpey® for too little or too high temperature or incorrect curing time.

Permanency of Data Acquired

The major factor affecting permanency is how well the Sculpey® is cured. If undercured, it can eventually become brittle and crumble (Allman 2019). Otherwise, if stored in labelled polypropylene bags and in proper environmental conditions it should remain stable. The

Polyform Products Company laboratory reported in an email to the author that they are not aware of a formal study on the longevity of cured Original Sculpey®. They do, however, have examples of their products that are at least 15 years old. They also reported that PVC is a stable resin with an average lifespan of 30 years (Polyform Products Company, Personal Communication 2020). As seen in the properties of PVC (Fig. 3.15), PVC undergoes dehydrochlorination under exposure to heat and light (Shashoua 2008:252), so one should be careful not to allow extended exposure to either of these in storing cured casts.

NextEngine

Accuracy of Method

Some of the digital measurements differed from those recorded directly from the Sculpey® casts, so averages were calculated based on absolute difference. On average, cord diameter measurements taken from the NextEngine varied 0.35 mm absolutely from the same measurements taken from the Original Sculpey® casts (see Appendix B for data tables of the measurements). This may be due to a variety of reasons: First, the digital representations "fill in" based on points, then use an algorithm to decide how to shape the space between. Both the NextEngine and the GoMeasure3D HDI R1X connect the vertices with lines, creating simple polygons like triangles and rectangles.

When measuring attributes of 2-ply cordmarkings, the NextEngine and Sculpey® casts produced similar data, but the mesh produced was not a good representation for the complexity of the impressions. Measuring attributes for Sherd 7 illustrates the greatest difference between the two methods in quality of representation. Sherd 7 (see Fig. 4.8 for Sherd 7 decoration organization) appears to be fabric-impressed, though without the obverse of the fabric it is difficult to see how the warp and weft connect to one another. It could also be an elaborate series

of single-cord impressions, though structures in Zone 2 suggest fabric. Fig. 4.13 is an illustration of a Madison cord impressed potsherd with similar fabric markings to Sherd 7, as well as Hurley's illustration of the proposed fabric structure. In Zone 1 and 2 as well as the parallel single cords, it is clear that the cordage used is more than just 2-ply. One can see 4 beads per segment in the cast, but not in the 3D meshes. This strongly suggests that the level of detail that these 3D scanners can obtain are not quite enough.

Meshlab, while a free, opensource software product, had limited measuring ability. There was no way to measure exactly 1 cm or other discrete measurement, but it will give the exact value of a created line in millimeters. The twists per centimeter had to be rounded to what appeared to be the nearest twist. Other authors have been able to report a fraction of a twist (e.g. Drooker 1992) while others (e.g. Karroll 2009) did not. Measuring fractions of a twist was not possible due to Meshlab's inability to set a discrete measurement, such as 1cm. However, its ability to measure more than 1/100th of a millimeter was comparable to the handheld digital calipers. Therefore, while Meshlab is not perfectly suited, it functioned well enough.

Damage to Sherds

Since the object depends on two points to secure it to the platform, if it is weighty enough and the platform is tilted enough, the object may fall out. This is one of the few circumstances where a scanned object may be physically damaged by the scanning process. Another potential source of damage results from the scanner's inability to collect data from highly reflective surfaces. Thus, sherds with polished or burnished surfaces must be treated with talc or some other medium that reduces reflectivity. However, the sherds were not reflective so this was not much of a consideration.

Cost per sample

The standard package for the NextEngine is $2,995, and includes the NextEngine scanner itself, a mechanized turntable with a gripping arm, the ScanStudio™ software, and a few extra minor accessories such as marking pens and talc. Because the sherds have significant contours, the Multi-Drive was also necessary, and cost an additional $995. Finally, in order to have full resolution and to enable Macro Mode, the ProScan software was also purchased for an additional $995. Thus, total cost is approximately $4,985. The cost of a laptop computer is excluded from the total. However, minimal requirements consist of a machine like an HP Omen laptop with Windows 10 Home (64-bit) an Intel® Core™ i7 processor, a NVIDIA® GeForce® GTX 1660Ti (6GB), 16 GB memory, and 256 GB SSD. At the time of writing this configuration is available for about $1,049.99. However, it is clear from this project that effective use of the NextEngine requires a more powerful computer with at least 19GB of RAM.

The proprietary NextEngine software, ScanStudio™ ProScan, must be installed on the chosen computer as the NextEngine only works with this software. The ProScan software enables twice the scan speed and four times the density of points captured, as well as "macro mode", which was used extensively for this project because of the level of detail needed. Also used was the multi-drive turntable device, which not only rotated 360-degrees, but also tilted the scanning platform up to 45-degrees backwards or forwards. This was necessary to maximize the penetration of the laser into the sometimes-deep impressions of the cordage.

Ease of Use

Calibrating the multi-drive takes roughly 20 minutes. According to the NextEngine specifications, the average scan file is 200 MB. The scan files created in this study were between 500 MB-1,000 MB, so they are above average size for the NextEngine. Gaining facility with the

NextEngine requires negotiating a steep learning curve, as it is not immediately apparent what certain terms such as “Light”, “Neutral”, and “Dark” (Lemeš and Zaimović-Uzunović 2009) mean in the interface, nor is it clear what scan families are.. Also, the gripping of the part arm that holds the item to be scanned is not totally secure, even if screwed in place. If the object is heavy enough and the multidrive is tilted too much, the object will slowly rotate forwards or backwards. It is important that a scanned object remain in the same position for the entirety of the scanning so that the automatic global alignment feature in ScanStudio™ can properly align different scans. Thus, if the object is moved incorrectly, the final scan can be ruined.

Macro Mode is limited to a 5.1” x 3.8” field. If the sherd is larger than this, it can create problems. For example, the exterior surface of Sherd 1 is completely covered with cordmarkings, but it is also the largest sherd in the sample. The scans, when a workflow was established, took about 40 minutes each. The scanner will create three scan families, then the software needs to align them, producing a successful mesh. What was not expected, however, was the amount of time it would take to save the files, which took about 15 minutes per file. The files could not be saved to the computer that had scanned them, so they were uploaded to the UWM anthropology server, which had plenty of space to store the several gigabytes of data for this study. If the server had not been available, files would have had to be shuttled to the HP Omen via jumpdrives, which is a much slower process.

Since processing memory is crucial to successful scans, programs running concurrently with the scanner software can hinder or stall the process of creating a useable scan. In the present case, a few programs ran on the HP Omen that used up available memory at any given time, as shown in Figure 4.4. The programs include Cortana (an irritating digital assistant feature that cannot be turned off) and Avast antivirus, which is an anti-malware program that the author

installed purposefully as an alternative to Windows Defender. Cortana utilizes 48.3 MG of memory and Avast uses about 28.9 MG. This, according to the task manager, uses ~30% of the available memory, along with Microsoft Word. All this memory usage is important to note because opening any of the .5-1.5 GB 3D files uses a lot of memory, CPU, and graphics. Some of these programs will automatically start upon turning on the laptop, like the Microsoft Teams application, OneDrive, Adobe Creative Cloud, the AvLaunch component (also part of the AVAST antivirus software), Steam, Windows Defender, Pulse Secure User Interface (a VPN), CCleaner, and some HP software that came with the computer. So, it is not advised to have only necessary background programs running and no other active programs running while working in Meshlab. One can modify which programs open automatically upon startup in the settings of Windows.

At first, it was assumed that the CPU or RAM was not enough to open the files, which led to much frustration. Meshes 5, 1, and 7 would not open or were very choppy, therefore unworkable. Weeks later (and after much frustration), it was discovered that it was a graphics issue, not RAM or CPU. The graphics card is responsible for the visualization of data. As previously stated, some laptops have two graphics cards: an integrated one and a high-performance one. When Meshlab is first downloaded and opened, it runs off the integrated GPU by default. Even after setting it to open with the high-performance GPU option, one must manually change the setting to allow it to use a larger amount of GPU processing, as stated previously in methods. Simply by changing these two settings, the meshes for sherds 1, 5, and 7 finally visualized on the HP Omen and were not even choppy. While this seems a very foolish error, it serves as an important lesson in demonstrating that 3D technology is only as good as the expertise of the operator. Therefore, the learning curve for utilizing 3D technology can be

surprisingly steep. The author, admittedly, did not initially understand the difference between the CPU, RAM, and GPU. Having a more than basic understanding of computers is necessary to have the best results while attempting to co-opt 3D technology for archaeological use.

Permanency of Data Acquired

Like any digital file, the use-life of the mesh files created by the scanner are tied to the use-life of the medium they are stored on. The use-life of digital media varies widely. Modern optical media (CD, DVD, etc.) may have relatively short life spans of 5-12 years but some manufacturers claim as much as 100-200 years if stored in a controlled environment. Manufacturer claims for the M-Disc suggest a 1000 year data storage life (CLIR website; Lunt 2012). Magnetic hard drives are suggested to be useable for up to 7 years, while static memory cards and drives may be good up to 12 years. The use life of data stored on servers will depend on the degree to which the servers are maintained and updated. Theoretically, there should be no limit to this kind of storage Regardless of how the data is stored, it is strongly recommended to have multiple copies of the meshes and native NextEngine (or any 3D scanner) files saved to a few data storage options. For instance, for this thesis, all data was saved to the HP Omen hard drive, backed up to the UWM ARL server, and finally saved on a personal external hard drive. One can save the file in various places, but one should also know whether the file is changed in anyway when it is saved to a different source, especially online, in a compressed format, or changed to a different file type.

GoMeasure3D HDI R1X

Though it is outside the scope of this project to discuss in detail the cost and ease of use for the GoMeasure3D HDI R1X structured light scanner, attribute measurements were taken to contrast with the NextEngine scans. In general, the meshes produced by the GoMeasure3D HDI

R1X had fewer kilobytes, face, and vertices than the NextEngine files (see Figs. 4.6 and 4.7) and possessed less accurate representation.

Accuracy of method

The cordage diameter measurements taken from the GoMeasure3D HDI R1X meshes were 0.40 mm different on average from the Original Sculpey®. What is interesting is that, in close-up, the way the meshes filled in between points was different (see Figures. 4.5 and 4.6). The GoMeasure3D HDI R1X filled in between points with basic polygons, while the NextEngine appeared to fill in with contoured shapes. It is possible that there was a setting in ScanStudio™ ProScan that prevented this way of filling in between points, but the two methods varied from each other by only 0.20 mm.

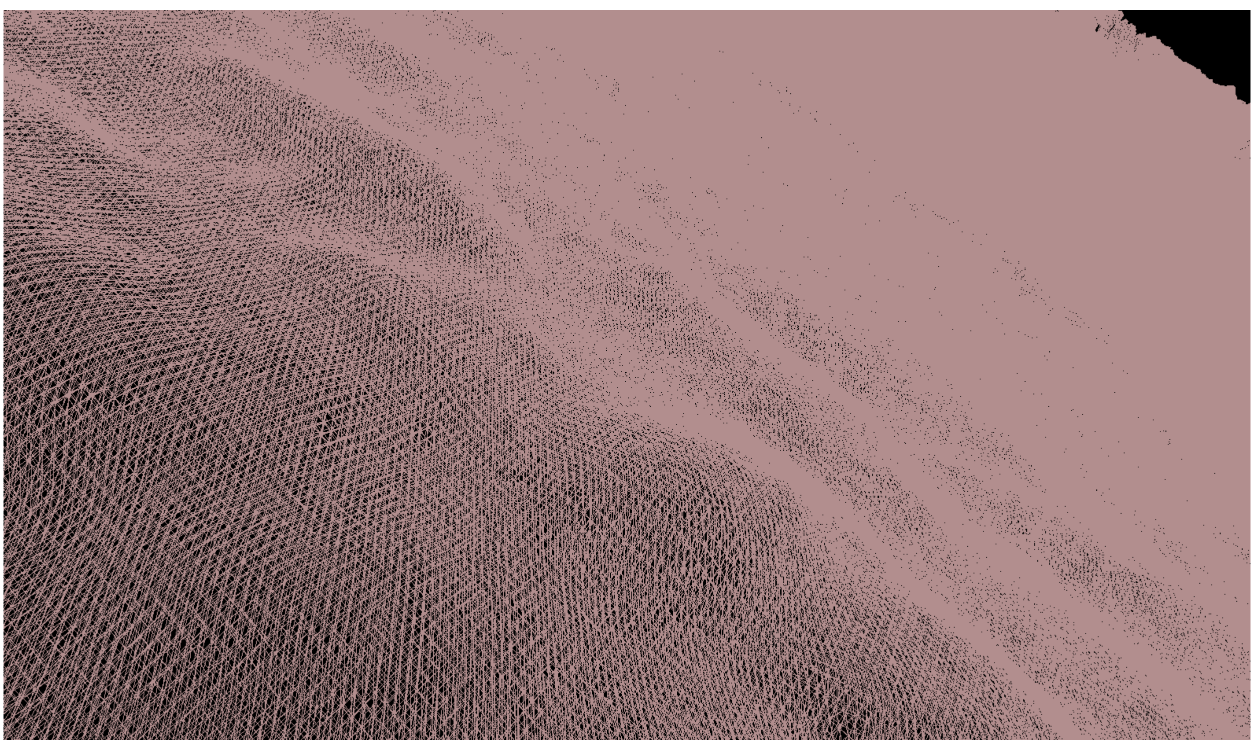

Figure 4.11. Close-up of the mesh of Sherd 4. Note the density of points.

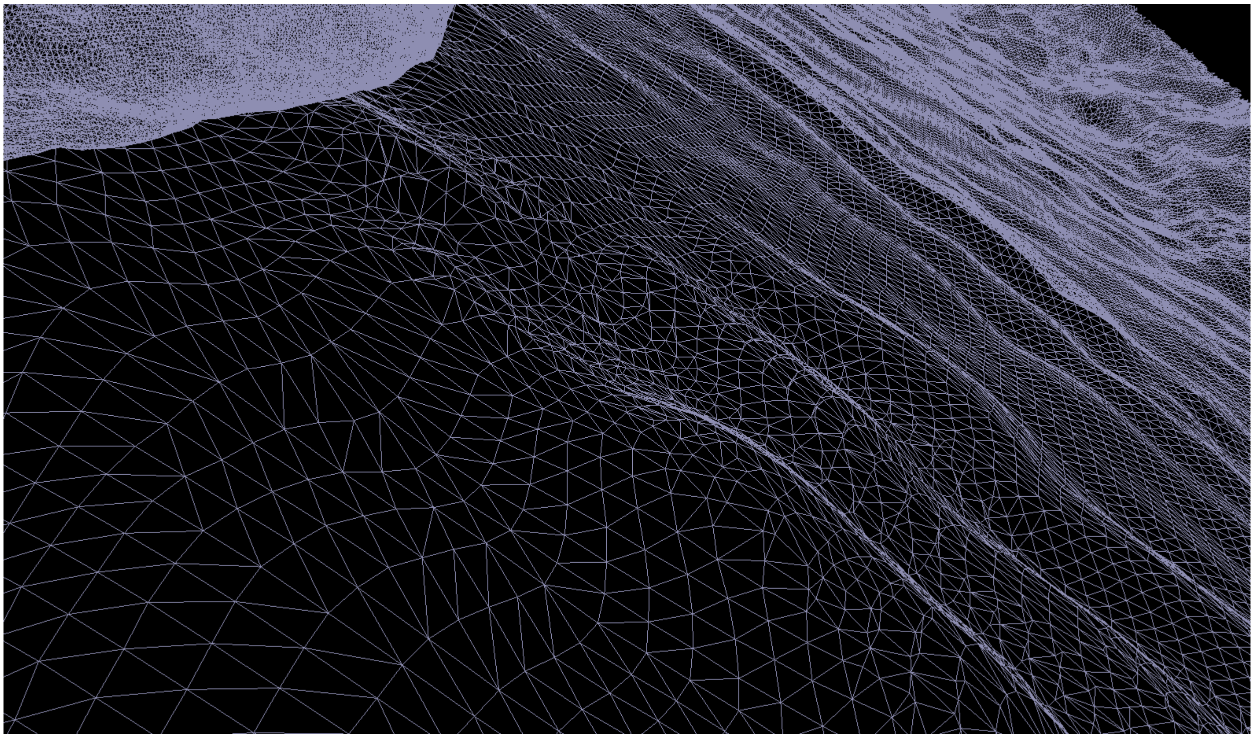

Figure 4.12. Same view of Sherd 4 as Fig. 4.6, but of the GoMeasure3D HDI R1X mesh.

Ease of Use

Like the NextEngine, the GoMeasure3D HDI R1X must be calibrated, but the process is different and takes longer to complete. One must select a calibration target depending on the size and scale of the object one wishes to scan. The target is placed on a turntable facing the scanner, and the software takes a measurement. The target is rotated at different angles until a sufficient calibration percentage is achieved. This required the operator to position the board 75 times, and the process took 30 minutes. However, all seven scans were completed within one 8-hour workday, including calibration, setup, and takedown.

Cost per Sample

The GoMeasure3D HDI R1X was purchased by Dr. Derek Counts. The total cost that was paid was $15,118. This cost includes the entire setup--the scanner, the turntable, the software, the DSLR camera, the Point Grey cameras, and other accessories.

Permanency of Data Acquired

Similar to NextEngine; see above discussion under “NextEngine: Permanency of Data Acquired”.

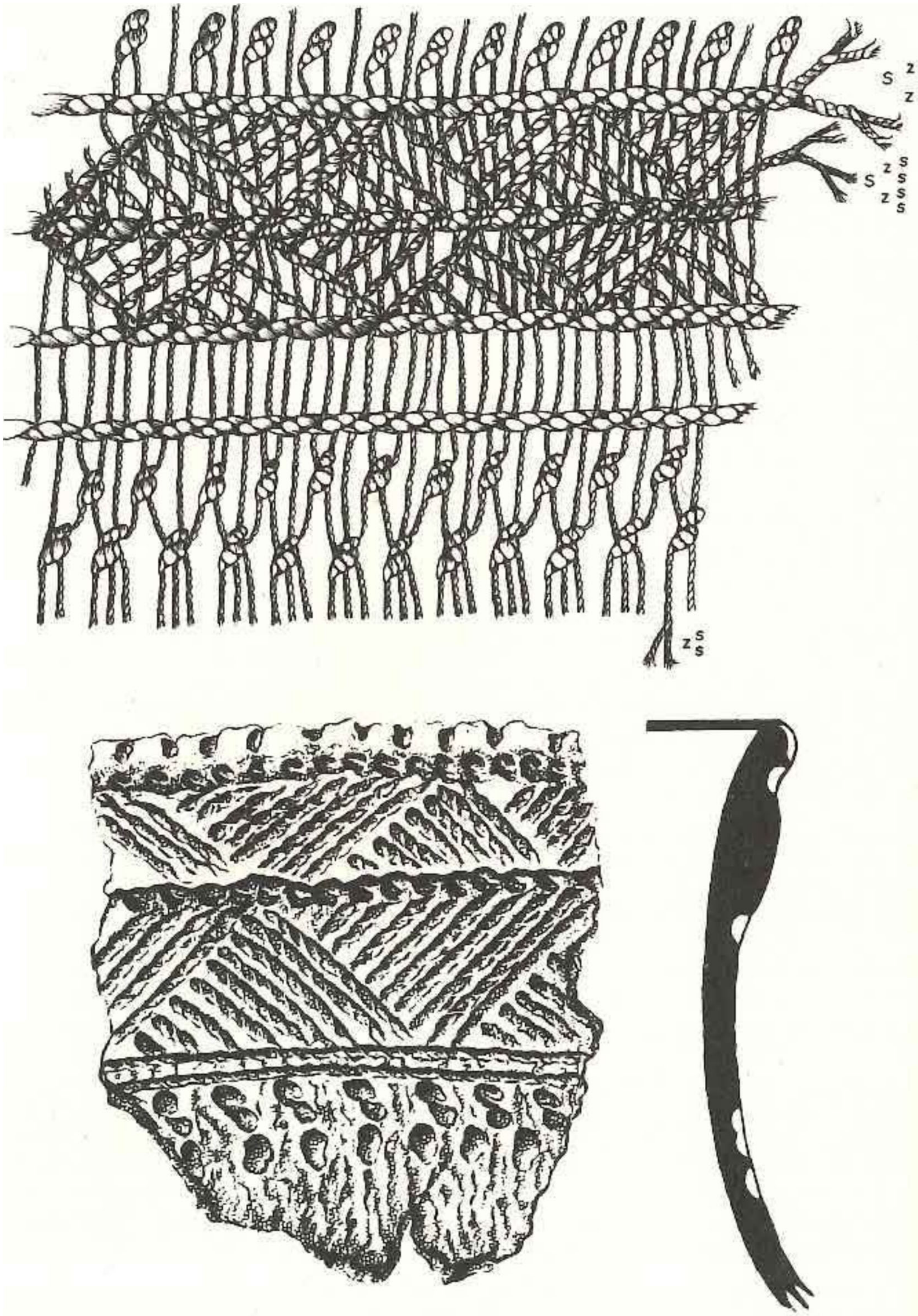

Figure 4.13. Top, reconstruction of a woven fabric capable of creating the surface impressions seen on the rimsherd; bottom, rimsherd of the type Madison Cord-Impressed (Hurley 1979).

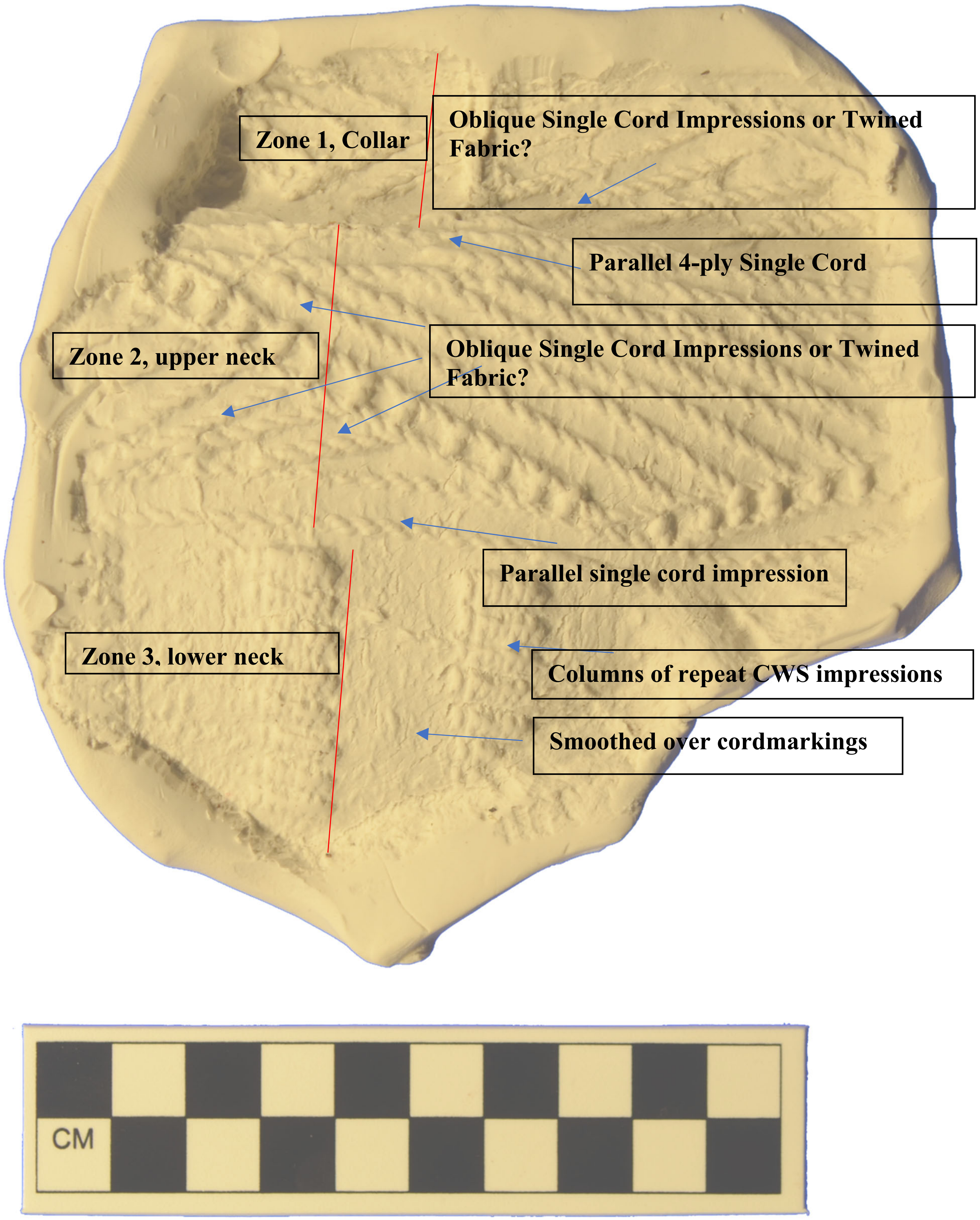

Figure 4.14. Organization of Sherd 7 decoration.

Chapter 5: Summary and Conclusions

Summary of Results

Results were assessed by a qualitative comparison of the three methods tested across seven variables. Variables include ease of use, startup costs, cost per sample, time per sample, level of detail captured, surface alteration, and data permanency. Results are shown in Table 5.1 and are discussed below.

Table 5.1. Summary of Comparison of Representation Methods

	Original Sculpey®	NextEngine	GoMeasure3D HDI R1X
Ease of Use[1]	3	4	N/A (expert used)
Startup Costs	\$35 for a Toastmaster \$30 for digital thermometer \$10 for foil and cornstarch \$13 for one 1 lb. box of Original Sculpey® \$103 total.	\$4,985 for NextEngine package \$1,050 for laptop \$6035 total.	\$1,050 for laptop \$15,118 for scanner, software, travel cases, DSLR camera, etc. \$16,168 total
Cost per Sample	\$3.91 per sherd 87.43 cm² in size	Depends on # of sherds	Depends on # of sherds
Time per Sample	2-3 hours per tray of casts	After calibration, ~45 min to scan, then additional ~20 min. to export and save	After calibration, sherds took 10-15 minutes to obtain
Level of Detail	Sufficient, but may require multiple castings	Can only see final twist diameter consistently	Can only see final twist diameter consistently; does not capture as many points as NextEngine
Damage to artifact	Moderate to Severe	Low (Object may fall from platform)	None.
Data Permanency	Possibly more than 30 years.	Based on server storage, 3-10 years[2]	Based on server storage, 3-10 years[2]

1. Ranked 1-5, easiest to most difficult
2. May be indefinite with proper maintenance, data conversion, and/or cloud storage

Ease of Use

Using Original Sculpey and the NextEngine were almost similar in difficulty. Sculpey was surprising in its difficulty, since the concept of what needs to be done is simple (press into clay and then bake), but the execution requires finesse. The NextEngine (and then working with the meshes in Meshlab) is quite the opposite; the concept of what needs to be done and why requires research but once a procedure is established the process becomes streamlined. The benefit of obtaining a representation with the NextEngine is that once it is setup and the scanning begins, it is a passive process during which one can accomplish other tasks, albeit while still in the same room to monitor.

With both the NextEngine and GoMeasure3D HDI R1X, one needs to understand how the scanner functions, what algorithms are used to fill in data, how to use the program, how it will work with the object being scanned, what file to save and why, which program to use for visualization, and how to use that visualization program. In other words, east of use for 3D scanners is only as good as the researcher has prepared. Otherwise, it can lead to such frustrations as working for weeks with a false assumption (with regards to the CPU/GPU confusion) or saving files unnecessarily as ASCII encoded .stl's.

Startup Costs

For this project, startup costs for Original Sculpey® included a toaster oven, digital thermometer, foil, and cornstarch. Therefore, startup costs were approximately $103 for Original Sculpey®, assuming at least one box of polymer clay is purchased.

The NextEngine requires the base NextEngine package, the Multi-Drive, ProScan software, and a computer to run them on. The total is $6035.

The GoMeasure3D HDI R1X. It is much more expensive ($16,168) than the NextEngine, though it had less resolution.

Both scanners require a laptop with enough GPU, CPU, and RAM to run the software and to visualize the meshes. Meshlab is free.

Cost per Sample

For Original Sculpey®, it is $3.91 per sherd 87.43 cm^2 in size, not factoring in the cost of one-time purchases like the toaster oven, thermometer, foil, and cornstarch.

For both the NextEngine and the GoMeasure3D HDI R1X, only the startup costs are necessary, so the cost per sample diminishes as more objects are scanned. However, it is not known when these scanners will fail or become obsolete technology. It is important when considering what equipment to purchase for a laboratory to remember that what is purchased will likely be used for more than one project and maybe for more than one purpose.

Time per Sample

Original Sculpey® must be kneaded for workability, rolled out, pressed into the sherd, and then removed and placed onto a bed of cornstarch. This process takes about 10-15 minutes per sherd. Then, once the tray is full, then the casts must be cured. It takes the toaster oven a while to come to the correct temperature, then it must be held at that temperature for at least 15 minutes. In total, this process takes at least 40 minutes, then the casts must be allowed to cool. This process can take up to two or three hours per tray, then, including setting it up, curing, and cooling. It is necessary to monitor the curing process to ensure that the casts do not burn and are held at the correct temperature, but one is free to do other work while waiting for the temperature probe to read 275° and during the cooldown process. The temperature must be watched closely during the 15 minutes after it reaches 275°. The time that it takes to cure would improve

significantly if large cookie sheets and a large kitchen oven was used. However, it may not be possible to bring the casts to an oven without deformation or to move the sherds. The initial cost would increase (especially if a new oven is needed), but it would reduce significantly the amount of time spent curing.

The NextEngine takes about 20 minutes to calibrate the multi-drive. Then the scan must be set up and taken, which takes about 45 minutes. The researcher is free to accomplish other pursuits while the scan occurs. Then the file must be exported, which can take 10 minutes. In total, the process takes at least 75 minutes to accomplish including calibration, 55 excluding calibration.

Level of Detail Captured

Original Sculpey® can capture detail enough to see individual fibers, provided one has pressed the clay into the details of the sherd enough. Individual beads were visible. The NextEngine measurements varied from the Sculpey measurements 0.35 mm absolutely. This can be due to user error, lack of enough points per square inch, or the algorithm that the software uses to fill in the space between points.

Both the NextEngine and GoMeasure3D HDI R1X did not capture detail beyond cordage diameter and final twist. The beads in the cordage on Sherd 7 were not visible at all. The GoMeasure3D HDI R1X did not capture as many points per square inch as the NextEngine.

Damage to Sherd

Original Sculpey® poses severe risk to the integrity of the sherds. The plasticizer can weaken consolidants like B-72, it contaminates the sherd with residue making which does not allow for residue analyses, and it is not clear how it can be removed. Additionally, this can

hinder future consolidation efforts. One should sample a collection to cast with Original Sculpey® or other casting media,

The NextEngine poses a low amount of risk to the sherds. This is due to only having two points of contact to secure the object on the turntable and the rig that is meant to keep the object secure. If the object is tilted too much on the Multi-Drive (the sherd were only tilted to 15° in either direction), the weight of the sherd will cause the rig to rotate. This movement would not only ruin the results of the scan, but the sherd can fall out of the Multi-Drive, causing physical damage.

The GoMeasure3D HDI R1X also poses low risk to the sherd. It depends on how one chooses to place it on the turntable or how to prop up the sherd.

Data Permanency

The actual shelf life of baked polymer clay casts is unknown, however the Polyform Products Company lab reported that they still have objects at least 15 years old. Additionally, Drooker reported that casts made 30 years ago for the Wickliffe project are still in good shape (Drooker, Personal Communication, 2019). Consequently, one should expect at least 30 years before properly baked and stored Sculpey® casts begin to deteriorate.

The use life of digital media varies widely. Modern optical media (CD, DVD, etc) may have relatively short life spans of 5-12 years but some manufacturers claim as much as 100-200 years if stored in a controlled environment. Manufacturer claims for the M-Disc suggest a 1000 year data storage life (CLIR website; Lunt 2012). Magnetic hard drives are suggested to be useable for up to 7 years, while static memory cards and drives may be good up to 12 years. The use life of data stored on servers will depend on the degree to which the servers are maintained and updated. Theoretically, there should be no limit to this kind of storage. Again, it is important

to note that data should exist in multiple places and that one should be aware of how that data changes if saved as a different file format, compressed, or uploaded to the internet.

Conclusions

This research has shown that even with the benefits of digital imagery, the NextEngine scanner is not yet adequate as a tool for detailed analysis of archaeological fabric impressions. This research has also demonstrated that Original Sculpey® poses substantial risk to sherds and, especially, consolidation efforts. Thus, one should continue to investigate alternative methods to obtaining analyzable representations of cord and fabric impressed pottery. Until a better solution is found, casting media is preferable, especially if one wishes to see multiple plies, the complexity of fabric, or individual fibers.

Before choosing a casting method, it would be best to consult with a conservator prior to applying the proposed method to a specific collection. Alternatively, if a product's website lacks information about the casting material a Google search may identify a blog, subreddit, or other crowd-sourced information to supplement the information from the product's website. It is very important that one investigate a material thoroughly before using it for an archaeological use. Some companies (such as Smooth-On) do understand that their products may be used to cast artifact, but one would still need to do some investigation as to how a product may affect an object. Of course, a conservator's opinion would be best, but sometimes one might not have access to a conservator's knowledge. In such a case, one should test materials on a similar object that is to the one that is being investigated.

In the near future, 3D scanners will likely become able to capture the appropriate detail. Some scanners likely do now, but the cost may be prohibitive. Despite the exciting prospects of 3D technology, however, this research has also reinforced what Tocheri has already warned

about the use of 3D scanning for archaeology (Tocheri 2009). Indeed, the technology was only as good as the operator. Much frustration led from trying to collect data based on insufficient research or incorrect assumptions. It is strongly advised that if one wishes to use a 3D scanner for archaeological purposes, one should consider each step of the process carefully. For instance, don't save files as ASCII-encoded .stl files unless one intends to alter the code of the file. Don't spend weeks assuming that the visualization software is slow because of CPU limitations when, in fact, it is that the software is not utilizing the full potential of the GPU.

3D scanning must be project specific. For instance, in order to 3D scan an underwater shipwreck in turbid water, one might need a different scanner, have different scanning conditions, and need to record data in a different way. One might need to consider the portability of a scanner, especially if the object to be scanned is one that is portable. One must also consider how the final scans will be used—curation, analysis, morphometrics—as this will dictate the level of detail one needs out of the scans. Finally, one must ask the possibly radical question: Is 3D technology really the best approach for the project? Because if there is already a method one can use that is cheaper, easier, and faster, then the choice should be obvious. Do not be lulled by fancy lasers and shiny new tech, because 3D technology possesses a learning curve that can quickly make the usage of it very frustrating for someone who is not technologically inclined.

It is worth mentioning that these methods can be complimentary. 3D files and physical casts can be scrutinized at the same time with the original sherd in hand. In fact, if the sherd is available, then scrutinizing both at the same time is preferable. 3D representations do not replace an object, and neither do physical casts. Sometimes the structure one observes in either kind of representation is clarified by physical examination of the sherd.

Future Directions

Again, 3D scanners will likely become more cost effective and able to capture smaller and smaller details in the near future, given the progress of computer technology since the 90s. Though neither the NextEngine nor the GoMeasure3D HDI R1X could capture the detail necessary to identify more than 2-ply cordage and cordage diameters, another test in the near future similar to this thesis's methods would likely prove worthwhile.

Reflectance Transformation Imaging (RTI) may represent a good technology for the analysis of impressed pottery. Drooker stated "A good light source, adjustable in height to allow side-lighting of the casts, was essential. Rotating a cast under side-lighting causes different yarn elements to become prominent, depending on their orientation. In order to be sure that no subtle structural attribute was missed, I did this for all sherds, paying particular attention when structures were complex or yarns were fine" (1992:252). RTI is a natural choice based on this because it allows one to artificially alter lighting scenarios on a representation of the object. The technique mostly focuses on the topography or texture of an object and has been used to identify such small details as brushstrokes in paintings (chimaging 2010). According to Mytum and Peterson, "Reflectance Transformation Imaging (RTI) uses many images of the same artifact taken from the same location, each with a light from a known direction, to create a composite image… The basic principle of RTI is that light reflects off the surface of an object, and the program can identify the light that reflects at right angles to that surface, the surface normal. By calculating the surface normal for numerous points, the topography of the surface is defined. This therefore creates a virtual 3-D topography of the object surface, which can allow the simulation of raking light from any direction, or the modeling of a more evenly lit composite image" (Mytum and Peterson 2018). RTI uses a fixed, single camera that takes a photo of

multiple light sources. A shiny sphere is used as a reference point, and the software can determine from a few angles of lighting all the angles of lighting possible. From that point, one can create a 3D mesh of just the topography of an object. Mytum and Peterson used RTI to create images of a variety of historic artifacts but did not include an example of fabric or fabric impressions. However, Goldman et al. (Goldman, et al. 2018) have presented a method they refer to as "micro-RTI" that the authors used to successfully image archaeological textiles using a Digital microscope. This method allowed for more detailed images of fabrics, otherwise not possible using regular photography.

Finally, it is possible to obtain partial 3D images from RTI that are very similar to the bracketed view produced by the NextEngine. In a paper presented at the 2016 Computer Applications & Quantitative Methods in Archeology Conference (2015) in Oslo, Norway, Porter, Missal, and Pawlowicz presented a paper that compared methods of creating 3D models of obsidian artifacts. Mostly, they were concerned with reducing the shininess of obsidian for scanning, since the shine can make it difficult to obtain the data. They discovered that the 3D representations created using RTI produced a distorted version of a lithic, as compared to the representation produced by the structured light scanner (Porter, et al. 2016) It was not made clear in the presentation as to why this happened, but it is not something to ignore if one wishes to explore this method.

If one wishes to obtain a 3D scanner, it may be beneficial to build one from parts rather than purchasing a system from one company. While it might not be an easier approach, it may be cheaper and more suited to the application. Schroeder et al. (Schroeder, et al. 2016) were able to obtain 3D files from equipment not originally intended for 3D capture utilizing a DSLR camera and a turntable. An RTI system used by Pawlowicz was also built from parts, which he has also

shared on the website Hackaday.io so that others may build the same setup (Pawlowicz 2016). RTI can also be accomplished with two people, a light bulb on a fixed string, a DSLR camera at a fixed point with a tripod, and a shiny sphere (a Christmas ornament would do perfectly). This demonstrates that one does not necessarily need to purchase a 3D scanner—one can co-opt other imaging equipment to suit the purposes of the project, provided there is software that will make a 3D file of the data. As Counts et al. notes, "A custom-built system is not only more cost efficient than comparable commercial scanners (US$40,000+), but allows for increased adaptability (adjustable for artefact scale, materials and so on), as well as continual upgrade as emerging technologies become available (e.g. higher quality parts can be added to the system and software can be re-written)" (Counts, et al. 2016). Many of the 3D scanners currently available are not meant specifically for archaeology, thus may not fit the specific needs of project, or are prohibitively expensive, so it is important to note that something that will fit one's need can likely be built from other imaging equipment and software.

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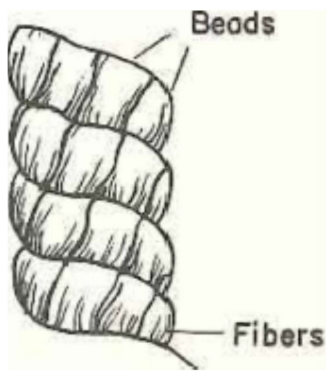
Appendix A: Glossary of Terms

Emery may have written an entire book to standardize the way researchers discuss fabric and other things made of fibers, but many deviations persist regardless, especially when one is discussing "cord" impressions in pottery. Additionally, after reviewing the literature surrounding the usage of 3D scanners for archaeological research, there exist some disagreement about "3D" terminology. Therefore, a glossary of terms is necessary for this thesis in case the language used here comes at odds with any other related literature.

Bead: In reference to cordage, "A division within a segment, representing one of its component strands. Beads are usually clearly defined because of the opposing angles of twist of the strands" (Hurley 1979:5) When beads are present, it indicates that a cord is more than 2-ply.



Appendix Figure A.1. A visual of a bead in a cord section with 4 segments (Fig. 4 Hurley 1979:5)

Cords, Cordage: Spun fibers that can also be plied. This is the basic unit used to make fabric structures, either by knotting, twining, or looping. "Cords" here is the same definition as Emery's definition of "Yarn": "the general term for any assemblage of fibers or filaments which has been put together in a continuous strand suitable for weaving, knitting, and other fabric construction." (Emery 2009)

Furthermore, Emery seems to take offense to the continued usage of "cord":

Rope-making terms

> From time to time various technical terms have been borrowed from the terminology of modern ropemaking for descriptions of primitive 'cordage.' When, as frequently happens, similar (if not identical) yarns and cords are found serving as elements of fabric construction, the same terms which were used to describe them as 'cordage' are applied to them in the fabric context. Soon the terms are being applied to all yarns in the fabric context, and as the usage is extended it becomes increasingly inappropriate. It may be entirely reasonable to expect that a worker in any of the extensive and varied fields of fabric study will have some familiarity with the special terminologies of other fields, including that of *ropemaking* and *knot-work,* but substitution of special *rope-work* terms either for terms in general use in connection with fabrics, or for descriptive devices which are without special connotation, has little to recommend it as a means of communication of fabric information. The use of the term *rope,* for example, to describe the *re-plied* structure of a delicate yarn, would seem unnecessarily misleading even if we were justified in assuming general agreement on its special meaning in relation to yarn structure. But in *rope-work,* as elsewhere, there are differences of opinion about the exact meaning of terms; and while it is frequently argued that such terms as *cable-twist* and *hawser-twist* provide a simple means of designating specific sequences in the changes of direction of twist in yarns and cords, investigation indicates a lack of agreement among authorities on the exact implications of either term. We also find other sequences for which there are no specific tenns. All in all, simple enumeration of the successive directions of twist found in each yarn or cord seems to provide more precise information and less opportunity for misinterpretation than the use of borrowed terms of doubtful relevance. A distinctive form of letter to designate the final - the visible - twist will add to the clarity and precision of the enumeration (e.g. z-S, s-s-Z, s-z-s-Z), although it is usually assumed (and always when the slanting line is used alone) that the final letter or symbol in any series designates the final (and visible) twist (2009:13-14)

Since every other piece of literature about these impressions in pottery refer to “cords” or “cordage”, “yarn” will not be used here. However, all must be warned of Emery’s warning of the inappropriate usage of rope terms and any notion that the “cordage” is in any way “primitive”.

Fabric: “…fabric as the more generic term for all fibrous constructions…” (Emery 2009:xvi) This term is used throughout. Textiles are not referred to here as Emery defines them as woven fabric (Emery 2009:xvi). Netting, textiles, etc. all fall under this generic term.

Impressions vs. Markings: As in “cord-marking”, “fabric-impressed”, etc. Impressions represent an intentionality in the use of the impressor as decoration. On the other hand, “cord-markings” or possibly net-markings or fabric-markings are a side effect of function rather than intentional decoration and would be considered a “texture” or “surface treatment” by Rice (Rice

2015). Rice also states that impression techniques are similar to "texturing", but that impressions do not occupy as much space on the vessel (2015:155). Cord-markings exist as a side-effect of having used a cord-wrapped paddle to even out the walls of a vessel and to allow the clay to release from the paddle. Net or fabric markings might be a side effect of having used a piece of fabric to allow a vessel to detach from a mold, as in Mississippian salt pans (Kuttruff 1993) and may even be smoothed over.

Mesh: A 3D mesh refers to the visualized 3D file. It's called a "mesh" because it looks like a net that connects points. A mesh can be approximately encoded (made of triangles), precisely encoded, or composed of constructive solid geometry (making it no longer a mesh, really) (Chakravorty 2019).

Representation: Used to refer to meshes produced by 3D scanning of real objects. "Copies" are not used because it would be misleading.

Textiles: Refers specifically to woven fabrics, with a warp and a weft, made on a loom (Emery 2009). This term is not used here, as most impressions on pottery that are fabric are twined or knotted. Therefore, to say that a sherd is "textile-impressed" would be inappropriate.

Appendix B: Data Tables

Sherd 1
File size:
GoMeasure .stl: 169,116 KB. Vertices: 1,733,833. Faces: 2,398,146.
NextEngine .stl: 1,419,223 KB

	NextEngine	GoMeasure3D	Original Sculpey®	NE Differences	Differences for GM3D
Markings or Impressions? (Impression type?)(	Markings	Markings	Markings.		
Cord Diameter	1. 2.78mm 2. 3.20mm 3. 2.13mm	1: 3.03 2: 3.58 3: 2.63	1: 2.18 2: 2.83 3: 2.43	+0.60 +0.37 -0.30	+0.85 +0.75 +0.20
Final Twist Direction	N/A	S	S and Z?	0.42 mm absolute difference	0.6 mm absolute difference
Twists per cm	3	3	3		
Plies?	2	2	2		
Individual fibers?	No	No	Yes		

Sherd 2
File size: GoMeasure .stl: 22,219 KB. Vertices: 228,512. Faces: 455,040
NextEngine .stl: 596,540 KB Vertices: 36,651,402. Faces: 12,217,402

	NextEngine	GoMeasure3D	Original Sculpey®	NE Difference	GM3D Difference
Markings or Impressions? (Impression type?)	Markings, rocker stamped, hole, punctate.	Markings, rocker stamped, hole, punctate.	Rocker stamped, holes, punctate, cordmarkings.		
Cord Diameter	1: 1.94 (marks do not seem clear) 2: 2.61 3: 1.98	1: 1.26mm 2: 2.96 mm 3. 1.38 mm	1: 2.33 mm 2: 3.04 mm 3:1.83 mm	-0.39 mm -0.43 mm +0.15 mm	-1.07 mm -0.08 mm -0.45 mm
Final Twist Direction	S	S	S	0.32 mm average difference	0.53 mm average difference
Plies	2	2	2		
Individual fibers?	No	No	No.		
Twists per cm	~3	~2.5	~2.5		

Sherd 3
File size:
GoMeasure .stl: 52,731 KB. Vertices: 540,005. Faces: 655,702

NextEngine .stl: 892,537 KB Vertices: 54,837,420. Faces: 18,279,140
The "3B" on the paper label showed up raised for some reason, even though it is a 2D marking on a label. Perhaps this is due to the difference in color between the label and ink (see Lemeš and Zaimović-Uzunović 2009)

	NextEngine	GoMeasurePro	Original Sculpey®	NE Difference	GM3D Difference
Markings or Impressions? (Impression type?)	Cord Markings; Lip of sherd was cut off.	Markings	Markings, but not sure.		
Cord Diameter	1: 3.85mm 2: 2.96 3: 2.46	1: 4.01mm 2: 2.61 3: 2.98	3.94mm 2.84 2.59	-0.09mm +0.12 -0.13	+0.07mm -0.23 +0.39
Final Twist Direction	S?	S and Z.	S and Z cords? See microscope.	0.11 mm average difference	0.23 mm average difference
Plies	2	2	2		
Individual fibers?	No.	No	Possibly; see Digital microscope Photos.		

Twists per cm:	~3.5 (not well visible)	3	~2		

Sherd 4
File size:
GoMeasure .stl: 42,133 KB. Vertices: 432,477. Faces: 395,206.
NextEngine .stl: 558,348 KB. 5,732,919 vertices. 11,434,963 faces.
In all representations, the pattern of cordmarking repeats itself, suggesting repeat paddle hits.

	NextEngine	GoMeasurePro	Original Sculpey®	NE Difference	GM3D Difference
Markings or Impressions? (Impression type?)	Cordmarkings.	Markings	Cordmarkings		
Cord Diameter	1: 1.91mm 2: 2.71 3: 2.16	1: 1.93mm 2: 2.41 3. 1.98	1: 1.42mm 2: 2.09 3: 1.41	+0.49mm +0.62 +0.75	+0.51 +0.32 +0.57
Final Twist Direction	S	S	S	0.62mm average difference	0.46mm average difference
Plies	2	2	2		
Twists per cm?	5	4 (hard to see)	4.5-5		

Individual fibers?	No	No	Yes		

Sherd 5
File size:
GoMeasure .stl: 41,071 KB Vertices: 420,851. Faces: 495,280.
NextEngine .stl: 956,214 KB
Vertices: 58,749,756. Faces: 19,583,252

	NextEngine	GoMeasurePro	Original Sculpey®	NE Difference	GM3D Differences
Markings or Impressions?	Markings	Markings	Markings		
Cord Diameter	1: 2.14. 2: 2.66 3: 1.94	1: 2.12 2: 2.71 3: 1.83	1: 1.56 2: 2.29 3: 1.97	+0.58 +0.37 -0.03	+0.56 mm +0.42 mm -0.14 mm
Final Twist Direction	Z	Z	Z	0.33mm average difference	0.37mm average difference
Twists per cm	3	3	3		
Individual fibers?	No	No	No		
Plies?	2	2	2		

Sherd 6
File size: GoMeasure .stl: 23,730 KB. Vertices: 243,429. Faces: 309,229
NextEngine .stl: 423,191 KB. 4,347,490 vertices. 8,666,948 faces

	NextEngine	GoMeasurePro	Original Sculpey®	NE Difference	GM3D Difference
Markings or Impressions? (Impression type?)	Markings	Markings	Markings		
Cord Diameter	1: 1.76mm 2: 2.62 3: 2.75	1: 1.88mm 2: 2.13 3: 3.37	1: 1.60mm 2: 2.46 3: 2.30	+0.16mm +0.16 +0.45	+0.28mm -0.33 +1.07
Final Twist Direction	Both S and Z are present. (some of the cords could be either?)	Unsure.	All Z.	0.26mm average difference	0.56mm average difference
Twists per cm.	3.5	3.5	3.5		
Individual fibers?	No	No	Few		
Plies?	2-ply	2-ply	2-ply		

Sherd 7

Sherd 7 is a collared rim of the Point Sauble type (Howell 2001). It has three zones of decoration (see fig. C.1), the first along the collar (Zone 1), the second 4cm along the neck just beneath the collar (Zone 2) the last is 4.5cm along the neck to the termination of the sherd (Zone 3).

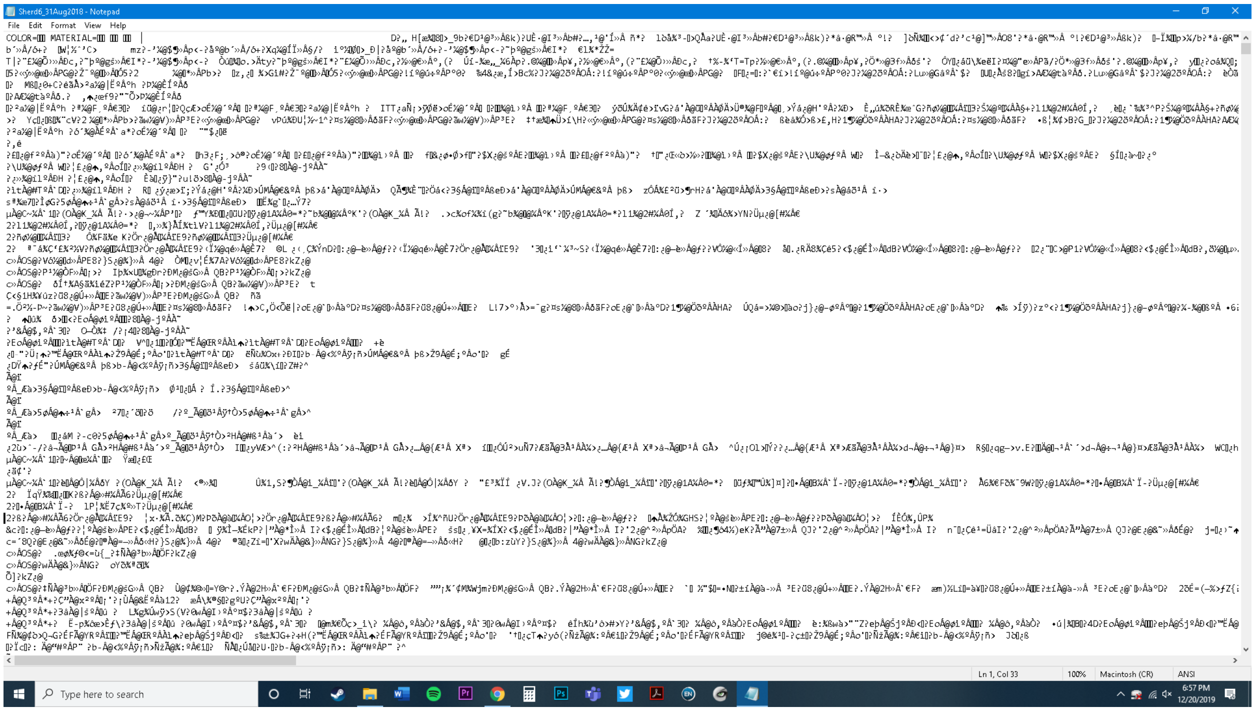
File size: GoMeasure .stl: 109,262 KB Vertices: 1,120,076. Faces: 1,411,160
NextEngine .stl: 1,072,321 KB, file did not open, Meshlab froze.

	NextEngine	GoMeasurePro	Original Sculpey®	NE Differences	GM3D Differnces
Markings or Impressions? (Impression type?)	Smoothed-over cordmarkings, single cord impressions, CWS, possibly fabric impressed?	Smoothed-over cordmarkings, single cord impressions, CWS, possibly fabric impressed?	Smoothed-over cordmarkings, single cord impressions, CWS, possibly fabric impressed?		
Cord Diameter	Zone 1: 2.10mm, 2.14, 2.53 Zone 2: 2.46mm, 2.75, 2.41 Zone 3: Cord: 2.38mm	Zone 1: 2.17mm, 2.88, 2.92 Zone 2: 2.65mm, 2.76, 2.46 Zone 3: Cord: 2.11mm	Zone 1: 2.49mm, 2.27, 2.32, 2.52 Zone 2: 2.85mm, 2.54, 1.92 Zone 3: Cord: 1.77mm	Zone 1: -0.39, -0.14, +0.21 Zone 2: -0.39, +0.21, +0.49 Zone 3: Cord: +0.61	Zone 1: -0.32, +0.61, +0.40 Zone 2: -0.20, +0.22, +0.54 Zone 3: +0.34 CWS dia:

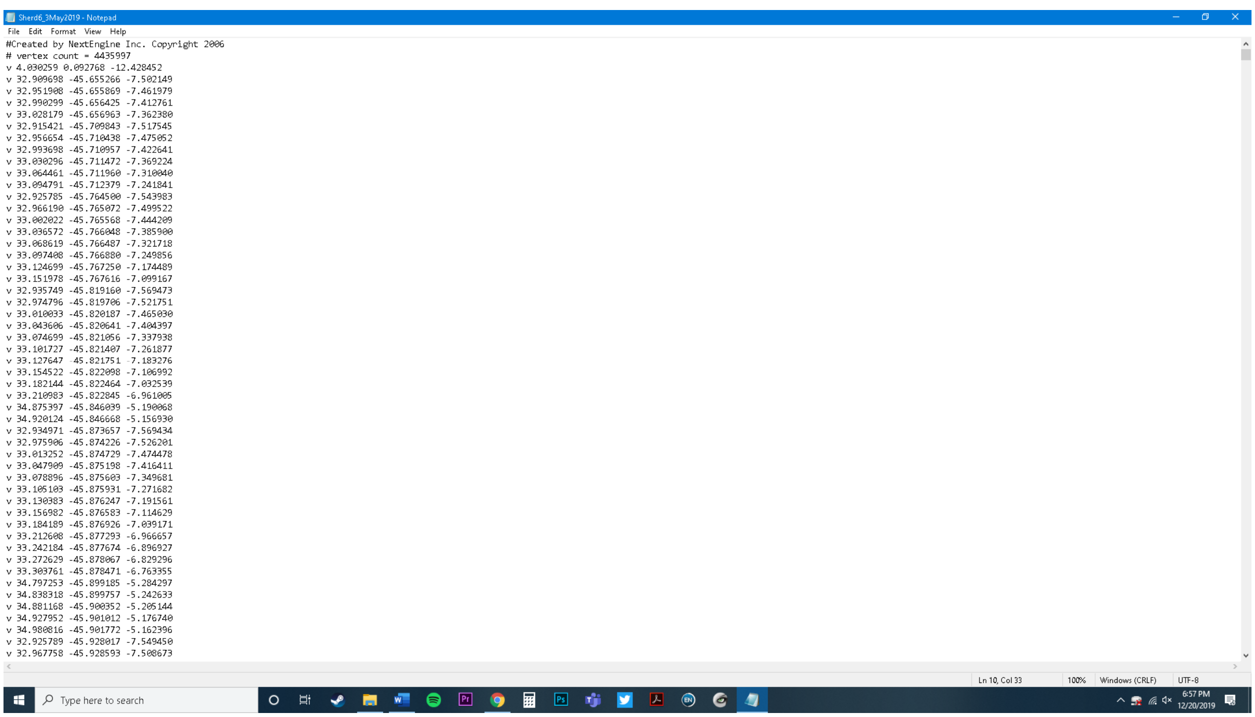
	CWS dia: 5.07 CWS width: 11.36mm Parallel Single Cord 1: 2.34 Parallel Single Cord 2: 1.76mm	CWS dia: 5.14mm CWS width: 11.55 Parallel Single Cords 1: 2.92 Parallel Single Cords 2: 2.74	CWS dia: 5.01mm CWS width: 10.78mm Parallel Single Cords 1: 2.42 Parallel Single Cords 2: 2.59	CWS dia: +0.05 CWS width: +0.58 PSC 1: -0.08 PSC 2: -0.83	+0.13 CWS width: +0.77 PSC1: +0.50 PSC2: +0.15
Final Twist Direction	Zone 1: Z Zone 2: Z Zone 3: ? PSC 1: Z PSC 2: Z	Zone 1: Z Zone 2: Z Zone 3: S Parallel Single Cords 1: Z Parallel Single Cords 2: Z	Zone 1: Z Zone 2: Z Zone 3: S Parallel Single Cords 1: Z Parallel Single Cords 2: Z		
Twists per cm	Zone 1: 4 Zone 2: 4 Zone 3: ?	Zone 1: 4 Zone 2: 4 Zone 3: ?	Zone 1: 4 Zone 2: 4 Zone 3:?	0.36 average absolute difference	0.38 average absolute difference

	Parallel Single Cords 1: 4 Parallel Single Cords 2: 4	Parallel Single Cords 1: 4 Parallel Single Cords 2: 4	Parallel Single Cords 1: 4 Parallel Single Cords 2: 4		
Individual fibers?	No.	No.	Few		
Plies? (how many beads per segment?)f	Zone 1: Not visible. Zone 2: Not visible	Zone 1: 3? Zone 2: 4 Zone 3: ? Parallel Single Cords 1: 4 Parallel Single Cords 2	Zone 1: 4 Zone 2: 4 Zone 3: 2-ply Parallel Single Cords 1: 4 beads Parallel Single Cords 2: 4 beads		

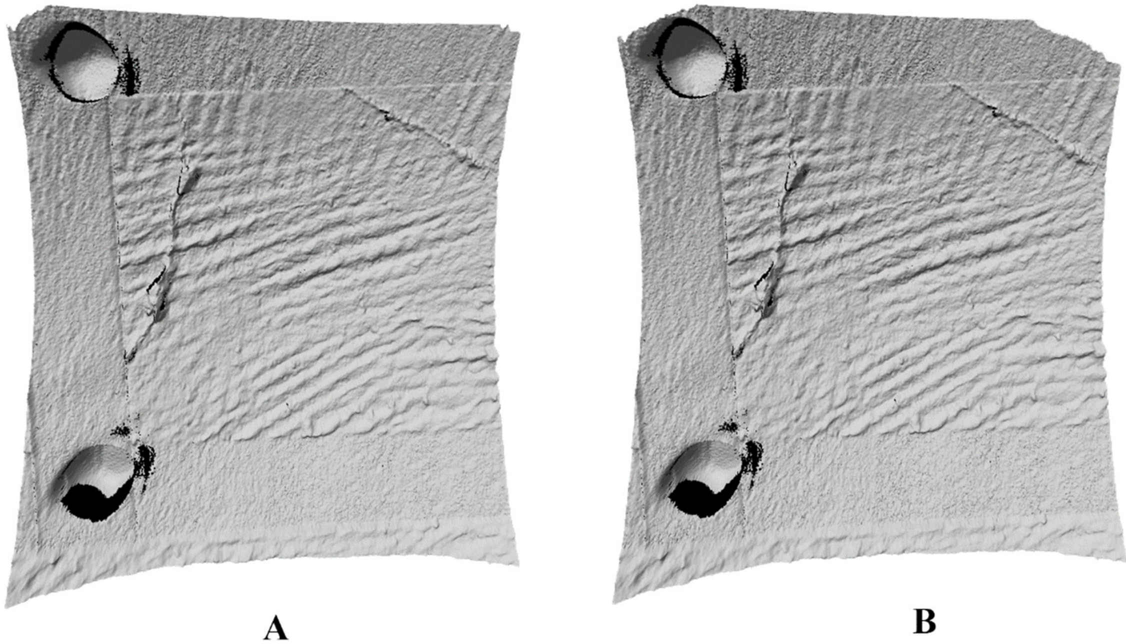
Appendix C: .obj and .stl Files from NextEngine Compared



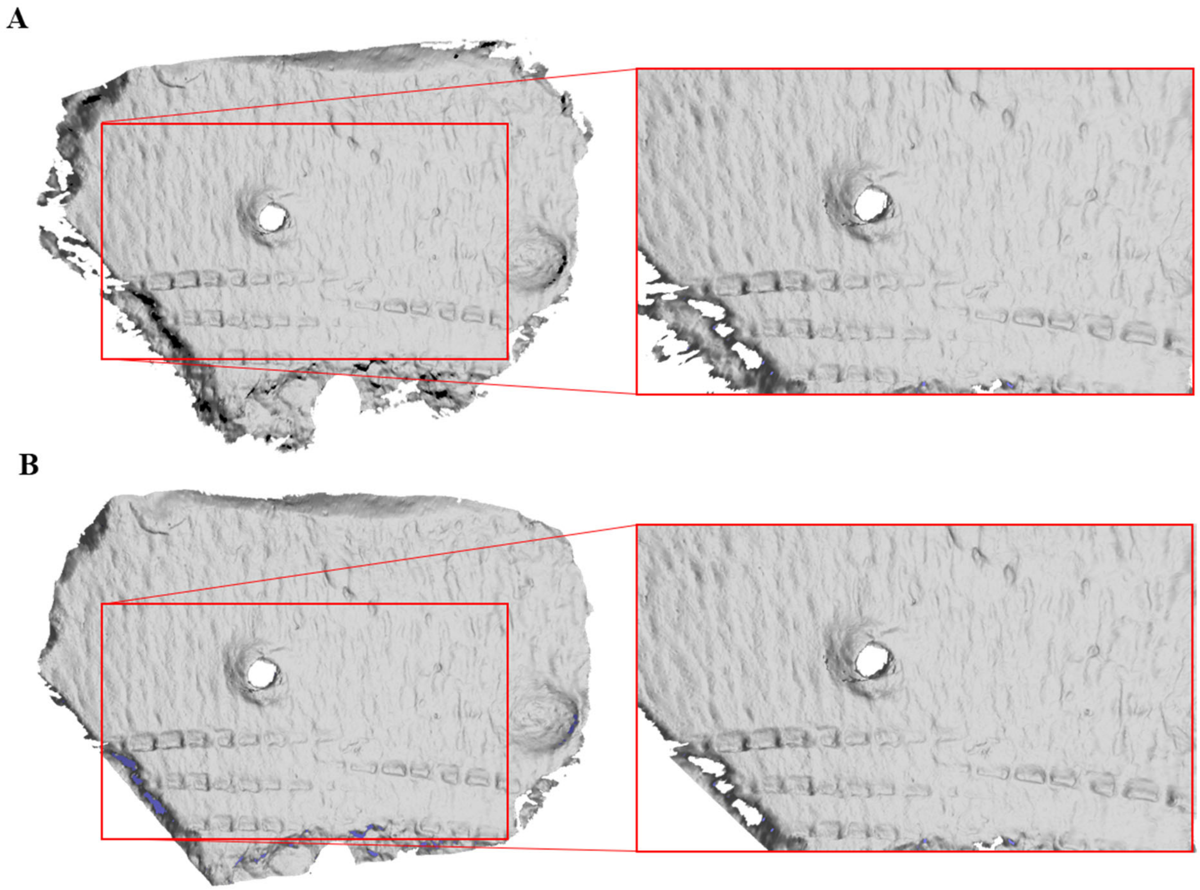
Appendix Figure C.1. Sherd 6's ASCII encoded .stl file as opened in Notepad.



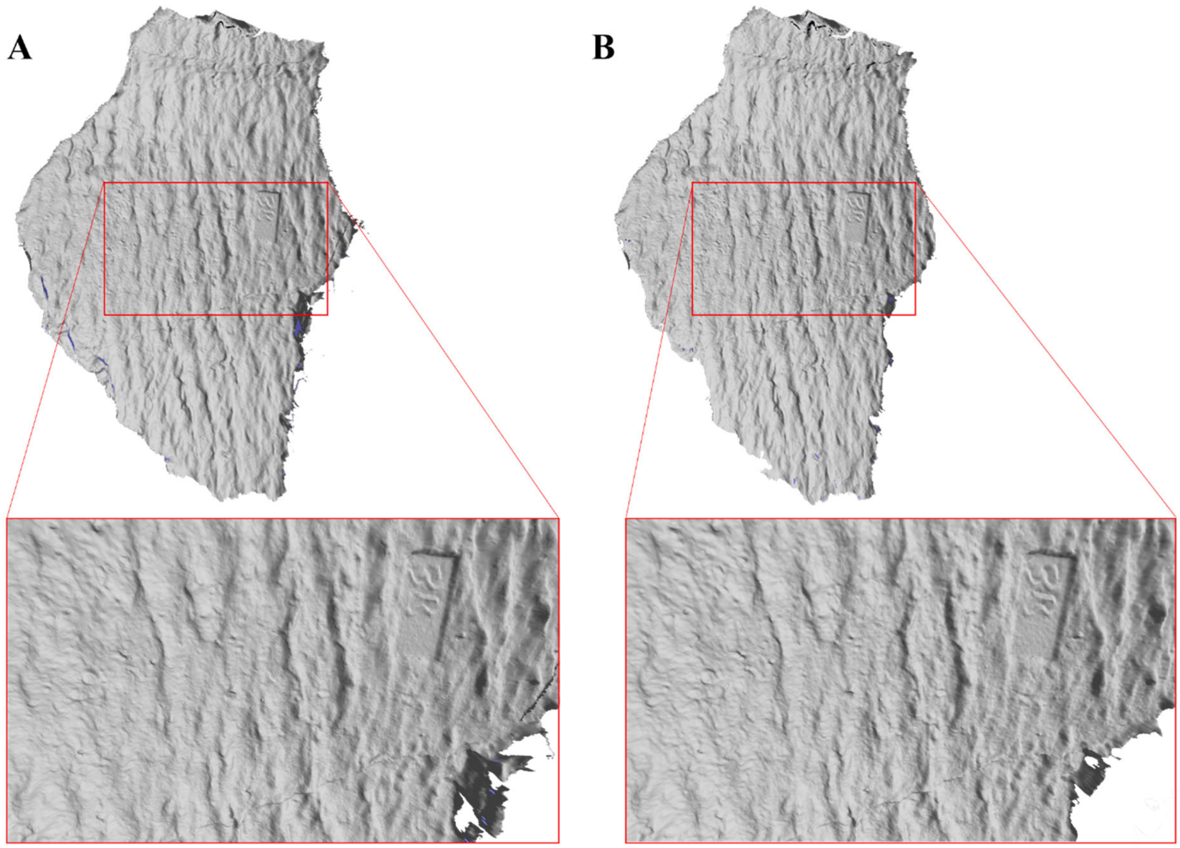
Appendix Figure C.2. Sherd 6's .obj file as opened in Notepad.



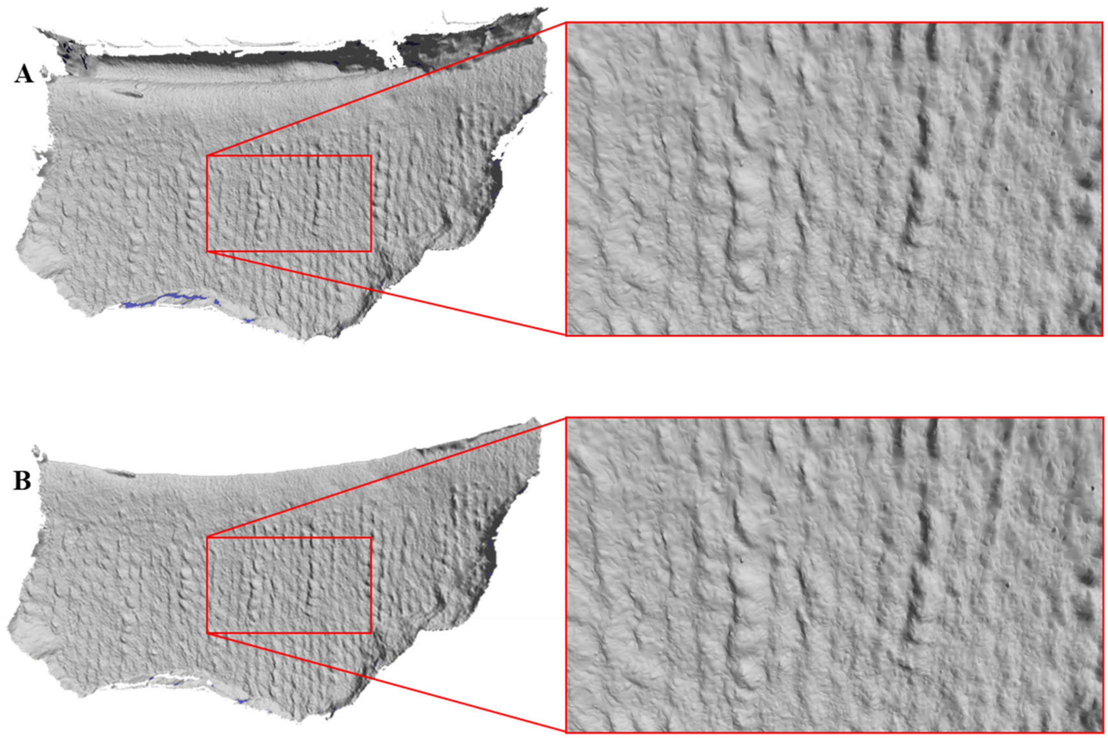
Appendix Figure C.3. A: ..obj file exported from ScanStudio™ of Sherd 3. B. .stl file exported from same.



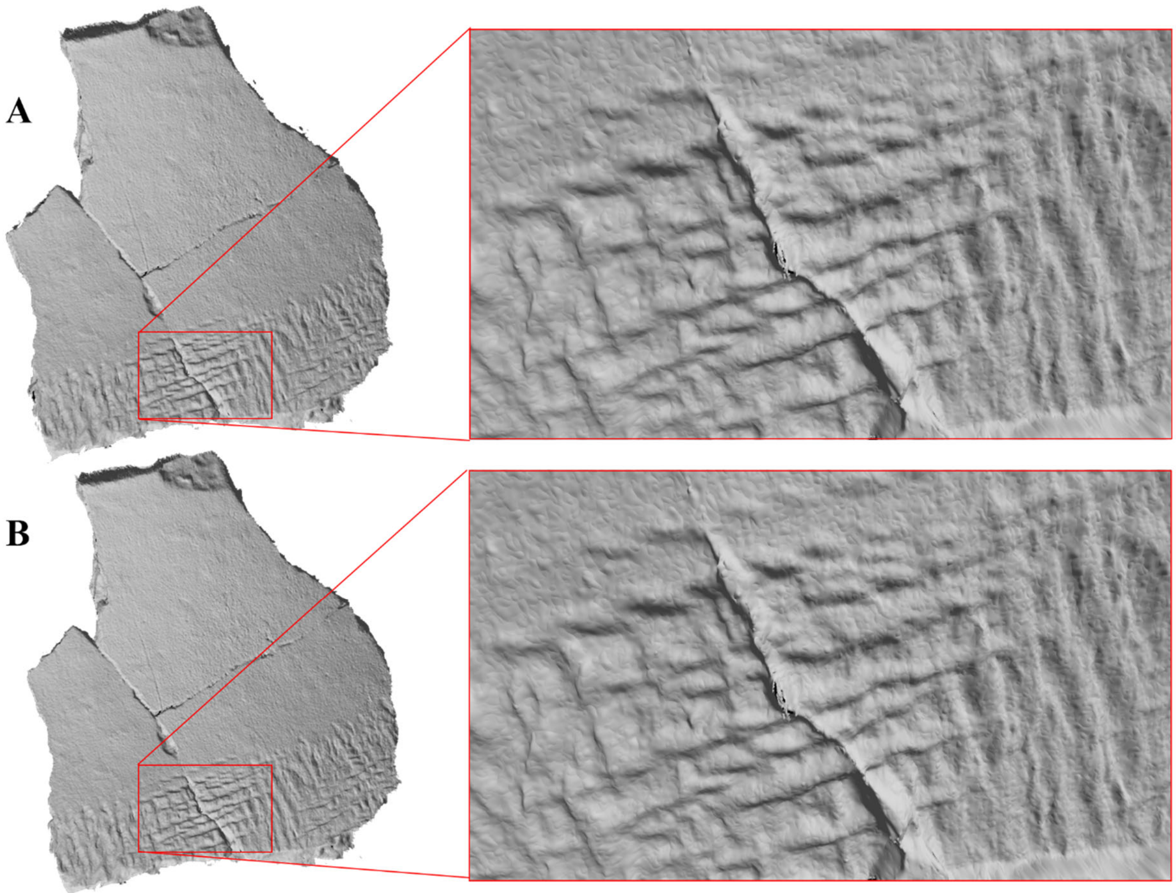
Appendix Figure C.4. A. .obj file exported from ScanStudio of Sherd 2. B: .obj file exported from same.



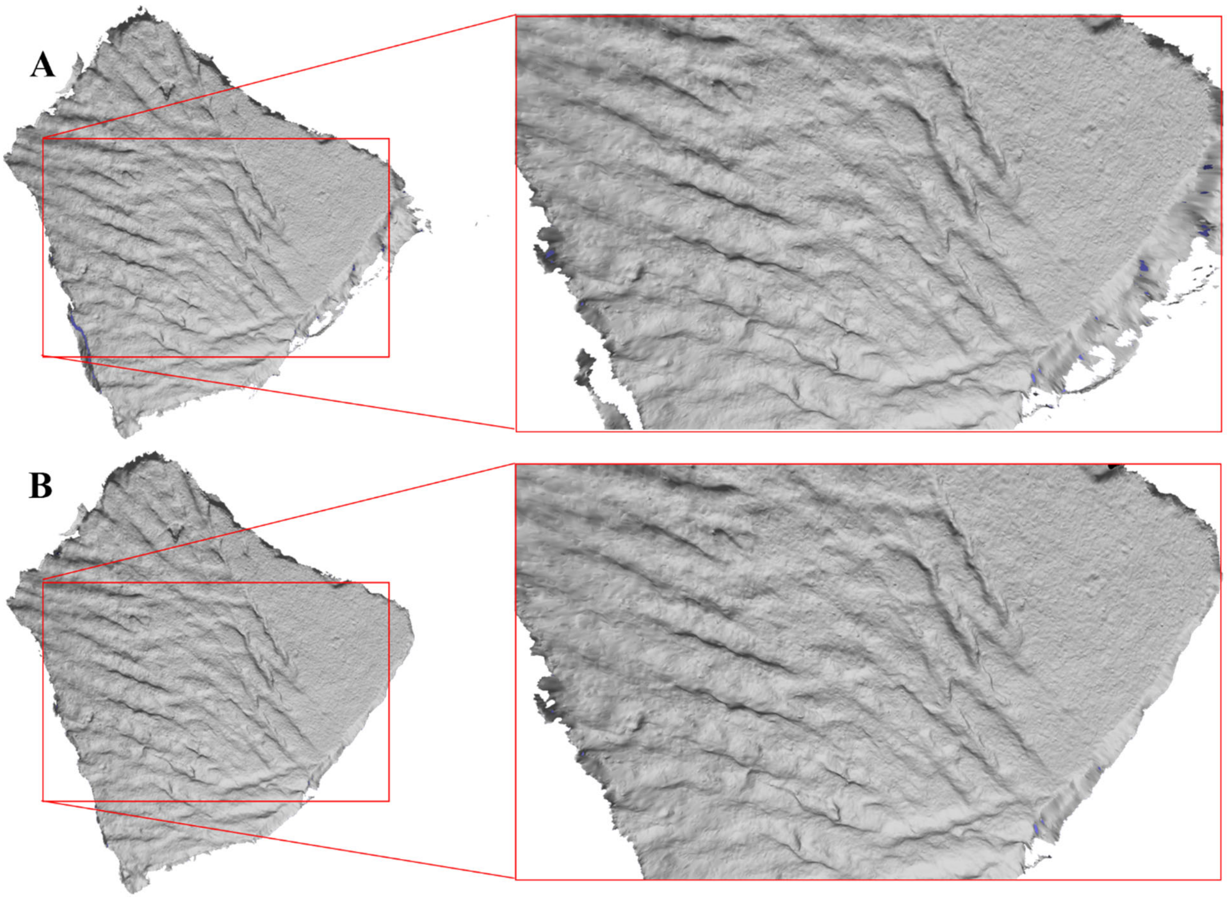
Appendix Figure C.5. A. .obj file exported from ScanStudio of Sherd 3. B: .obj file exported from same.



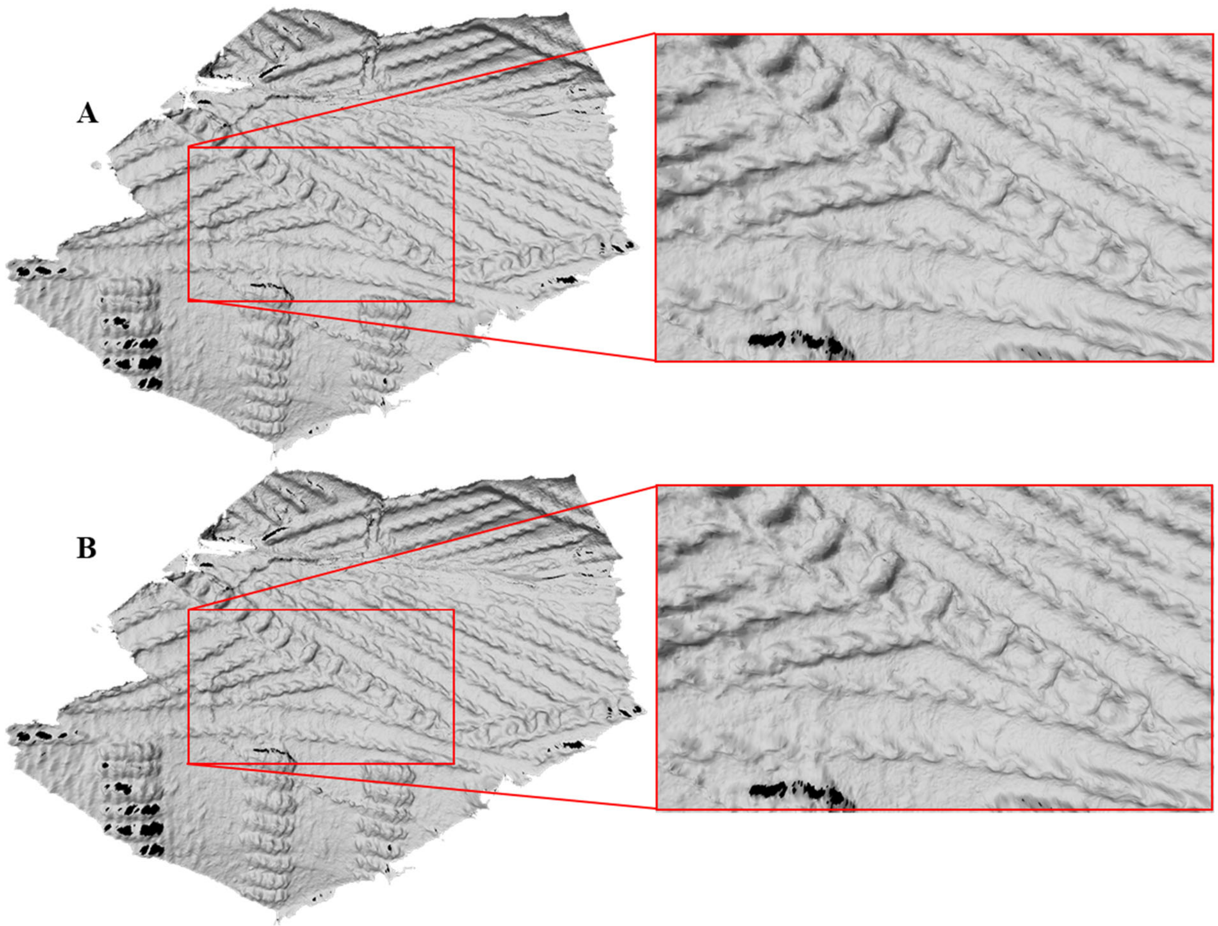
Appendix Figure C.6. A: .obj file exported from ScanStudio™ of Sherd 4. B. .stl file exported from same.



Appendix Figure C.7. A: .obj file exported from ScanStudio™ of Sherd 5. B. .stl file exported from same.

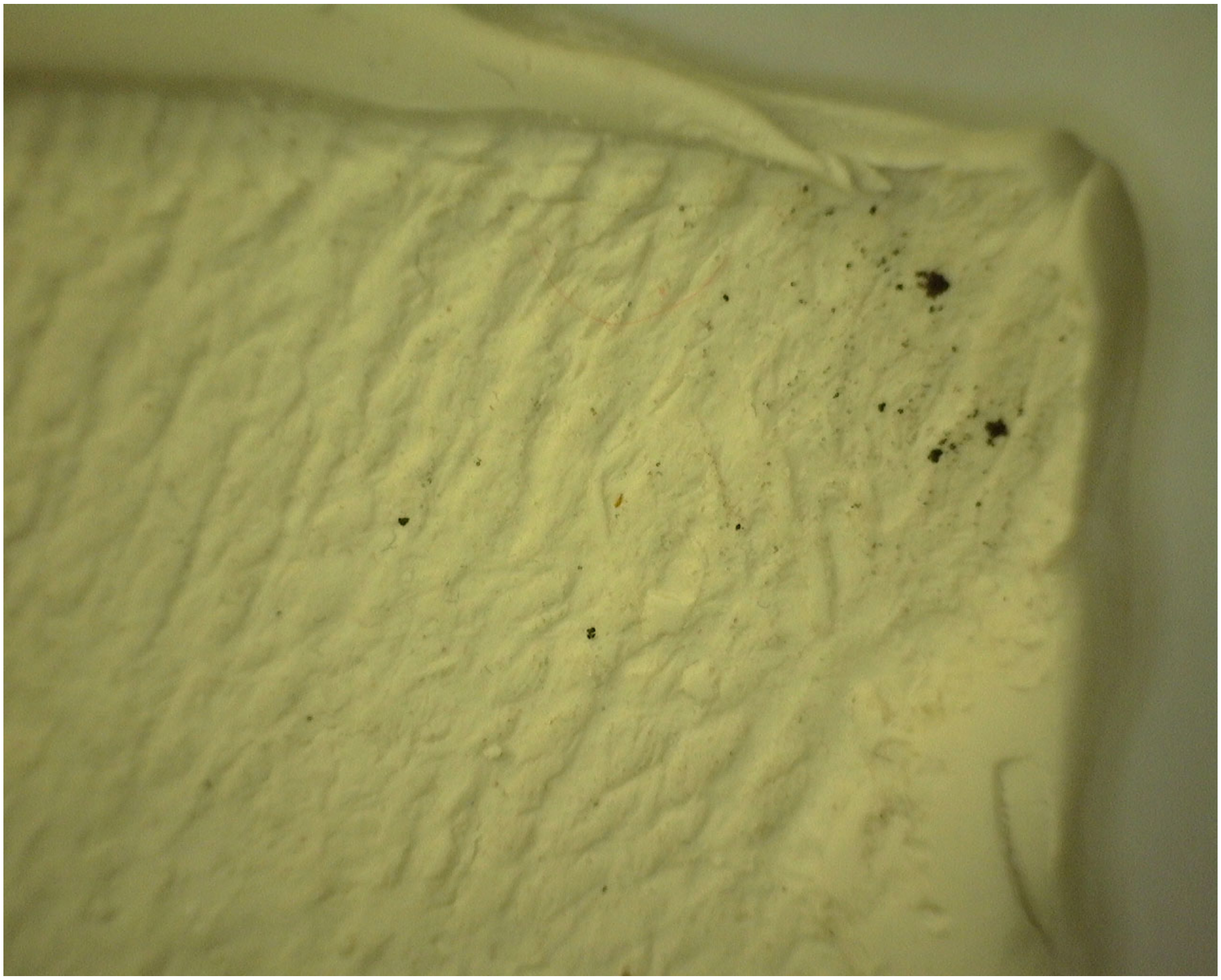


Appendix Figure C.8. A: .obj file exported from ScanStudio™ of Sherd 6. B. .stl file exported from same.



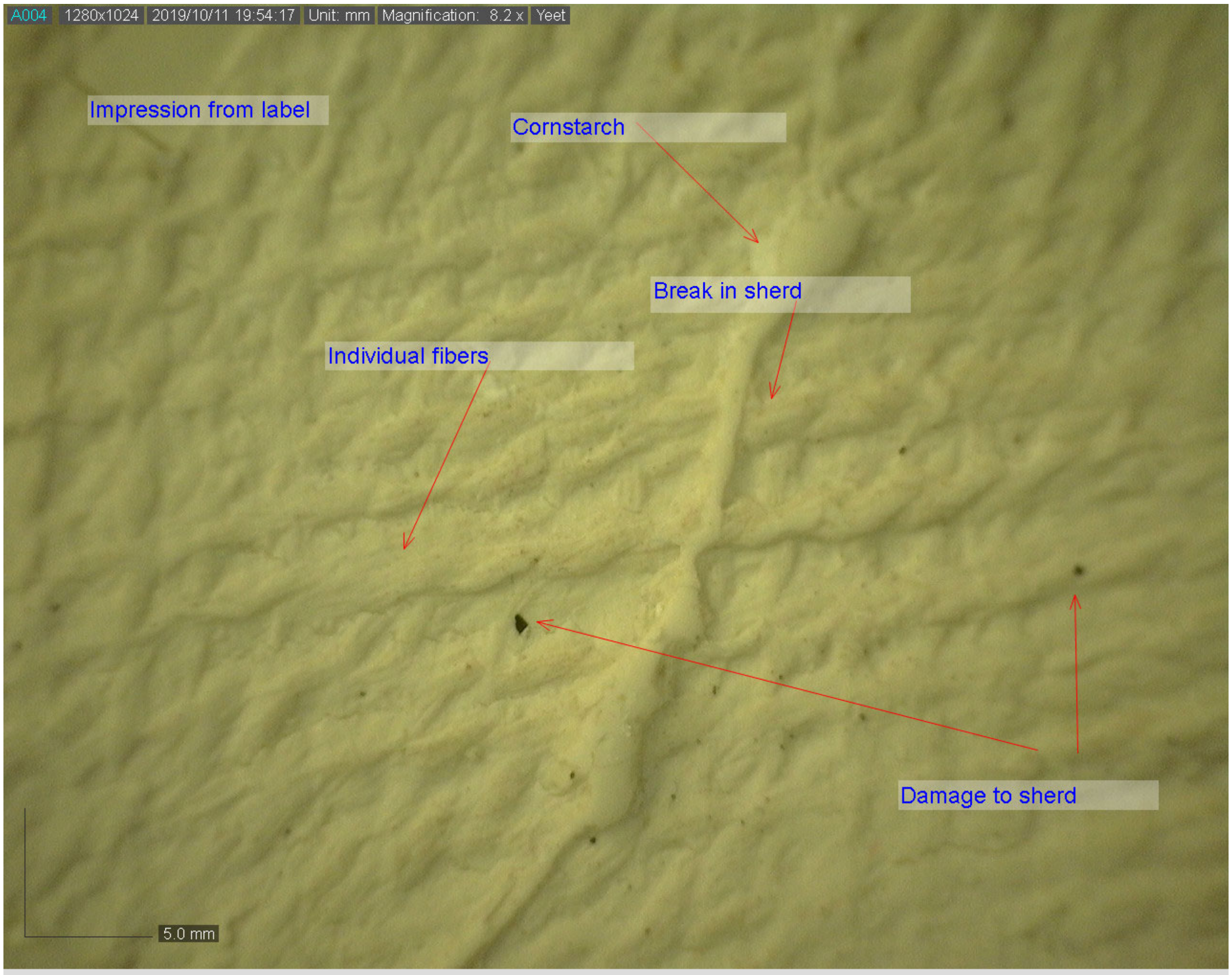
Appendix Figure C.9. A: .obj file exported from ScanStudio™ of Sherd 7. B. .stl file exported from same.

Appendix D: Sculpey® Casts Photographed with Digital Microscope

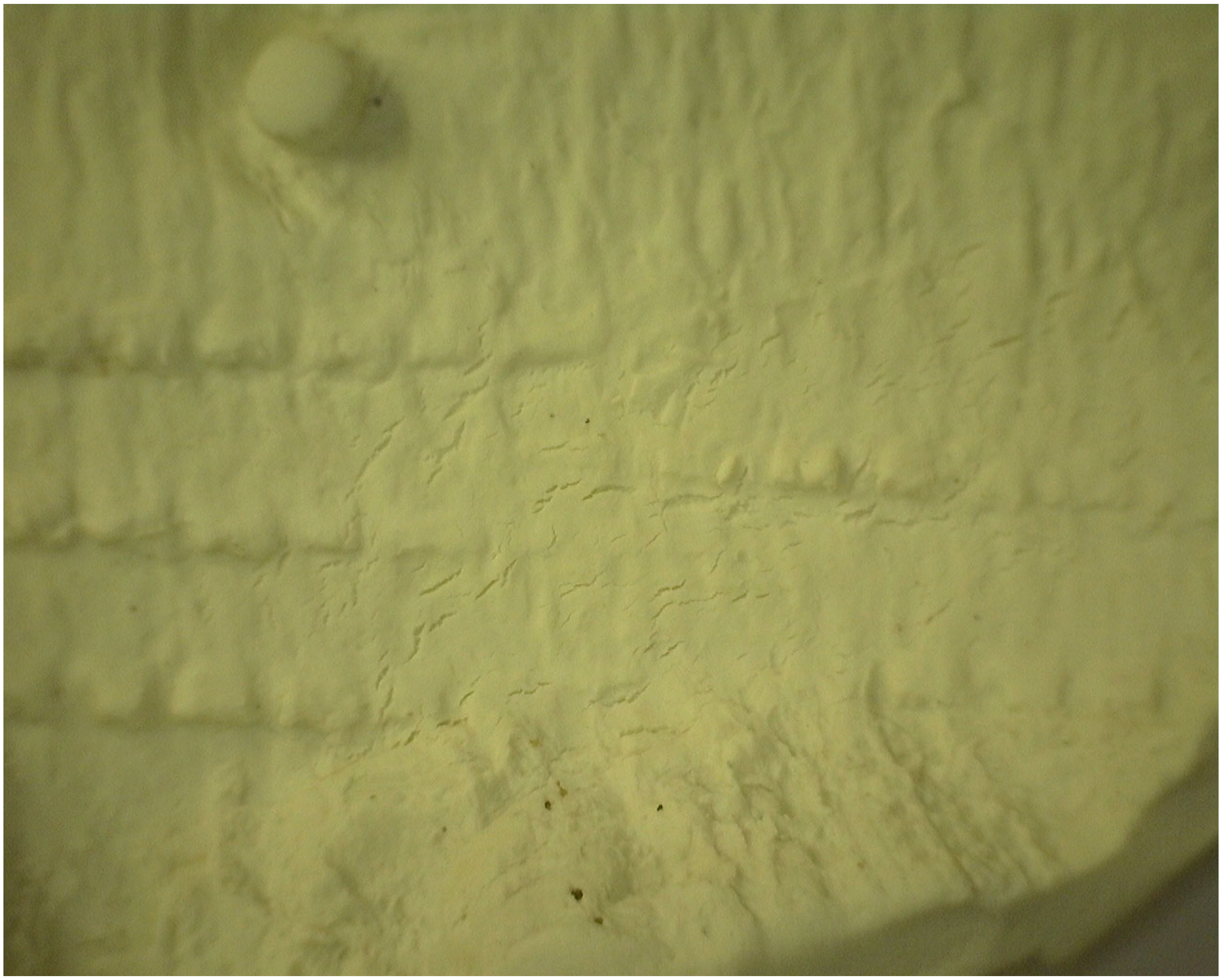


Appendix Figure D.1. Digital microscope image of cast of Sherd 1; note damage; magnification 8.2x.

Appendix Figure D.2. Digital microscope image of cast of Sherd 1; note damage; magnification 8.2x.



Appendix Figure D.3. Digital microscope image of cast of Sherd 1; magnification 8.2x.

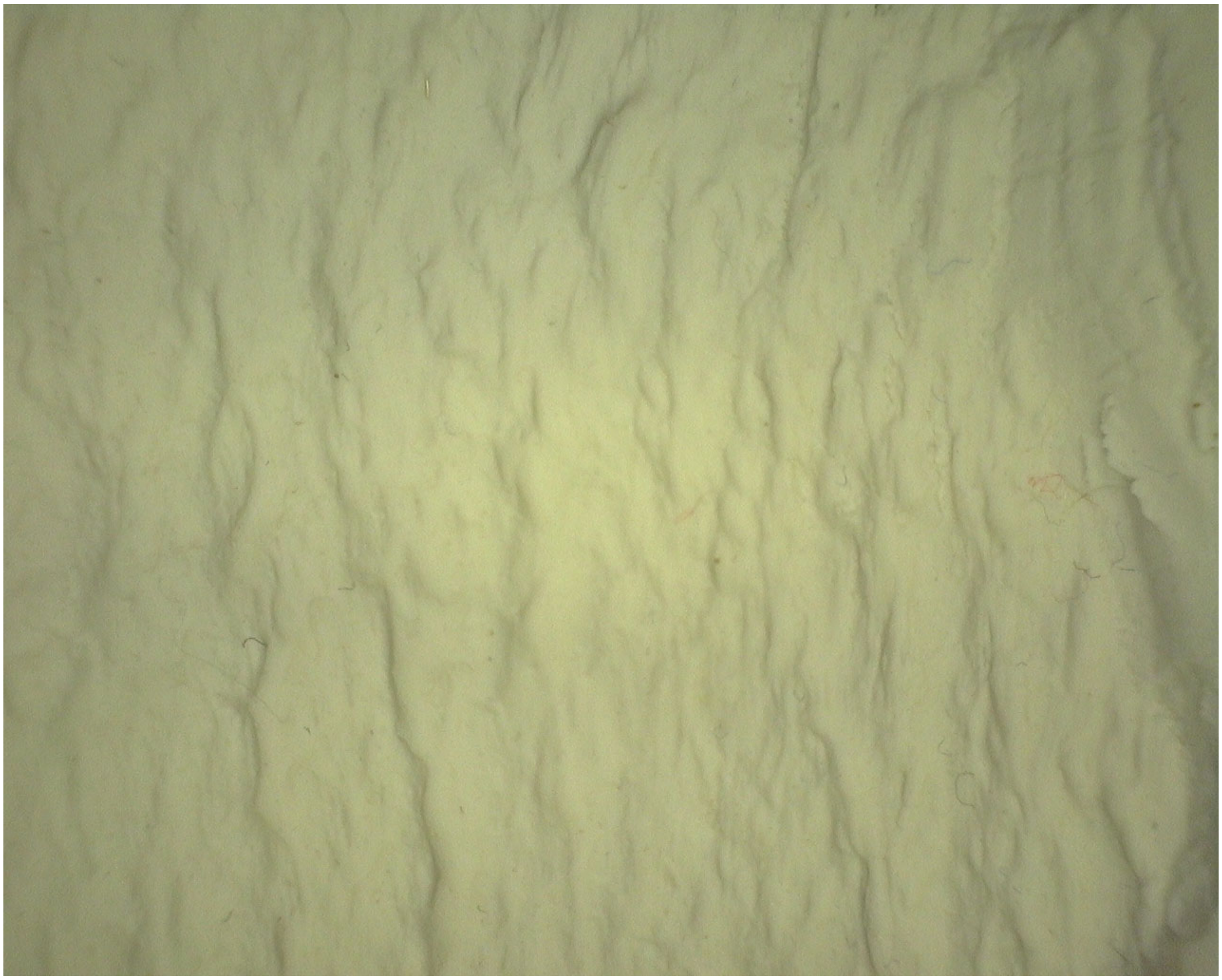


Appendix Figure D.4. Digital microscope image of cast of Sherd 2; note cracks in cast; magnification 8.2x.

Appendix Figure D.5. Digital microscope image of cast of Sherd 2; magnification 8.2x.

Appendix Figure D.6. Digital microscope image of cast of Sherd 2; note small specks lifted from sherd; magnification 8.2x.

Appendix Figure D.7. Digital microscope image of cast of Sherd 3; note flat area where label was; magnification 8.2x.

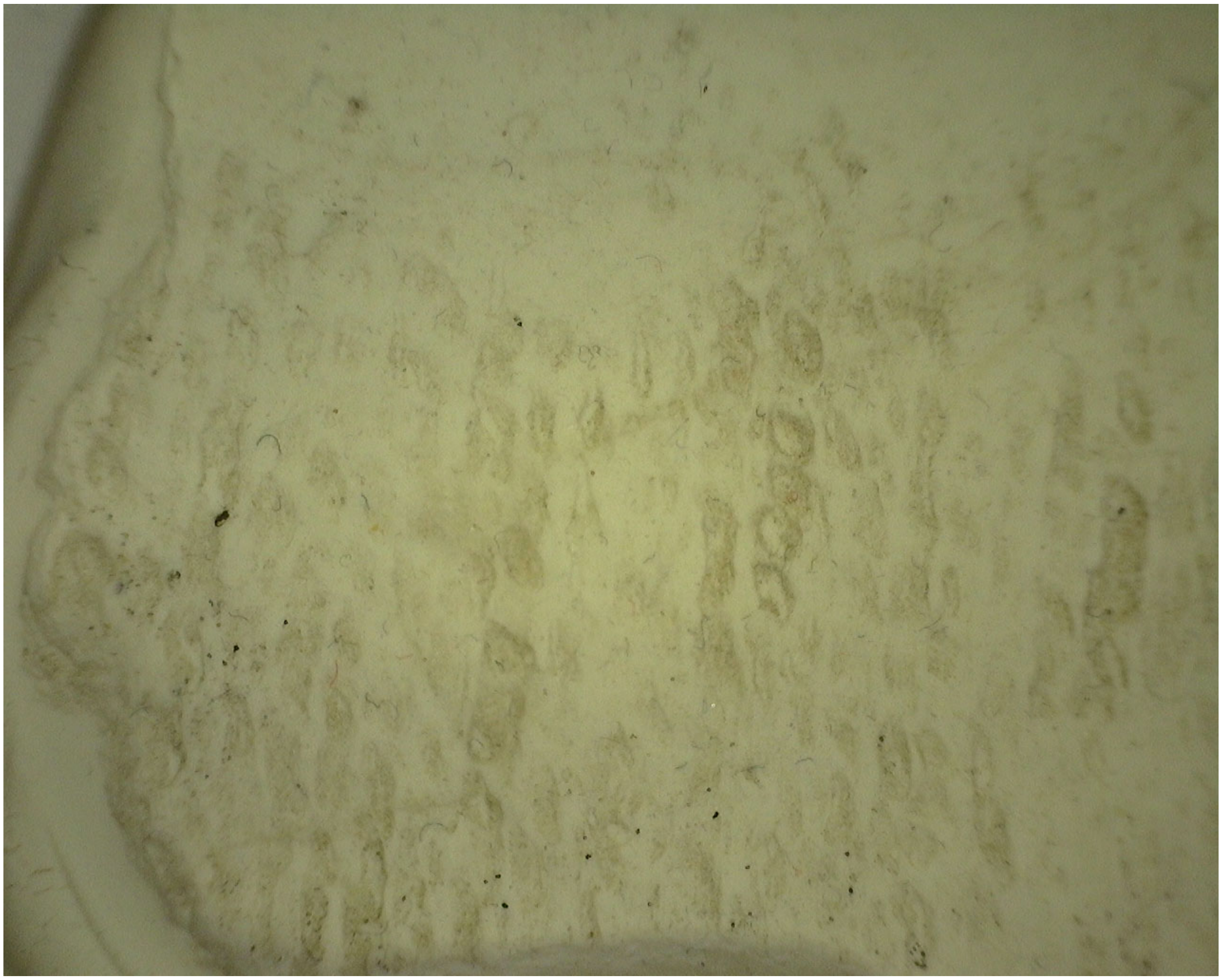


Appendix Figure D.8. Digital microscope image of cast of Sherd 3; magnification 8.2x.

Appendix Figure D.9. Digital microscope image of cast of Sherd 3; note lifted sherd particles; magnification 8.2x.

Appendix Figure D.10. Digital microscope image of earlier cast of Sherd 3; note lifted sherd particle; magnification 8.2x.

Appendix Figure D.11. Digital microscope image of cast of Sherd 4; note lifted sherd particles and discoloration; magnification 8.2x.



Appendix Figure D.12. Digital microscope image of cast of Sherd 4; note lifted sherd particles and discoloration; magnification 8.2x.

Appendix Figure D.13. Digital microscope image of cast of Sherd 4; note lifted sherd particles and discoloration; magnification 8.2x.

Appendix Figure D.14. Digital microscope image of cast of Sherd 5; magnification 8.2x.

Appendix Figure D.15. Digital microscope image of cast of Sherd 5; note cornstarch in top right and top; magnification 8.2x.

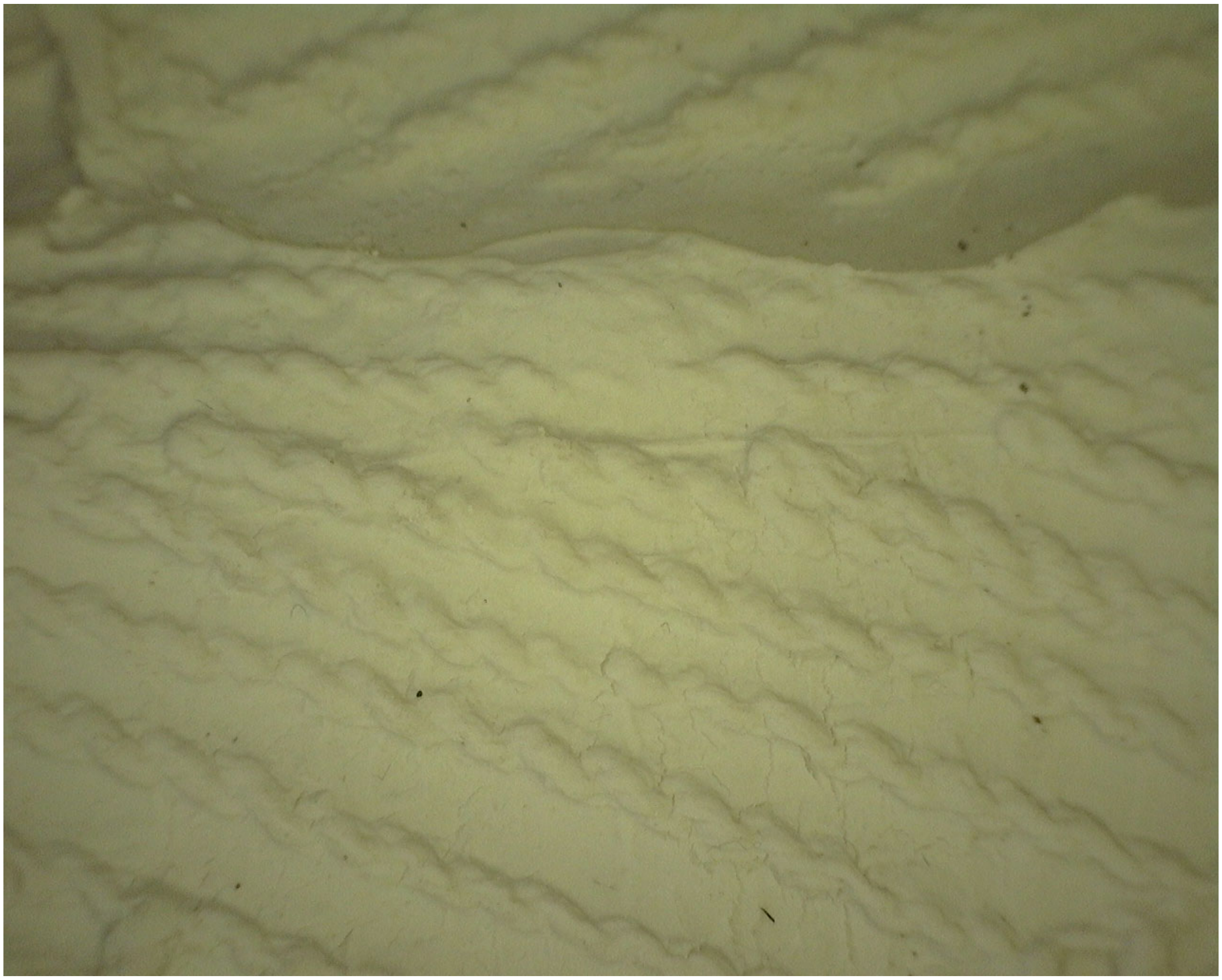
Appendix Figure D.16. Digital microscope image of cast of Sherd 6; note lifted sherd particles and discoloration; magnification 8.2x.

Appendix Figure D.17. Digital microscope image of cast of Sherd 6; note lifted sherd particles and discoloration; magnification 8.2x.

Appendix Figure D.18. Digital microscope image of cast of Sherd 6; note lifted sherd particles and discoloration; magnification 8.2x.

Appendix Figure D.19. Digital microscope image of cast of Sherd 6; note lifted sherd particles and discoloration; magnification 8.2x.

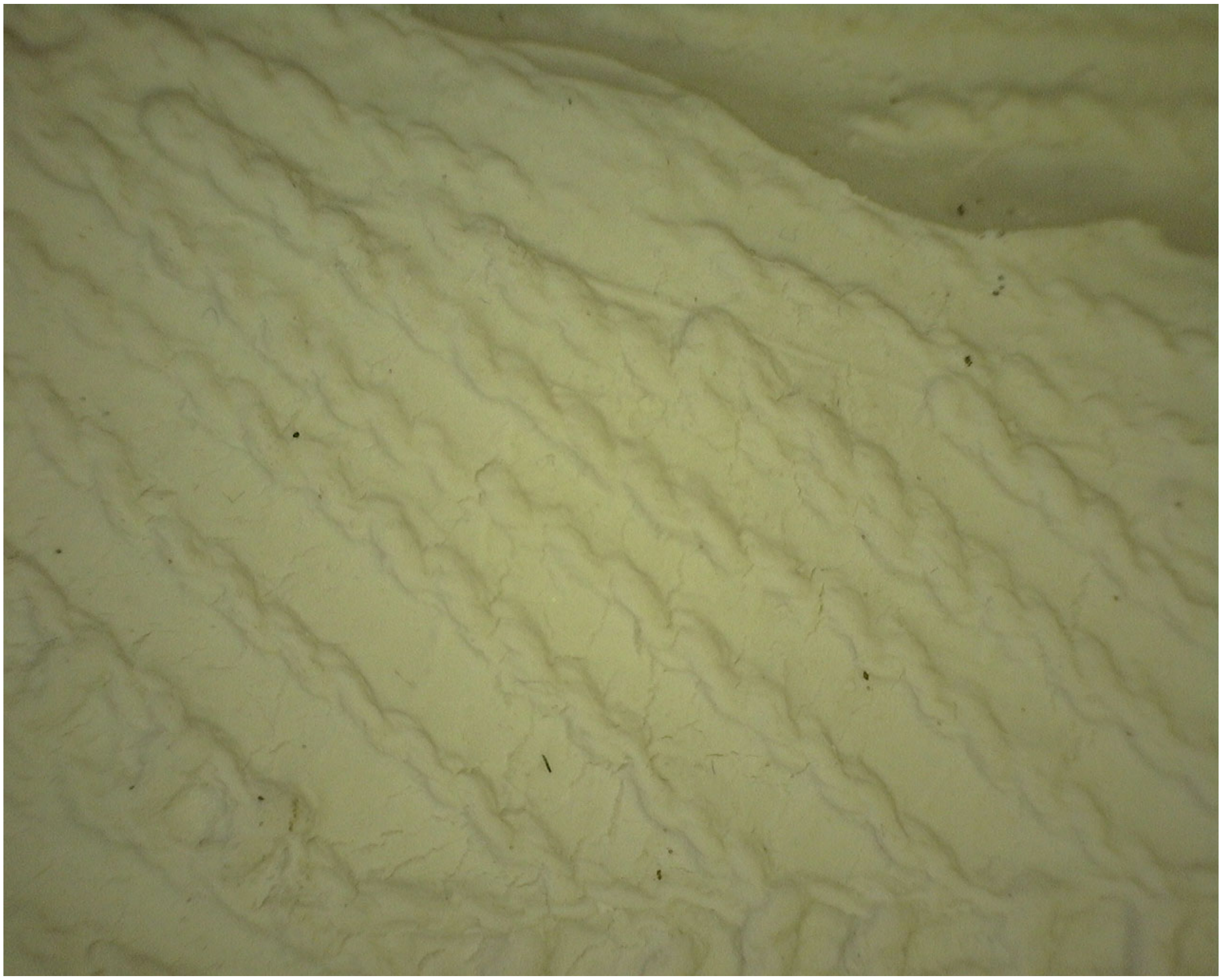
Appendix Figure D.20. Digital microscope image of cast of Zone 2 and Parallel Single Cords in Sherd 7; note clarity and beads visible in cordage; magnification 8.2x.



Appendix Figure D.21. Digital microscope image of cast of Zone 1, Parallel Single Cords, and Zone 2 of Sherd 7; note lifted sherd particles and visible beads; magnification 8.2x.

Appendix Figure D.22. Digital microscope image of cast of Parallel Single Cords and Zone 3 of Sherd 7; note lifted sherd particles and cracks in cast; magnification 8.2x.

Appendix Figure D.23. Digital microscope image of cast of Zone 3 of Sherd 7; note lifted sherd particles and cracks in cast; magnification 8.2x.



Appendix Figure D.24. Digital microscope image of cast of Zone 2 of Sherd 7; note lifted sherd particles and clarity of cordage structure; magnification 8.2x.

Appendix Figure D.25. Digital microscope image of cast of Zone 3 of Sherd 7; note incomplete casting of cord wrapped stick impressions; magnification 8.2x.

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Appendix Figure D.26. Digital microscope image of cast of Zone 3 of Sherd 7; note lifted sherd particles and cracks in cast; magnification 8.2x.